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Structure of Electricity Balance of Romania for the year 2020, Established Based on Optimal Primary Energy Resources Using the Multi-criteria Analysis Model

Irina Vodă

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CONTENT

1. INTRODUCTION

- In this article the authors explains how to build a multi-criteria model and the results of using it as a model for analysing the optimal electricity balance in Romania up to 2020, from the point of view of primary energy mix used to produce electricity.
- The model has gone from setting the electricity needs for a particular year and then settled its coverage by alternative scenarios.
- For each primary energy source analysed (natural gas, coal, uranium, biomass, wind, large hydro, small hydro), for environmental component it was applied the life cycle analysis method (LCA). We carried out an inventory, which identified the main pollutants for each primary energy source. It was developed, also, an environment impact assessment by which indicators were calculated for each impact class.
- It was calculated the cost of investment, the cost of operating, the cost of fuel and finally, calculate the total expenditure. To select the optimal scenario, the economic recovery cost was used as main criterion.
- Through this model the user can identify the optimal scenario for covering the electricity demand (balance) as from environment and technical/economic point of view.

2. HOW TO CREATE A MULTI-CRITERIA MODEL

2.1. Defining objectives and the field of study:

2.1.1. Defining objectives

- The main objective of the analysis was to develop a multi-criteria model that might to optimal load the electricity balance of Romania (in terms of primary resources used for electricity generation) in 2020, in terms of environmental, technical and economic criteria.

2.1.2. Coverage of electricity demand in 2020

- For this article, we will determine the particular needs of electricity in 2020. Of the scenarios made, for further development we chose the scenario under which the final electricity consumption in 2020 will be 6.3 million toe (73.3 TWh). The total electricity demand was calculated as the sum of the final electricity consumption, ancillary services consumption in networks and was obtained (taking into account specific documents for each parameter) value of 85 TWh in 2020 perspective.

- To meet demand the electricity (85 TWh) we have established different scenarios that would achieve the electricity balance of different loading. In making these scenarios we considered technological restrictions (conditions imposed) the various international engagement assumed by Romania, and some programs being implemented with government support. Under these conditions the imposed structure of electricity generation is as follows:

The structure imposed on electricity production

Total production, including:	85 TWh
- nuclear	20.2 TWh
- renewables	30.8 TWh
- thermo	34 TWh

- By combining the ways of producing electricity from renewable sources and thermo resulted eight scenarios and the quantities of electricity made by each chains within each scenario are presented in the table.

The amount of electricity carried by chains in the scenarios (TWh)

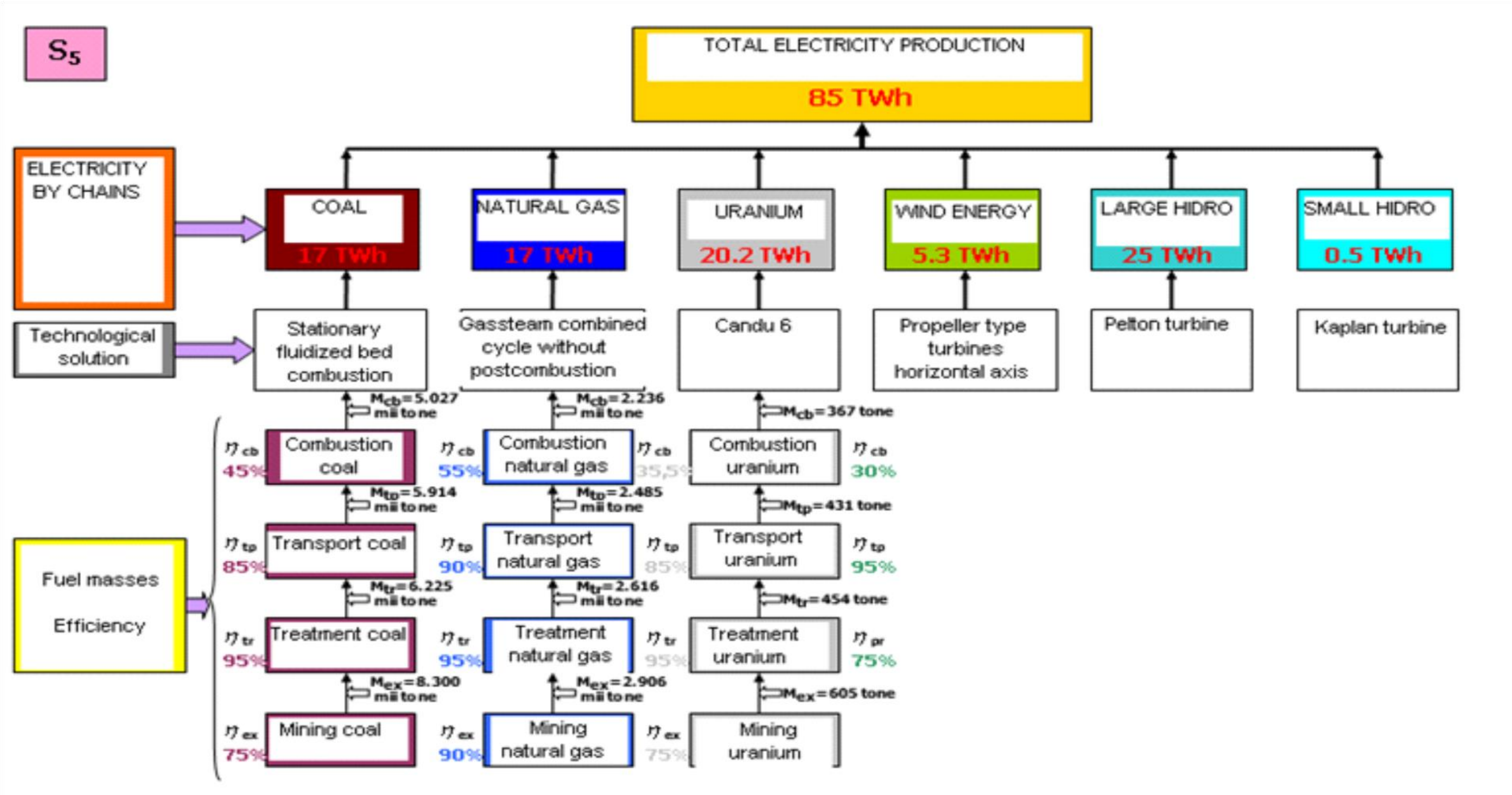
Energy chains	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Uranium	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
Large hidro	25	25	25	25	25	25	15.4	15.4
Small hidro	0	0	1.2	1.2	0.5	0.5	0	0
Biomass	5.8	5.8	4.6	4.6	0	0	15.4	15.4
Energy wind	0	0	0	0	5.3	5.3	0	0
Coal	17	25.5	17	25.5	17	25.5	17	25.5
Natural Gas	17	8.5	17	8.5	17	8.5	17	8.5

2.1.3. Defining the field of study

- First we established the field of study of each energy chains that will be part of the energy scenarios achieved. Then, field study was realized for each scenario separately. Given that the functional unit is defined on the basis of three units: the function, time and product is considered as the functional unit: Romania's electricity needs in 2020 (85 TWh).

- All scenarios are compared to this year's level. In conclusion, it will select the energy scenario which will cover energy needs with minimal environmental impact and minimum cost of production.

- For each scenario, electricity demand coverage in 2020 (85 TWh), we have made detailed study fields. For example the diagram shows the results for scenario 5 (results from the analysis, next figure).



The field of study for scenario 5

2.2. Inventory Analysis

- The inventory analysis was performed for each scenario, the emissions are reported according to the contribution of each chain to produce electricity. The total emissions in each scenario are presented in the table.

The pollutants for each scenario (thousand t/scenario)

Emissions	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
CO_2	28,363	32939	28,828	32,831	28,358	32,361	29,692	33,695
CO	16.473	14.610	16.263	14.401	15.408	13.546	18.053	16.191
NO	0.721	0.363	0.721	0.363	0.721	0.363	0.721	0.363
NH_3	2.224	2.883	2.182	2.841	2.020	2.679	2.562	3.221
CH_4	90.687	64.898	90.661	64.872	90.061	64.272	89.977	64.188
NO_2	82.082	102867	81.096	101.881	77.149	97.934	89.682	110.467
Dust	162.971	239166	162931	239.127	162649	238.844	163.044	239.240
Formaldehyde (CH_2O)	0.145	0.073	0.145	0.073	0.145	0.073	0.145	0.073
COD	1.209	0.641	1.208	0.640	1.203	0.636	1.217	0.650
SO_2	123.727	177.447	123346	177.065	121.775	175.495	126.587	180.306
N_2O	0.780	0.634	0.756	0.610	0.664	0.518	0.968	0.822
Lead	0.058	0.031	0.058	0.031	0.058	0.031	0.059	0.031
Arsenic	0.003	0.004	0.003	0.005	0.003	0.005	0.003	0.005
Barium	0.008	0.011	0.008	0.011	0.008	0.011	0.008	0.011
Chromium	0.005	0.007	0.005	0.007	0.005	0.007	0.005	0.007
Cobalt	0	0.001	0	0.001	0	0.001	0	0.001
Copper	0.002	0.004	0.002	0.004	0.002	0.004	0.002	0.004
Molybdenum	0.001	0	0	0	0	0	0	0
Nickel	0.004	0.006	0.004	0.006	0.004	0.006	0.004	0.006
Selenium	0.007	0.011	0.008	0.011	0.007	0.011	0.007	0.011
Vanadium	0.007	0.010	0.007	0.010	0.005	0.010	0.007	0.010
NH_4	0.399	0.597	0.399	0.597	0.399	0.597	0.399	0.597
Hydrogen Chloride (HCl)	1.229	1.229	0.984	0.984	0.039	0.039	3.183	3.183
Hydrogen Fluoride (HF)	0.004	0.004	0.004	0.004	0.004	0.004	2.413	2.413
Nitric acid	0.002	0.002	0.002	0.002	0	0	0.006	0.006
Isopren	123.172	123172	97.732	97.732	0	0	326.692	326.692

2.3. Impact Analysis

The table shows a comparison between the calculated impact indicators for each scenario.

The impact indicators for each scenario

Impact indicators	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
ADP [t equivalent Sb]	272,738	300,524	250,785	278,572	167,510	195,297	448,360	476,147
GWP [thou. t equivalent CO_2]	31,083	35,516	30,968	35,401	30,457	34,890	31,883	36,316
AP [t equivalent SO_2]	193,074	271,128	192,055	270,110	187,938	265,993	200,846	278,900
POCP [t equivalent ethylene]	143,316	146,533	115,534	118,751	8,792	12,009	365,544	368,761
EP [t equivalent PO_4^{3}]	11,760	15,044	11,617	14,901	11,047	14,331	12,867	16,151
HTP [thou. t equivalent 1,4-dichlorobenzene]	817.495	997.400	816.181	996.087	810.817	990.722	827.372	1.007
FAETP [t equivalent 1,4-dichlorobenzene]	13,171	18,141	13,171	18,141	13,175	18,145	13,165	18,135
MAETP [t equivalent 1,4-dichlorobenzene]	837,555	590,985	875,604	590,989	837,580	591,009	837,480	590,910
TETP [t equivalent 1,4-dichlorobenzene]	5,744	6,601	5,744	6,601	5,744	6,602	5,744	6,601

2.4. Technical and economic analysis

- Starting from the amount of electricity produced for each scenario we determined for each chain the power installed in each scenario for 2020. Taking into account the duration of the investment, the duration of exploitation and the duration of the study, were determined the investment costs, operating costs, fuel costs, resulting the total expenses. We used three cost scenarios eco-taxes. The table below shows the total expenditure eco-tax. It is noted that the scenario that requires the highest total expenditure is the scenario 7.

The total expenditure with eco-taxes for the energy chains and for the scenarios [million Euro]

Total expenditure without/with ecotax	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Total expenditure without ecotax	4,397	4,305	4,005	3,913	2,500	2,408	7,531	7,439
Total expenditure with minimum ecotax	4,658	4,629	4,264	4,235	2,753	2,723	7,804	7,774
Total expenditure with medium ecotax	5,389	5,525	4,996	5,132	3,450	3,586	8,559	8,695
Total expenditure with maximum ecotax	7,745	8,616	7,335	8,206	5,720	6,592	11,044	11,915

- The economic cost recovery was chosen as the criterion of selection the technical and economic scenarios.

The economic cost recovery for the scenarios [Euro/MWh]

Economic cost recovery(ECR)	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
ECR without ecotax	65.7	65.4	61.3	60.9	43.8	43.4	101.4	101.1
ECR with minimum ecotax	69.2	64.3	64.8	46.7	46.7	47.2	104.7	105.1
ECR with medium ecotax	79.9	73.0	75.3	55.2	55.2	57.6	113.6	116.0
ECR with maximum ecotax	116.4	100.7	111.7	82.1	82.1	93.1	143.0	154.0

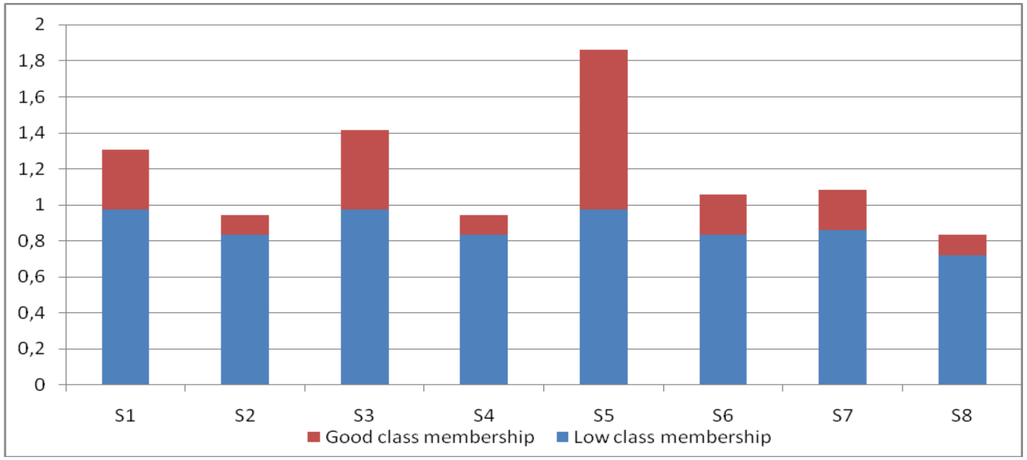
2.5. Multi-criteria Analysis

- The previous performed steps allowed us to obtain information about energy chains used to create scenarios. Further, we will achieve global comparison between scenarios.
- Evaluations were normalized after each criterion and were established in the class memberships good/low.
- We obtained the normalized matrix, based on which energy scenarios were evaluated by each set of criteria to finally obtain a global evaluation of energy scenarios.

The normalized matrix

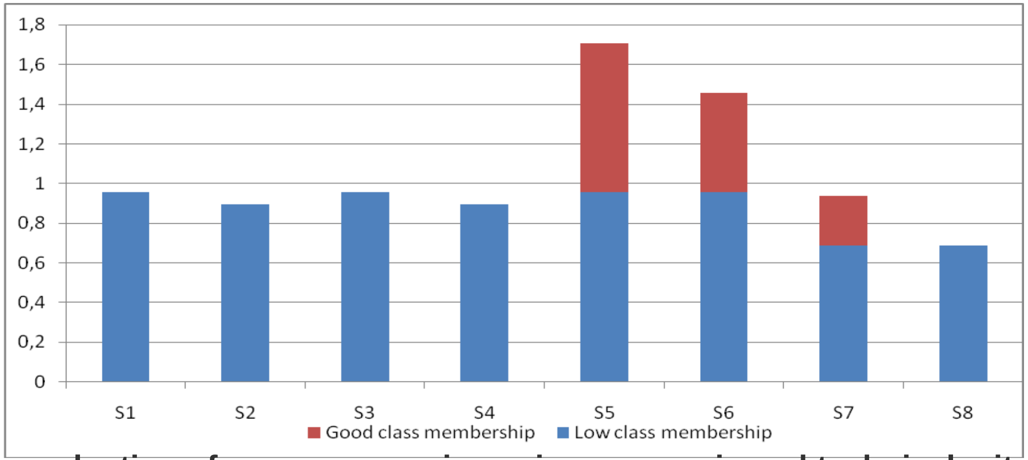
CRITERIA	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
Ecological								
ADP [t equivalent Sb]	0.573	0.631	0.527	0.585	0.352	0.410	0.942	1.000
GWP [thou. t equivalent CO_2]	0.856	0.978	0.853	0.975	0.839	0.961	0.878	1.000
AP [t equivalent SO_2]	0.692	0.972	0.689	0.968	0.674	0.954	0.720	1.000
POCP [t equivalent ethylene]	0.389	0.397	0.313	0.322	0.024	0.033	0.991	1.000
EP [t equivalent PO_4^{3-}]	0.728	0.931	0.719	0.923	0.684	0.887	0.797	1.000
HTP [thou. t equivalent 1,4-dichlorobenzene]	0.812	0.990	0.810	0.989	0.805	0.984	0.821	1.000
FAETP [t equivalent 1,4-dichlorobenzene]	0.726	1.000	0.726	1.000	0.726	1.000	0.726	0.999
MAETP [t equivalent 1,4-dichlorobenzene]	0.957	0.675	1.000	0.675	0.957	0.675	0.956	0.675
TETP [t equivalent 1,4-dichlorobenzene]	0.870	1.000	0.870	1.000	0.870	1.000	0.870	1.000
Technical and economic								
Investment expenses (thou. Euro)	0.928	0.979	0.937	0.988	0.949	1.000	0.854	0.905
Operating expenses (thou. Euro)	0.942	0.972	0.938	0.969	0.925	0.956	0.970	1.000
Fuel expenditure (thou. Euro)	0.563	0.548	0.508	0.494	0.299	0.284	1.000	0.985
Economic recovery cost without cost to emissions of CO_2, SO_2 and NO_x (Euro/ MWh) (at "a"=discount rate=8%)	0.856	0.886	0.842	0.871	0.771	0.801	0.971	1.000

- Referring to the environmental criteria, scenario 5 presents the highest value and is considered the best scenario, and scenario 8 is the worst scenario.



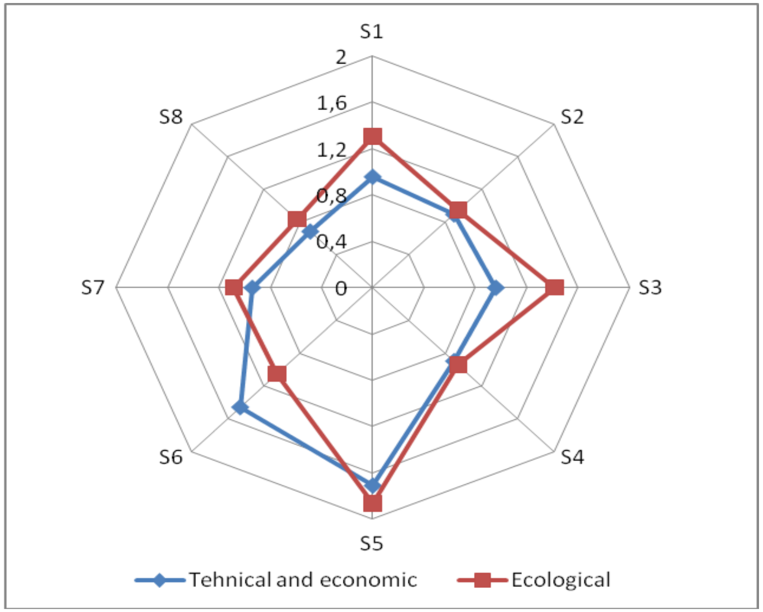
The evaluation of energy scenarios using environmental criteria

- Regarding the technical and economic criteria, scenario 5 presents the highest value and is, therefore, the best scenario.



The evaluation of energy scenarios using economic and technical criteria

- The evaluation results were represented by families of criteria set by a radar chart.



The global assessment of energy scenarios

- Observe the diagram above that scenario 5 is the scenario that the highest values recorded in terms of family environmental criteria and in terms of family economic and technical criteria, so scenario 5 is the optimal scenario.

2.6. Sensitivity analysis and robustness analysis

- The sensitivity analysis was performed taking into account both the change in the objective indicators (share of families of criteria etc.) and subjective indicators of change (fuel prices, introduction eco-taxes, the discount rate).

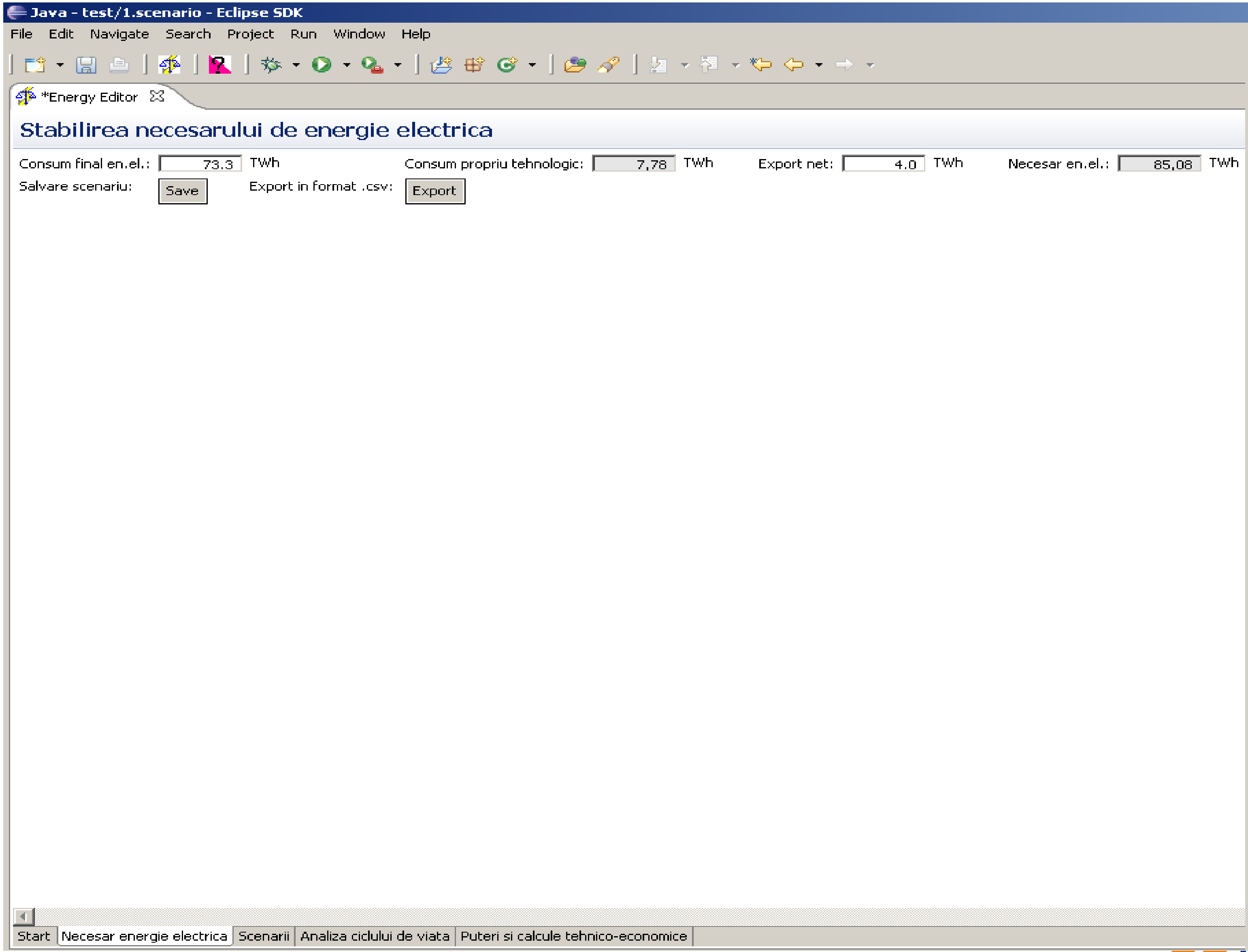
- The robustness analysis revealed that the chosen solution (scenario 5) remains the best.

3. THE STRUCTURE AND THE RESULTS OBTAINED WITH MULTI–CRITERIA MODEL USING “ECLIPSE”

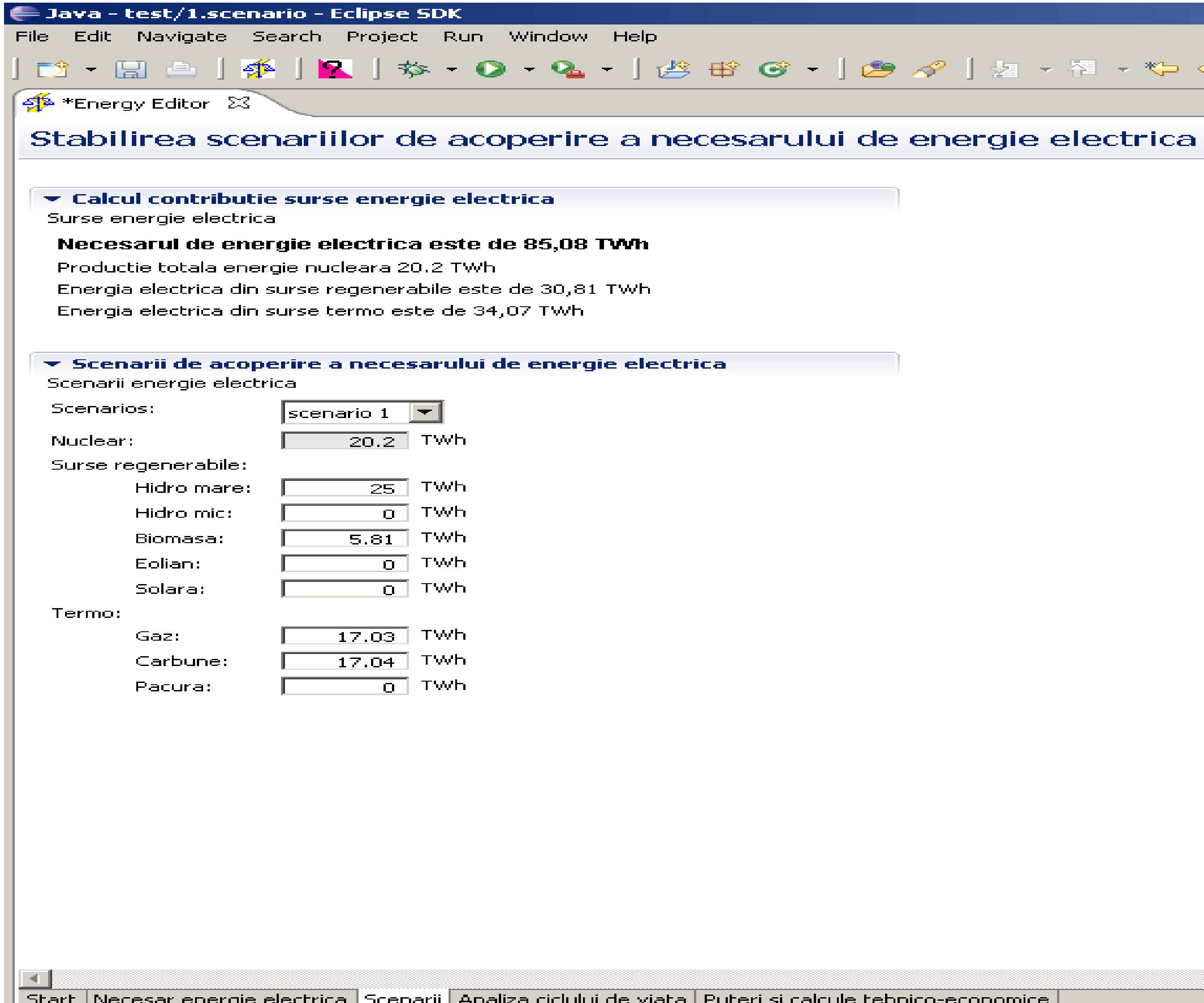
- In the previous chapter has presented the multi-criteria model as was done in Excel. Transposition was done in the "Eclipse" program (using Java) in order to quickly select an optimal energy scenario in detail using other values, where modification is done in a long time and with lower performance. Eclipse program offers an attractive graphical interfaces and database created multi-criteria model can be enriched by providing greater opportunities for simulation and interpretation of different data loads.
- The multi-criteria model developed consists of five modules, named after the steps necessary to achieve the program (and have been detailed in part 2 of article in the creation phase of the model), as follows:

  1. Establishment of electricity demand;
  2. Scenarios;
  3. Life Cycle Analysis;
  4. Powers, technical and economic calculations;
  5. Evaluation scenarios.

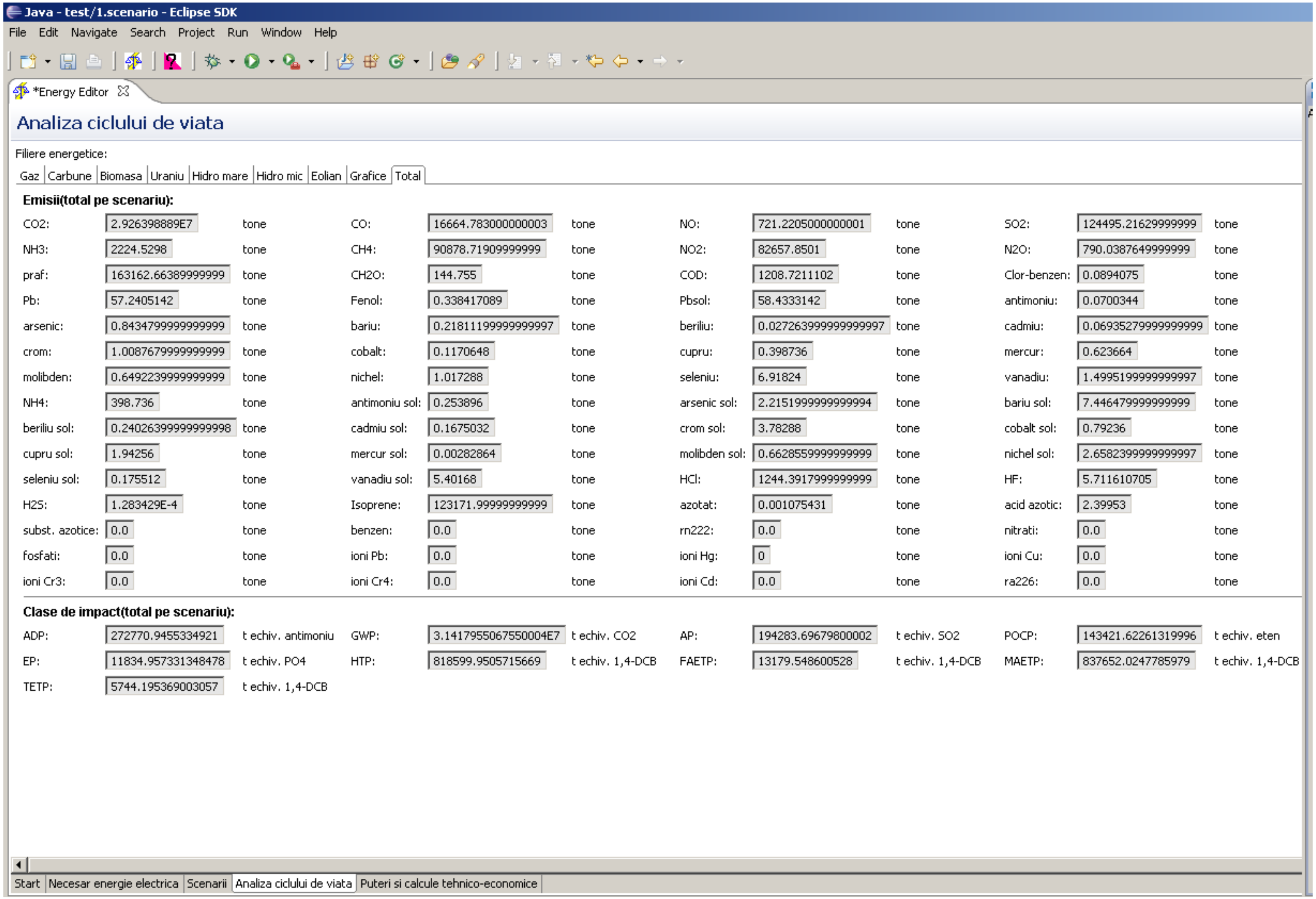
These modules are added to a home page, from which the user has direct access to the modules listed above.



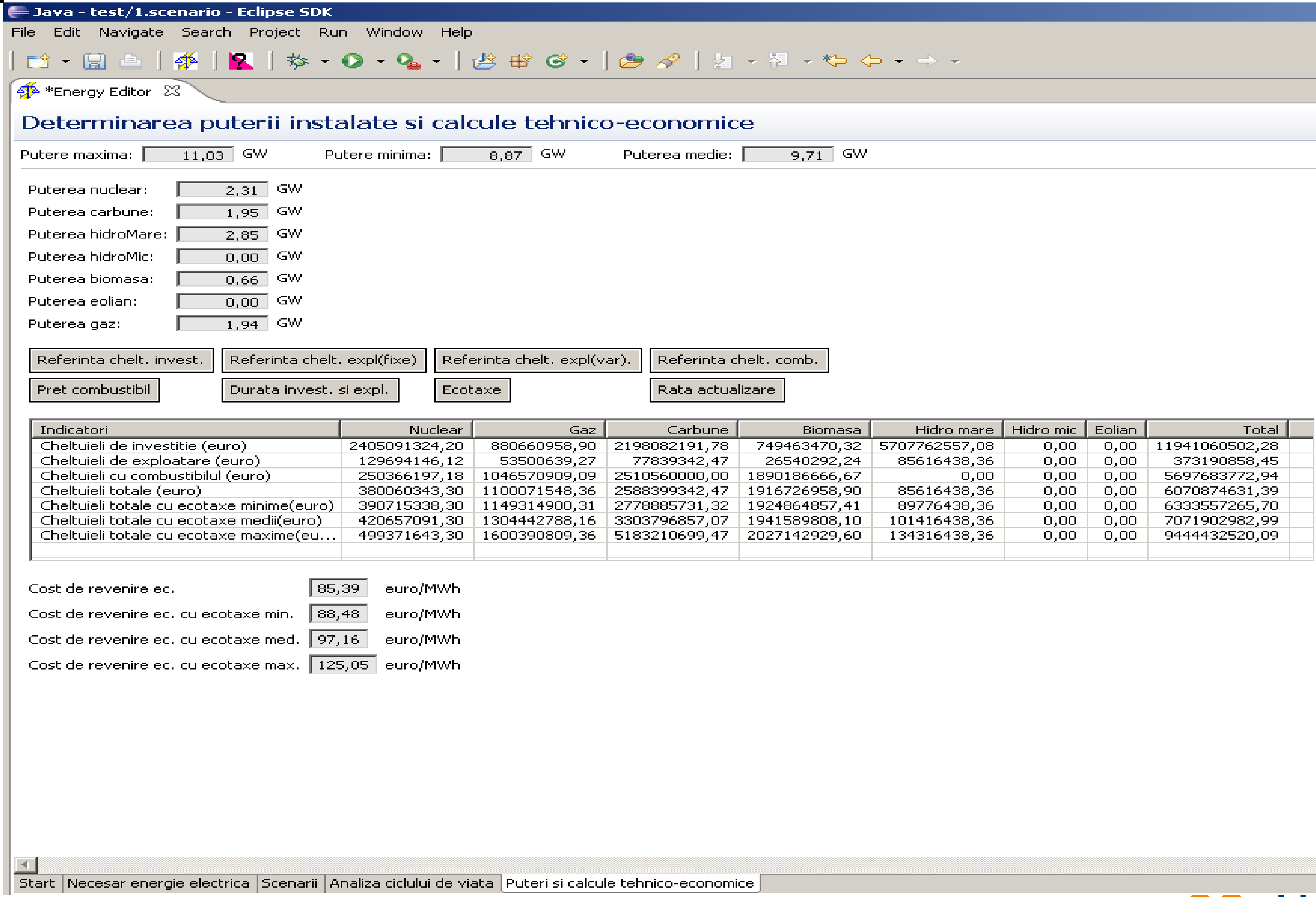
Module 1 “Establishment of electricity demand”



Module 2 “Scenarios”



From Module 3, The inventory analysis and the impact assessment on all scenarios



Indicatori	Nuclear	Gaz	Carbune	Biomasa	Hidro mare	Hidro mic	Eolian	Total
Cheltuieli de investitie (euro)	2405091324,20	880660958,90	2198082191,78	749463470,32	5707762557,08	0,00	0,00	11941060502,28
Cheltuieli de exploatare (euro)	129694146,12	53500639,27	77839342,47	26540292,24	85616438,36	0,00	0,00	373190858,45
Cheltuieli cu combustibilul (euro)	250366197,18	1046570909,09	2510560000,00	1890186666,67	0,00	0,00	0,00	5697683772,94
Cheltuieli totale (euro)	380060343,30	1100071548,36	2588399342,47	1916726958,90	85616438,36	0,00	0,00	6070874631,39
Cheltuieli totale cu ecotaxe minime(euro)	390715338,30	1149314900,31	2778885731,32	1924864857,41	89776438,36	0,00	0,00	6333557265,70
Cheltuieli totale cu ecotaxe medii(euro)	420657091,30	1304442788,16	3303796857,07	1941589808,10	101416438,36	0,00	0,00	7071902982,99
Cheltuieli totale cu ecotaxe maxime(eu...	499371643,30	1600390809,36	5183210699,47	2027142929,60	134316438,36	0,00	0,00	9444432520,09

From Module 4, The installed capacity and technical and economic calculations

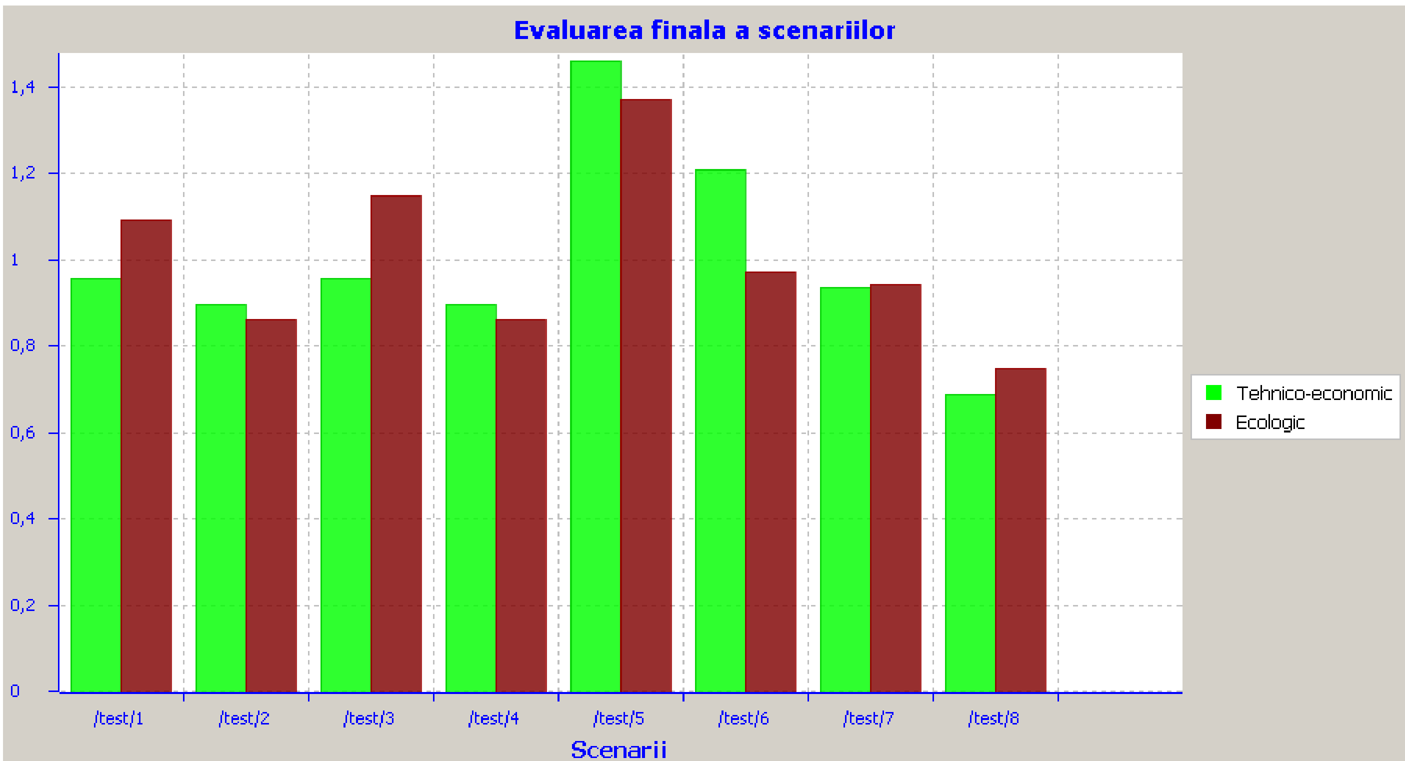
Java - test/1.scenario - Eclipse SDK

File Edit Navigate Search Project Run Window Help

Evaluation View

Matricea de evaluare finala:

Criterii	/test/1.scenario	/test/2.scenario	/test/3.scenario	/test/4.scenario	/test/5.scenario	/test/6.scenario	/test/7.scenario	/test/8.scenario
Tehnico-econo...	0.9583333333333334	0.8958333333333334	0.9583333333333334	0.8958333333333334	1.4583333333333335	1.2083333333333335	0.9375	0.6875
Ecologic	1.0925925925925926	0.8611111111111112	1.1481481481481481	0.8611111111111112	1.3703703703703702	0.9722222222222222	0.9444444444444445	0.75



From Module 5, Global assessment of scenarios

4. CONCLUSIONS

- **The implementation of this model enabled the identification of the optimal scenario to cover the balance of electricity in terms of environmental criteria and in terms of technical and economic criteria.**
- **Following analysis, scenario 5 is the optimal scenario to cover the electricity needs of 85 TWh in 2020. It was called "Wind – Natural gas Scenario. The loading of this scenario is as follows:**

- four nuclear groups, provide 20.2 TWh;

- wind energy provides 5.3 TWh;

- large hydro provides 25 TWh;

- small hydro provides 0.5 TWh;

- thermo energy is achieved in equal proportion of coal and gas, each making one 17 TWh.

- **Since the program supports changes to many parameters, it allows the user achieve many simulations and data interpretation (in a very short time) that can be used in determining strategies for energy sector development.**
- **The program also addressed to less initiated persons into multi-criteria model, encompassing a part of graphics makes it possible to interpret the data in an easier manner. It presents a tool that allows exporting data in Excel format.**

Thank you for your attention!

Irina Vodă
Institute for Studies and Power Engineering (ISPE)
Energy and Environment Division

1-3 Lacul Tei Blvd.
020371 Bucharest
Romania

ph: + 4021 2061309
e-mail: irina.voda@ispe.ro
www.ispe.ro