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Calculation of the CO_2 Emission Reduction Costs in Markal Model

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ABSTRACT

Possible introduction of nuclear power plants belongs to the supply side long term mitigation options. This options are modelled in MARKAL by describing the technical, cost, availability and environmental data of the corresponding technologies. Model MARKAL (an acronym for MARket ALlocation) is a demand-driven, multi-period linear programming model of the technical energy system that deals with supply and demand side options. It is a cost-minimizing energy-environment system planning model used to investigate long-term responses to different future technological options, emissions limitations and policy scenarios of energy systems.

Measures for CO_2 reduction can be analysed with MARKAL model in two ways, like conventional approach and forced introduction of technologies that do not appear in the baseline optimal solution. The latter way is used for calculation of the CO_2 emission reduction costs in the case of nuclear power plants candidates in Croatian energy system. The differences in marginal costs are shown in the case of nuclear and coal power plants candidates. This analysis are performed in the scope of complete energy system (not only power sector), from supply side to technologies for energy transformation, and to demand side (sectors for energy consumption).

This marginal costs are calculated as the ratio between the differences in discounted total system costs and emissions between the baseline and nuclear (coal) scenario. The results show which option is better from the optimality side of emission reduction, associated costs and possible final energy consumption changes in energy system.

1 INTRODUCTION

Model MARKAL (acronym for MARKet ALlocation) is a dynamic, process oriented optimization model; software that enable a user to represent a complex energy system - national, regional, local or sectorial, as linear program. MARKAL uses an integrated system wide approach tp modelling the energy system.

MARKAL is a long term multi-period energy technology optimisation model, that represents all energy demand and supply activities and technologies for a country. The dynamic behaviour of the energy system is obtained through maximising the consumer and producer surplus. Supply and demand clear the market through price fluctuations, taking into account any limit on emissions, resources or technological options [1].

In MARKAL the demand for energy services is linked to resources through a chain of processes, conversion and demand technologies. Processes are connected by energy carriers and materials flows. The complete representation of all possible chains form primary energy supply to demand for energy services is called the reference energy system (RES). The Figure 1. represents a simplified reference energy system on which structure the general description of the database is based.

Model optimises the technology mix for each time period using data on the already existing and possible new technologies. The attractiveness of a technology is determined by investment cost, cost of energy carriers used, efficiency, availability factor, emission factors and various constraints [2].

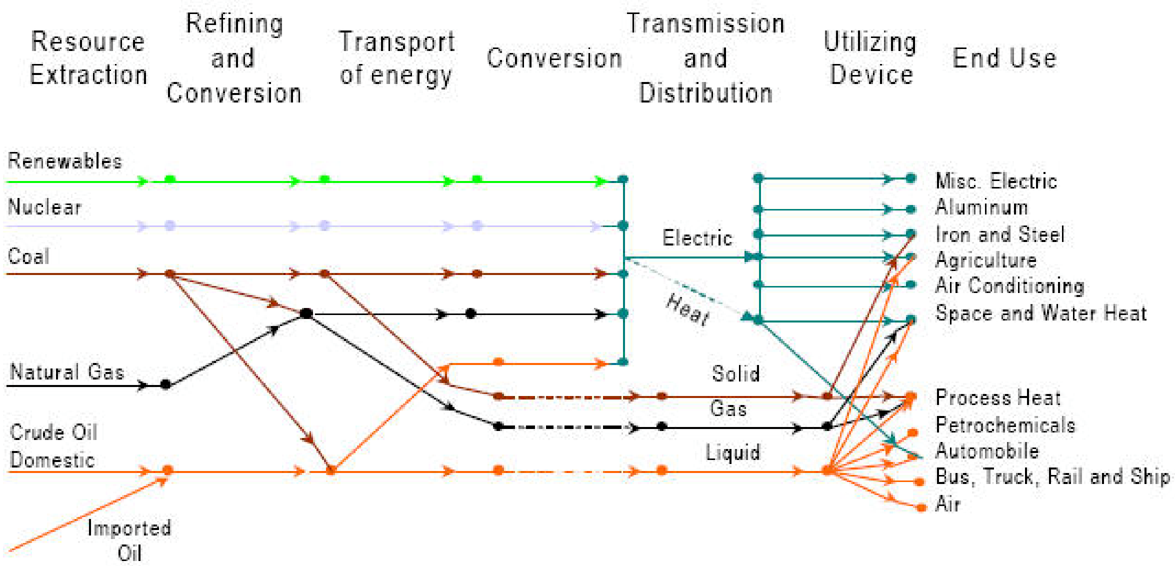


Figure 1: Example of reference energy system

2 GENERAL STRUCTURE OF CROATIAN RES

Republic of Croatia RES is modelled as complete energy system from supply to demand side, including the part for energy transformations; the overall structure is shown at Figure 2. This system consists of [3]:

- 31 energy types (primary and transformed)
- 8 import energy types (electricity, oil derivates, coal, crude oil, gas)
- 4 domestic production energy types (electricity, oil derivates, crude oil, gas)
- 10 export energy types (electricity, oil derivates)
- 3 plants for energy transformation (oil refinery, NGL plant, city gas plant)
- 30 power plants in power sector
- 37 demand categories, grouped in 8 sectors (households, services, industry, agriculture, transport, construction, other, own-use consumption)
- 83 technologies on demand side.

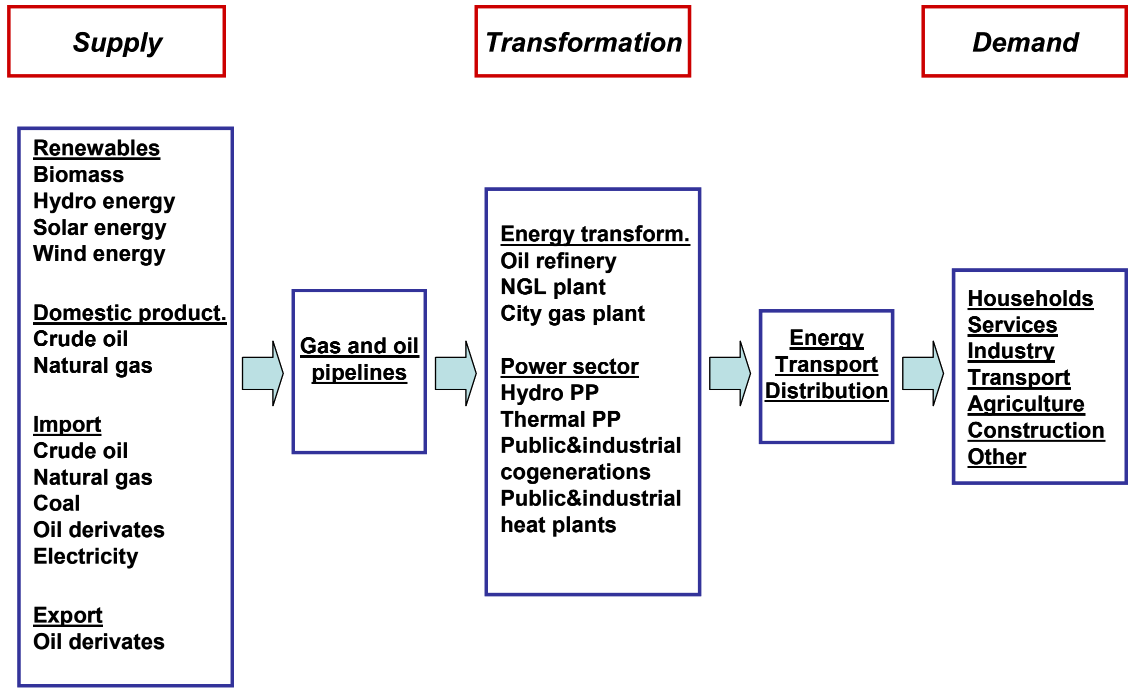


Figure 2: General structure of Croatian RES

GHG emissions can be reduced by changes in both supply and demand (consumers) side of the energy system. Possible introduction of nuclear power plants is the example of long-term supply side mitigation measure for CO_2 reduction.

All options for emission mitigations are modelled in MARKAL by describing the technical, cost, availability and environmental data of the corresponding technology.

3 MODELLING OF GHG REDUCTION MEASURES IN MARKAL MODEL

GHG reduction can be analysed with MARKAL in two ways [2]:

1. Conventional approach (The Integrated System Approach), when cost data are changed. MARKAL enables to model the marginal cost of CO_2 reduction as input data in the form of CO_2 tax. In that case the model finds the optimal solution for each given CO_2 marginal cost level and we can found out from the results the corresponding reduction of emissions and what changes will take place in the energy system.
2. Forced introduction of technologies (The Partial Solution Approach) that do not appear in the optimal solution or whose market penetration is too small under assumptions made due to their high cost. In this case cost analysis of each CO_2 reduction option can be made by comparing the total system cost and emissions data in the baseline and mitigation scenarios containing this particular option.

Marginal costs of specific CO_2 reduction options that do not appear or are not accounted in the baseline optimal solution, can be calculated with:

$$MRC_t = \left(CR_t^{;} - CR_t\right)/\left(R_t - R_t^{;}\right) \qquad (1)$$

where

MRC_t - marginal reduction costs in the year t

R_t - total CO_2 emission in the year t under baseline scenario
R_t' - total CO_2 emission in the year t under scenario with specific option
CR_t - total system cost in the year t under baseline scenario
CR_t' - total system cost in the year t under scenario with specific option.

Here R_t' and CR_t' correspond to the least cost MARKAL solution where specific reduction option is added to the baseline assumptions.

4 MODEL OF CROATIAN POWER SYSTEM

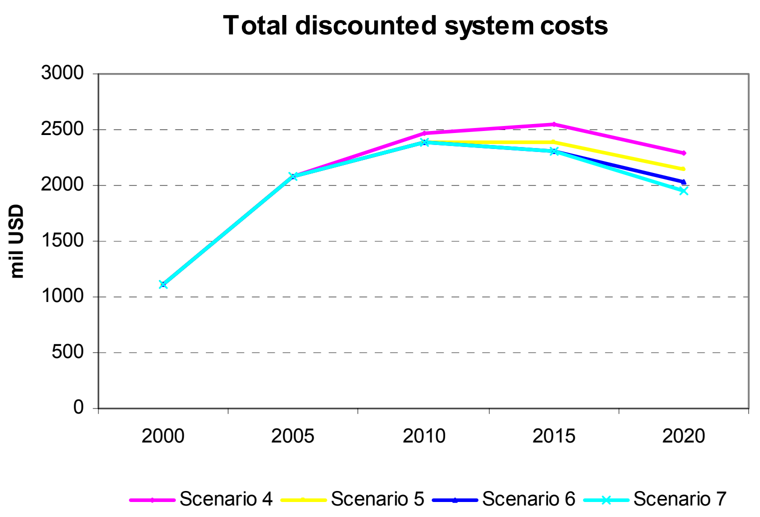
Croatian power system in MARKAL consists of present and future technologies (power plants). Presents power plants are hydro plants (run of river, storage, small), thermal plants and public and industrial cogeneration plants. For future technologies (candidates) different sources are combined in order to model conventional and renewable plants candidates. As a results of capacity expansion model (WASP) one scenario is chosen for gas and coal power plants, together with renewable options (wind, solar, biomass) from other scenarios (Energy Strategy) [3].

In the scenario of nuclear power plant impact on CO_2 emission model assumes start of operation of two LWR power plants at 2010 and 2015 with the capacity of 660 MW. Number of coal power plants (C500) candidates was different per scenarios, as shown in Table 1. Electricity import and CO_2 emission constraint were not in the scope of these scenarios.

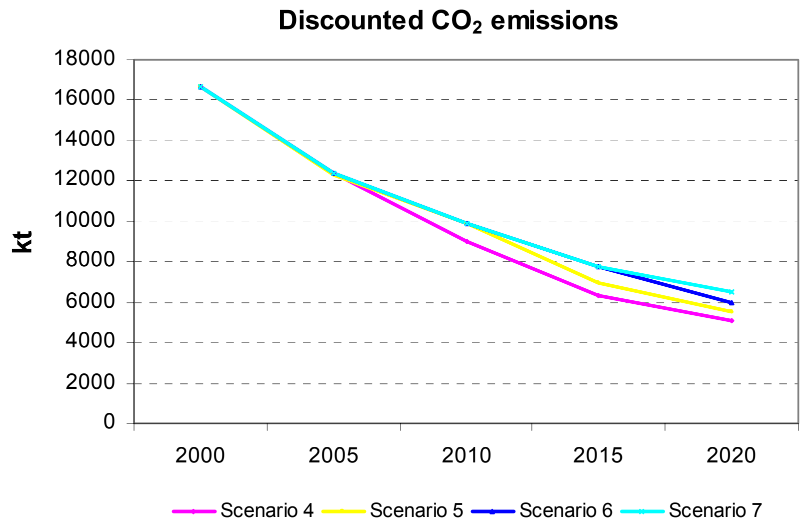
Table 1: Scenarios with nuclear power plants and coal power plants

	Electricity import	**Start of operation for C500**			**Constraint on CO_2 emission**
		2010	2016	2020	
Scenario 4	NO				NO
Scenario 5	NO	X			NO
Scenario 6	NO	X	X		NO
Scenario 7	NO	X	X	X	NO

As a result of nuclear scenarios, total energy system costs and CO_2 emission is changed depending on scenario, as shown in Figures 3. and 4. With the operation of coal power plants candidates, CO_2 emission are higher and total system costs are smaller. In the case of nuclear power plants operation this conclusion is opposite; nuclear plants have impacts on CO_2 emissions decreasing and on total system costs increasing.

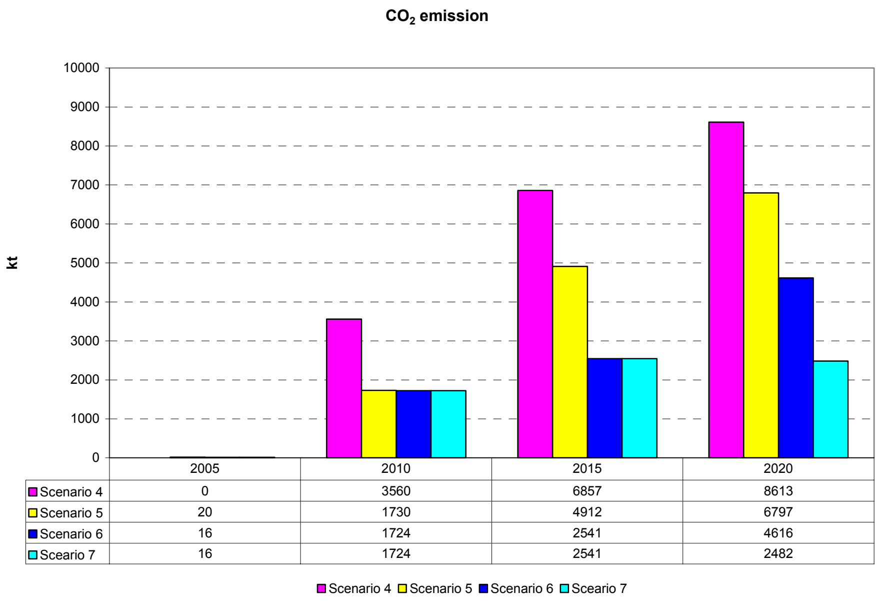


Figures 3: Total discounted system costs



Figures 4: Discounted CO_2 emissions

With nuclear scenario possibility for CO_2 emission reduction is much higher than with different measures in other demand sectors (households, services etc.), so nuclear scenario is long term measure for CO_2 emission reduction. Figure 5. shows potential for (undiscounted) CO_2 emission reduction in nuclear scenarios. Scenario 4 has the highest potential because there is no coal power plants candidates and both nuclear plants candidates are in operation. With the operation of coal plants CO_2 emission reduction potential becomes smaller.



	2005	2010	2015	2020
Scenario 4	0	3560	6857	8613
Scenario 5	20	1730	4912	6797
Scenario 6	16	1724	2541	4616
Sceario 7	16	1724	2541	2482

Figure 5: Potential for CO_2 emission reduction in nuclear scenarios

Marginal costs is another measure of emission reduction. For this calculation total system costs and emissions must be discounted. This costs are calculated based on forced introduction of technologies methodology, like the difference between costs and emissions in Reference scenario (without plant candidates) and Scenarios with plant candidates.

With the operation of coal power plants candidates, marginal costs of CO_2 emission reduction is higher and have negative value (for 2020 in Scenario 6 this value is -61 USD/t and for Scenario 7 is -269 USD/t).

With decreasing in number of coal power plants candidates, marginal cost of CO_2 emission reduction has positive values (for 2020 and Scenario 4 this is 95 USD/t and for Scenario 5 is 34 USD/t). As the most optimal from the cost side is Scenario 5 (with one coal plant candidate in 2010), with the potential for CO_2 emission reduction in whole period (undiscounted) of 13459 kt with marginal cost of 34 USD/t. Another impact of CO_2 emission reduction is fossil fuels consumption decreasing in energy system for the amount of 73.5 PJ in each period (5 years) starting from 2010.

5 CONCLUSION

Calculation of CO_2 emission reduction potentials introducing nuclear scenario can be obtained with the model of power sector only or with the model of the whole energy system (in this case). The second option is better, because can answer on many questions relating to the impact on supply and demand sides of RES: changes in final energy consumption, changes in fuel mix, impact in demand sectors (households, services etc.). Besides this good sides, this model has the implication on complexity and data consuming. The final conclusion of which approach is better, one must take into consideration all mentioned aspects.

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