COMPARATIVE ANALYSIS OF SOME FORECASTING METHODOLOGIES FOR GREENHOUSE GAS EMISSIONS PROJECTIONS

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0. Summary

0.1. Introduction, [1÷29]

Climate change is a major challenge of our days – a complex domain in which we should increase our knowledge and understanding in order to immediately undertake proper mitigation measures. Significant changes have occurred in climate regime over the past hundred years. Records show that mean temperature on Earth rose by approximately 0.6^{o} C during the 20th century. Climate change is a long-term challenge, that can be addressed successfully only through long-term actions and international cooperation at both regional and global levels (detailed in Chapter 2).

This research bring into discussion the analysis of climate change risk associated with the lack of firm mitigation measures in the near future. One of the major priorities identified at national level is to increase the life quality by reducing the risk of natural disasters, which can be achieved by applying the principles of sustainable development in all sectoral policies. Also, the research treats the main issues relating to climate change and describe the spectrum of anthropogenic activities that contribute to the enhancing of this process, with direct impact on the quality life.

Although the greenhouse effect, as a natural phenomenon allows life development on the Earth, (as shown in chapter 2.2), its increasing magnitude, due to the natural and the anthropogenic factors (with considerable influence starting with the industrial revolution) can cause serious disturbances in life conditions.

Greenhouse gases absorb and emit radiation with specific wavelengths to the infrared radiation spectrum. Burning fossil fuels, such as coal and oil, and deforestation have caused an ever-growing concentration of GHGs in the atmosphere.

Mostly due to the above reasons, the rise in the Earth's surface temperature is accelerating and, hence, visible results are generated, especially on climate change, equilibrium in main ecosystems and human security.

Global warming potential (GWP) of the main GHGs, are detailed in Figure 1.A.

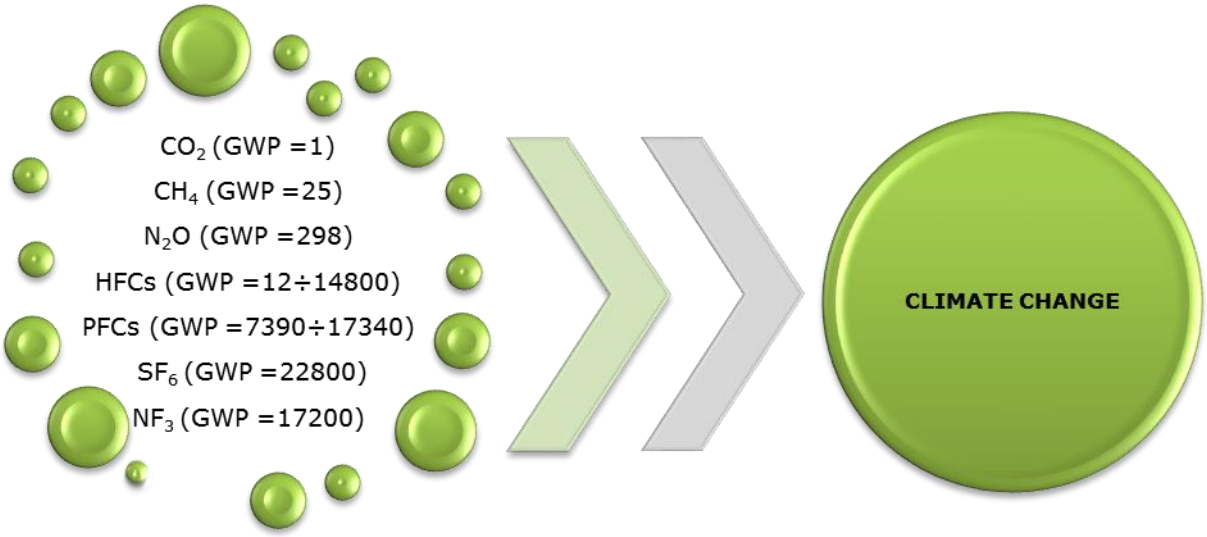

Figure 1. A. Greenhouse gases (GHGs) – *corresponding to figure 9.1 from the research study*

In order to allow comparisons of the global warming impact of the individual GHGs, a Global Warming Potential indicator was developed (defined in Chapter 2.4), which takes into account both the level of gas interaction with infrared radiation and the lifetime of the gas in the atmosphere.

Some significant events in the history of climate change science and some diplomatic actions taken to stabilize the concentrations of GHGs in the atmosphere over time are presented in Figure 2.A.

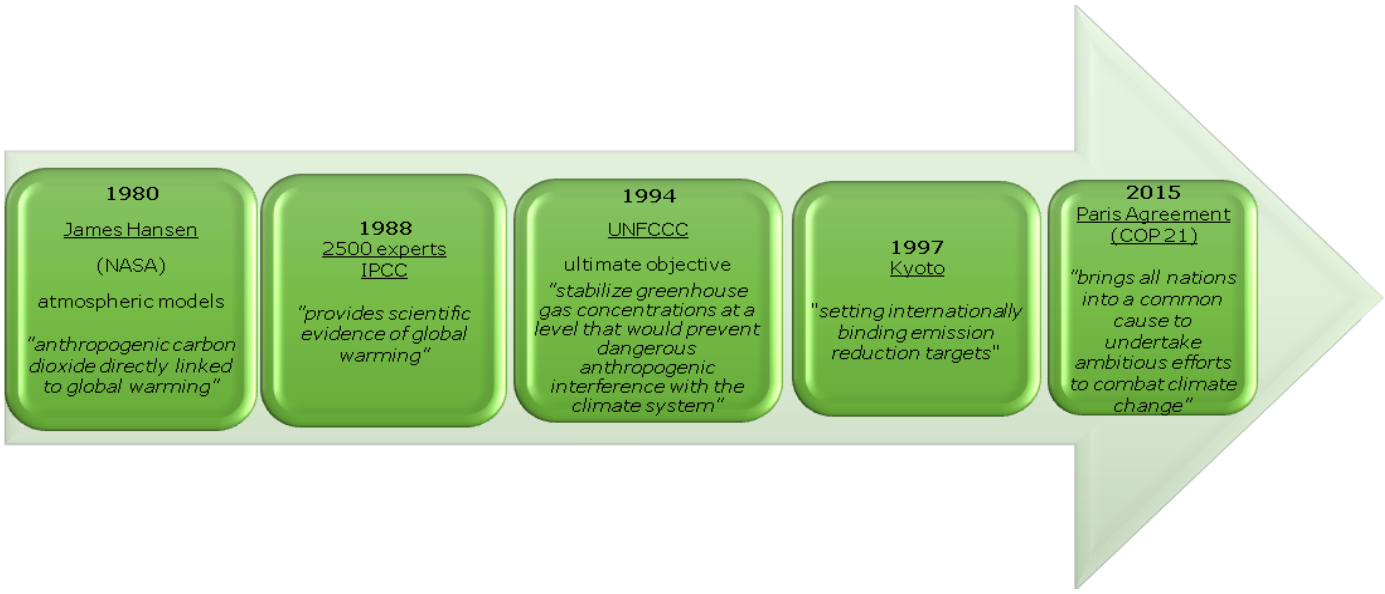

Figure 2. A. Key moments in the diplomatic efforts to reduce global warming – *corresponding to figure 9.2. from the research study*

The research study aims to analyze the main models used for the GHG emissions projections at international level in order to select the optimal with the highest probability to be suited for Romania context.

0.2. GHG emission evolution at national level, [30÷45]

Romania ratified the UNFCCC (United Nations Framework Convention on Climate Change) by Law 24/1994 and the Kyoto Protocol to the UNFCCC by Law 3/2001.

In addition, Romania initiated and completed the process of setting national targets for all objectives of the strategy, which was validated by the High Level Working Group on 8 June 2010. Agreed national objectives related to the implementation of the Energy Package - climate change, congruent with the provisions of the European Commission are presented in Table 1.A.

Table 1.A. Climate change policy objectives of Romania in accordance to the EU Energy-Climate Change Package - *corresponding to table 3.1 from the research study*

2020 Objectives	**Reducing GHG emissions**	**Share of Renewable Energy Sources-Energy in gross final consumption**	**Increasing energy efficiency**
EU 27 (%)	20	20	20
National objectives (%)	**20**	**24**	**19**

In order to assess the anthropogenic contribution to climate change, it is necessary to identify the responsible activities of GHG emissions at national level and to monitor their evolution in time in association with the climatic variations observed in Romania.
CO_2 has the largest contribution to the total amount of national GHG emissions, followed by CH_4 and N_2O, and the energy sector is responsible for an approx. 70% of the total GHG emissions. Other sectors, such as industrial processes and products use, agriculture, LULUCF (Land Use, Land-Use Change and Forestry) and waste, summarizes to an approx. 30% of the total GHG emissions at national level.

Trends of the national GHG emissions for the period 1998-2014 are presented in the figure 3.A.

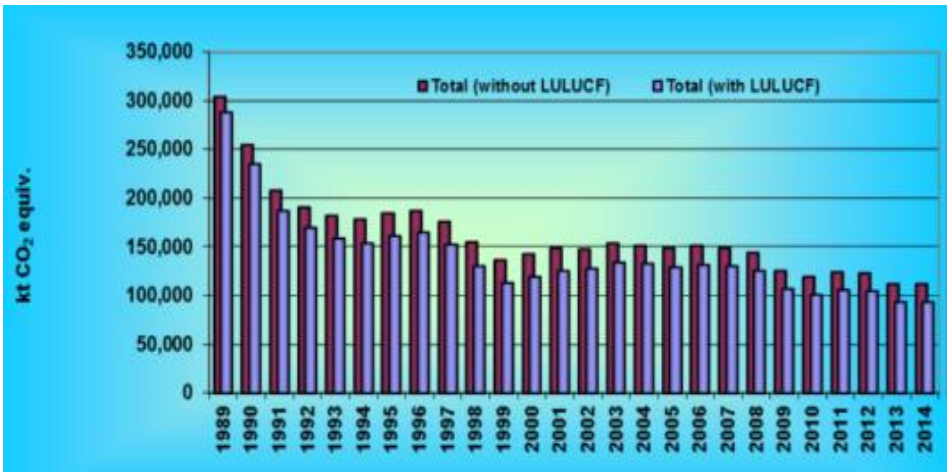

Figure 3.A. Trends of the national GHG emissions – *corresponding to figure 4.1. from the research study*

The emissions trend at national level reflects the changes in this period characterized by a transition process to a market economy and can be divided in the following relevant periods:

- 1989-1992: decline of economic activities and energy consumption
- 1992-1999: economy revitalization
  (1997: starting operation of the first reactor - Cernavoda nuclear power plant)
- 1999-2008: economic development
- 2008-2014: the emissions show a decrease due to the economic crisis

According to the latest National Inventory Report submitted to UNFCCC (United Nations Framework Convention on Climate Change) in August 2016, the total GHG emissions in Romania decreased with 63.40% in 2014 compared to 1989.

The sectors analyzed in this research study (households, agriculture, services, industry, transport and energy) contain multiple sub-sectors, characteristics and dynamic elements, and for their analysis there is a need to use models to describe, organize and predict their behaviour, in different scenarios on climate change policies.

0.3. Projection models, [46÷65]

Forecasting models are generally used in the process of elaboration of the legislative framework and regulations adopted at national level but can also be used as planning tools. In Chapter 5, a documentary summary of the most representative GHG emission projection models has been achieved.

The identified models were classified (according to the different approaches) and described in detail to allow the highlighting of the main specific criteria used in the selection stage (Figure 4.A.).

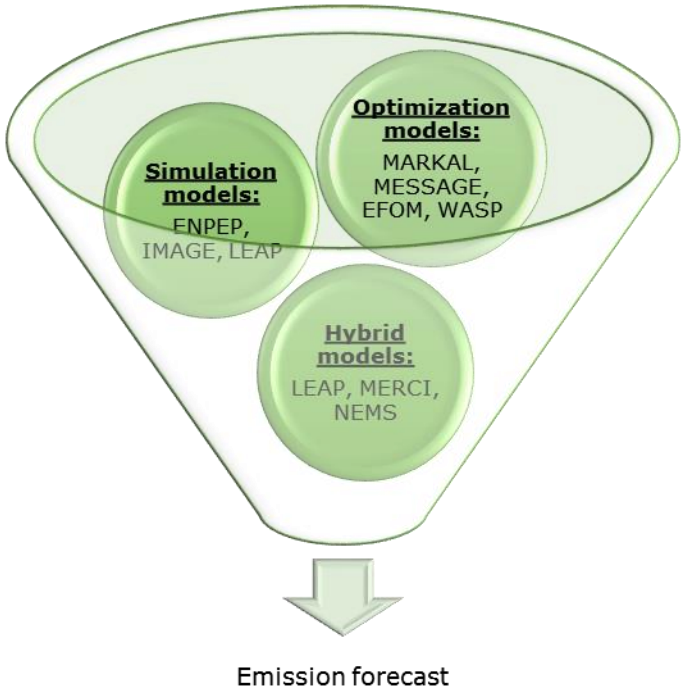

Figure 4.A. Projection models – *corresponding to figure 9.3. from the research study (ENPEP - Energy and Power Evaluation Program, IMAGE - Integrated Model to Assess the Global Environment, LEAP - Long-range Energy Alternatives Planning, MARKAL - MARKet Allocation, MESSAGE - Model for Energy Supply Strategy Alternatives and their General Environmental Impact, EFOM - Energy Flow Optimisation Model, WASP - Wien Automatic System Planning Package, MERCI - Model for Evaluating Regional Climate change Impacts, NEMS - National Energy Modeling System)*

Considering criteria such as accessibility, the applicability in developing European countries, and the projections possibility in different socio-economic scenarios, the models ENPEP, LEAP, MARKAL, MESSAGE and MERCI have been selected for a forward evaluation.

ENPEP (Energy and Power Evaluation Program) - developed in 1999 by the Centre for Energy, Environmental and Economic Systems Analysis (CEEESA - Argonne National Laboratory in the USA) and the U.S. Department of Energy:

- determines the response of various segments of the energy system to changes in energy prices and demand levels
- bottom-up/non-linear/equilibrium model

LEAP (Long-range Energy Alternatives Planning) - developed in 1980 in the USA:

- is a widely-used software tool for energy policy analysis and climate change mitigation assessment
- bottom-up/accounting model

MARKAL (MARKet Allocation) - developed in the late 1970's by the Brookhaven National Laboratory (USA):

- facilitates the analysis of different future energy system pathways over a medium to long term, by integrating energy, environmental, and economic factors
- bottom-up/dynamic/partial equilibrium model

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) - developed in 1980s by the International Institute for Applied Systems Analysis:

- technology-rich energy systems model with economic and environmental modules
- bottom-up model
- systems engineering optimization tool

MERCI (Model for Evaluating Regional Climate change Impacts) - developed in 2009 by the Institute for Advanced Studies (IHS) Vienna:

- designed to assess different possible future developments in a complex economic and ecological sense, and to evaluate them with respect to the criteria important to the user
- hybrid/dynamic/general equilibrium model

These models are used to estimate costs and benefits of climate policy options, always related to a possible future development of the social, economical and environmental system.

The selection of the optimal model for climate change mitigation for Romania, from the list of the models previously presented, raises the issue of their comparative evaluation and through them, the selection of the optimum alternative (presented in Table 5.2.).

Table 2.A. Evaluation matrix – *corresponding to Table 5.2. from the research study*

	UE applicability	**Transparency**	**Required data intensity**	**Flexibility in building scenarios**	**Cost**	**International recognition**	**TOTAL**
ENPEP	**3**	**3**	**2**	**2**	**3**	**2**	**15**
MARKAL	3	1	1	1	1	3	10
MERCI	1	2	2	3	3	1	12
LEAP	**3**	**3**	**3**	**3**	**3**	**3**	**18**
MESSAGE	2	2	2	1	3	2	12

The meaning of the marks in the above table was as follows:

- Low level: 1 point
- Moderate level: 2 points
- High level: 3 points

After this first evaluation stage, the LEAP and ENPEP models were generated to be best suited to estimating GHG emissions at national level.

LEAP and ENPEP software models have been analyzed in detail (in the Chapters 5.3 and 5.4.) in order to identify a number of relevant selection criteria to differentiate the appropriate model to be used for the national greenhouse gas emissions projection.

The two models resulting from the first selection procedure were evaluated in a multi-criteria analysis, presented in Chapter 6, based on the following relevant selection criteria: flexibility, robustness, complexity, data availability and transparency (see Figure 5.A.).

Following the multi-criteria analysis, LEAP achieved the maximum score, so this model can be successfully used to predict the evolution of GHG emissions and to determine the environmental impact of government policies at national level over the 2050 time horizon.

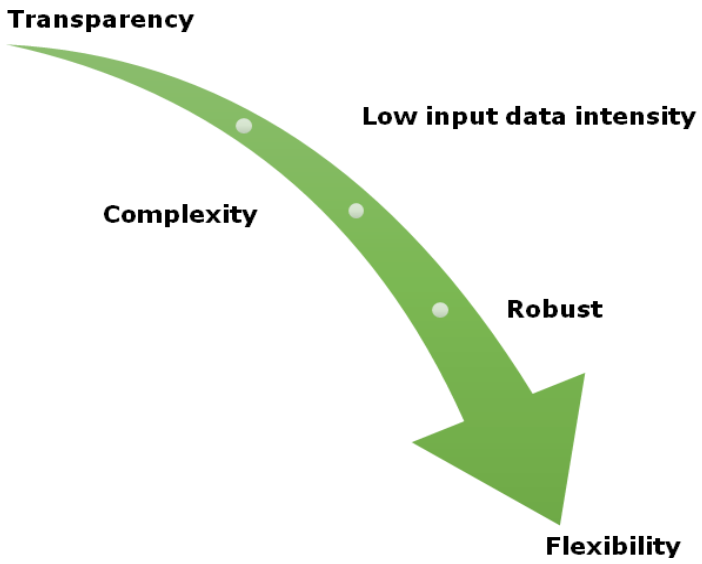

Figure 5.A. Criteria selection used in the multi-criteria analysis – *corresponding to figure 9.4. from the research study*

The LEAP model is the most suited for addressing developing countries characteristics and the main features are shown in Figure 6.A.

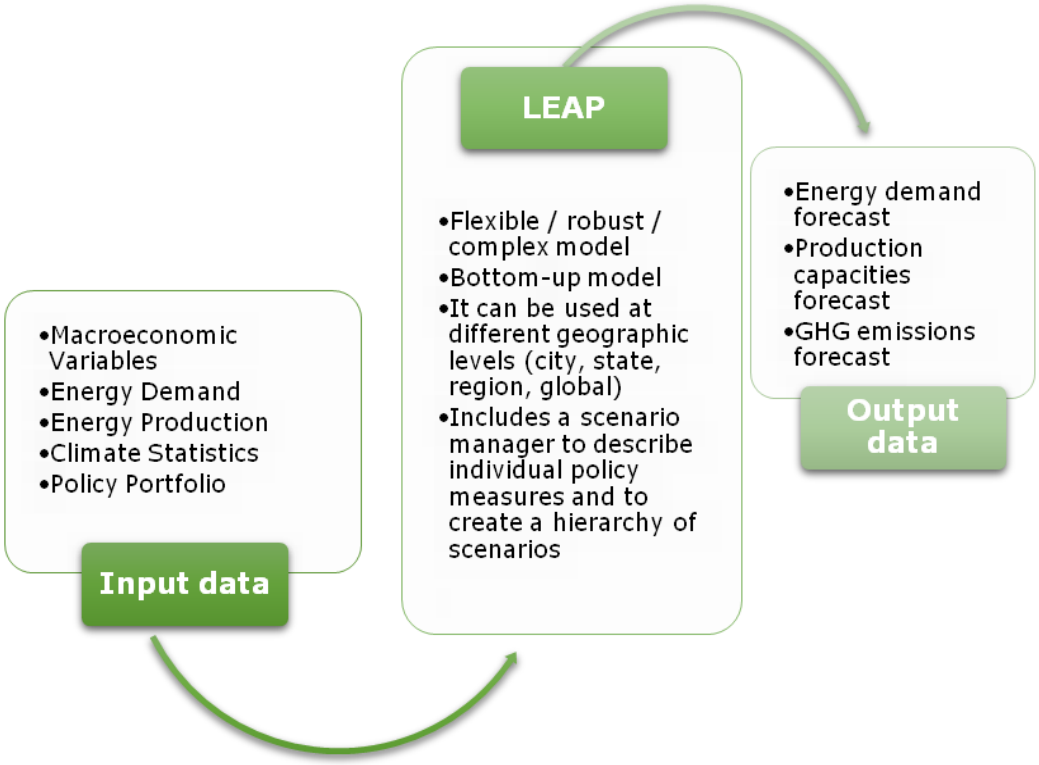

Figura 6.A. Model description – *corresponding to figure 9.5. from the research study*

LEAP is a useful tool for conducting strategic studies based on energy-environment integrated scenarios, such as: energy sector projections, greenhouse gas reduction methods analysis, energy balances and GHG inventories.

0.4. National GHG emissions projection using LEAP model, [66÷79]

LEAP presents complex energy analysis concepts in a transparent and intuitive way. It is flexible enough for users with a wide range of expertise: from leading global experts who wish to design policies and demonstrate their benefits to decision-makers to trainers who want to build capacity among analysts who are learning to understand the complexity of energy systems.

To elaborate the national GHG emission projection, using LEAP model, three scenarios were developed by comparing their energy requirements, their social costs and benefits, and their environmental impacts, under various assumptions (detailed in chapter 7.3).

These scenarios are described in Figure 7.A.

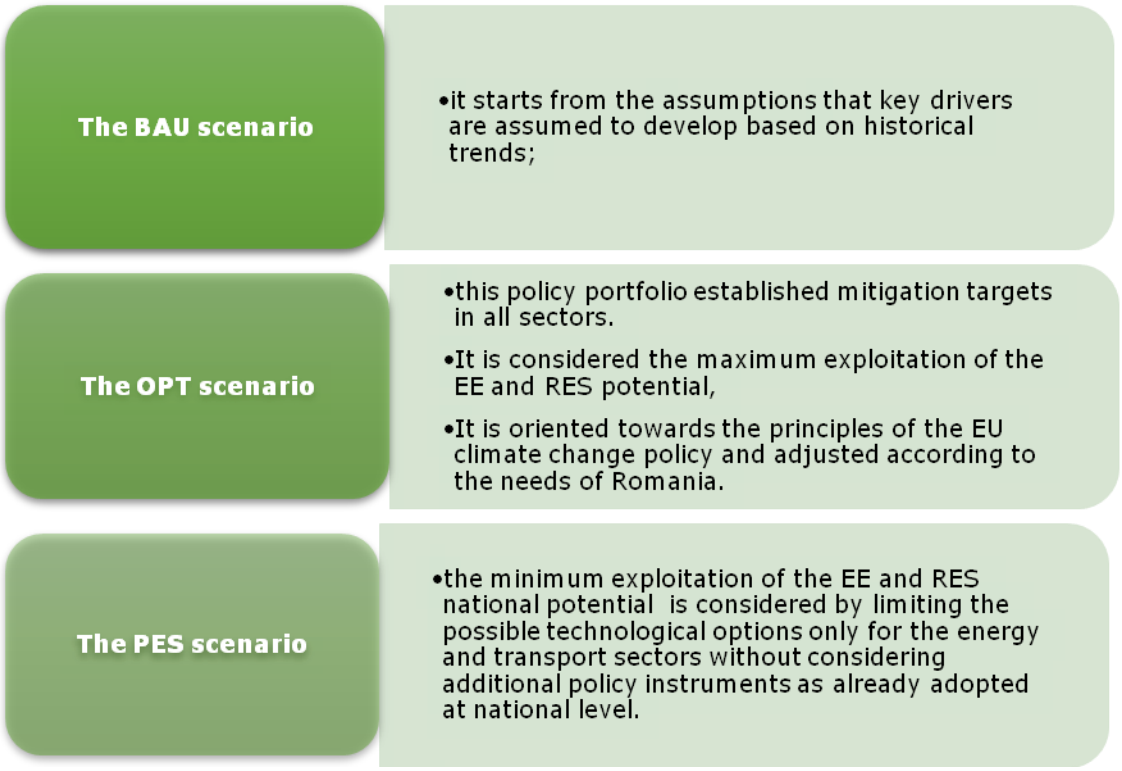

Figure 7.A. Scenarios Description – *corresponding to figure 9.6. from the research study*

The main sources for input data used for LEAP projections were INSSE (National Institute of Statistics), EUROSTAT (Statistical Office of the European Communities), ANRE (Romanian Energy Regulatory Authority), UNFCCC, CNP (Romania's National Prognosis Commission), the Romanian Government, INEGES (National Inventory of Greenhouse Gas Emissions) and the IPCC.

GHG emissions projections generated using LEAP model at the national level are centralized for the time horizon 2050 for three analysis scenarios assumptions, in the cumulative diagram presented in Figure 8.A.

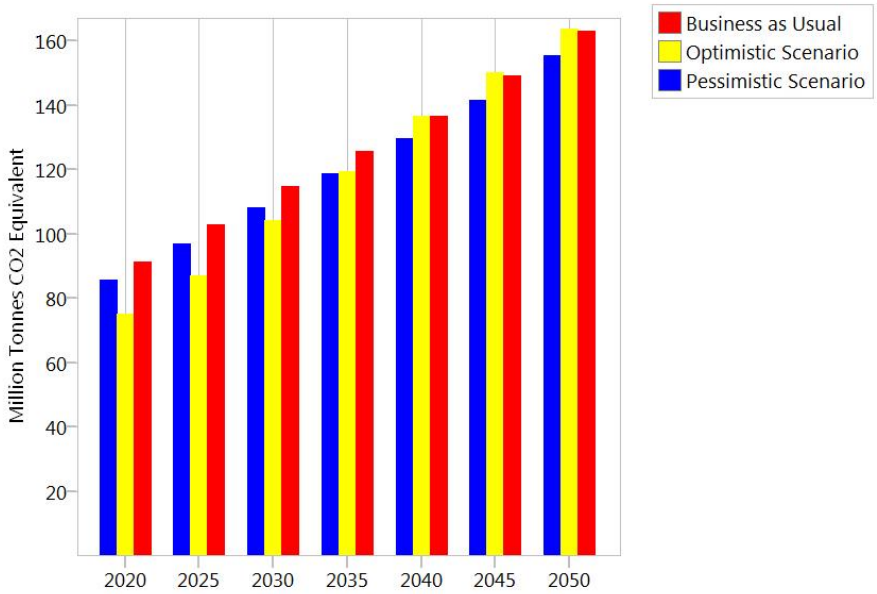

Figure 8.A. The evolution of the GHG emissions for the three analysed scenarios – *corresponding to figure 9.7. from the research study*

The diagram (presented in figure 8.A.) highlighted the lowest GHG values for PES Scenario. This is due to the low values of growth economic rates associated with fuel consumption values taken into account in the initial assumptions of this scenario.

Due to the considered assumptions regarding the economic growth rates, the energy production in the OPT scenario increased considerably, leading to the need for investments in energy sector.

Even if emission values are lower in the PES scenario. The policy portfolio used in the OPT scenario is oriented towards the principles of EU climate change policy, generating benefits such as: economic growth, increasing energy efficiency measures across all sectors, encouraging the use of national energy resources and the decrease in import dependence. So, following the environmental impact assessment process, political acceptability and feasibility of implementation, the OPT scenario generated the best results in terms of energy demand and emissions reduction policies.

0.5. National GHG emissions reduction measures, [80÷95]

The last chapter highlights GHG emissions reduction measures identified at national level and presents the potential risks identified in case of ignoring the climate change alert signals or in case of delayed the reduction measures implementation.

The best options for reducing greenhouse gas emissions identified for Romania are presented in figure 9.8.

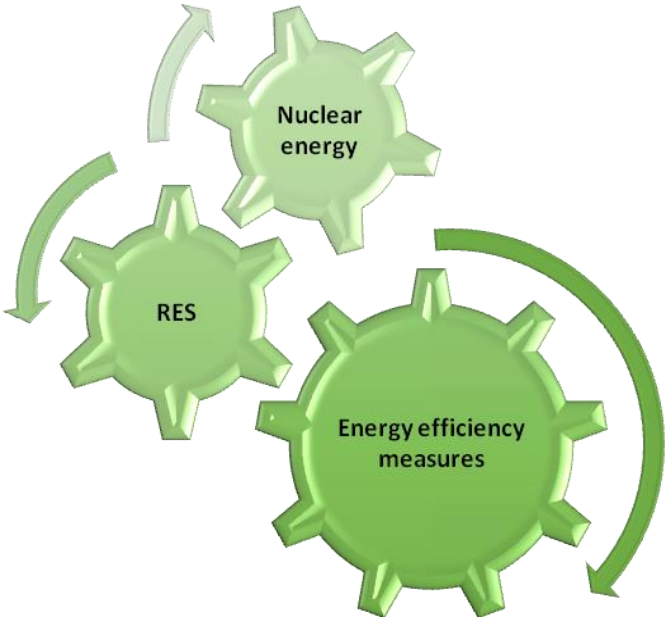

Figure 9.A. Reduction measures for GHG emissions at national level – *corresponding to figure 9.8. from the research study*

Economic and behavioral changes, as well as the immediate implementation of mitigation measures in parallel with the implementation of adaptation measures (already available in national strategic documents), could considerably decrease the consequences of climate change at national level, such as increasing the frequency of heat waves and intensifying the drought phenomenon, reducing the snow thickness, all with a strong final impact on the quality of life.

0.6. Research study conclusions

The 20th century has been marked by a series of environmental and social changes due to technological progress, which has bring forward the acceleration of the development of all scientific fields and, hence, generating enormous pressure on the natural environment that can lead to a unprecedented ecological crisis in the near future.

Climate change is one of the major challenges of our century - a complex term, on which we need to improve our knowledge and understanding, in order to take immediate and effective actions, respecting the precautionary principle. This phenomenon influences various components, including water resources, which is one of the critical variables regarding the safety of the population.

The extreme meteorological phenomena facing Romania in the last period, associated with the evolution perspectives of the GHG emissions at the national level resulting from the projection, lead us to a clear conclusion related to the future challenges on population safety.

Since 1988, the IPCC (Intergovernmental Panel on Climate Change, the international body that coordinates climate change scientific activities) recommends as priority action directions, to develop advanced GHG emissions projection models that can be used to develop coherent strategies to respond to the effects of climate change.

This research study addresses the topic of identifying the most suitable model for the GHG emissions projections at national level for the first time and also generates the basic assumptions for the realization of a novel projection model, specific to the technical, economical, statistical and political context of Romania.

General remarks resulting from the conclusions of the research study:

- GHG reduction national targets that occur in the post-Kyoto period,
- requires special attention to the emission forecasting process, in order to ensure a permanent process of assessment and adjustment of policies and measures previously adopted to achieve the assumed target. In this context, the importance of using accurate and complete forecasting models, developed to the specifics of each region is highlighted.
- This research study presents the current status of GHG national emissions, and provides an overview of the models that should be considered for developing GHG projections at national level and for quantifying adaptation and mitigation scenarios.

  Regarding the GHG projections conducted, the major difficulty was the collection of input data. The lack of transparency in data reporting by operators, the gaps and weaknesses, identified in the statistical infrastructure, as well as access to data from disaggregated sources, have raised great difficulties at this stage.

  The input data collection, was a laborious process that involved several verification steps, as: data source examination, measurement units, transcription errors and completeness of data.

  Starting from the calculation formula for CO_2 emissions, which is at the base of the forecast process (CO_2 emissions = Activity Data x Emission Factor x Oxidation

Factor), it can be concluded that some of the input data used by the forecasting model come from the measurement of physical quantities that can inevitably may have errors such as errors due to measuring devices, resulting from the introduction of erroneous data or the defective data processing.

- Following the GHG national projection phase, it was found that the LEAP model does not take into account the planned interruptions of the energy groups and does not perform a competitive analysis regarding the use of RES (Renewable Energy Sources) compared to fossil fuels.
- Therefore, in the future, it may be useful to carry out a new GHG projection model at national level with the highest accuracy, a specialized software that includes a better definition of the above-mentioned parameters, appropriate to the aggregated data at national level. Thus, the development of a new model dedicated to the national context, taking into account the availability and aggregation approach of data at national level, as well as the key parameters with impact on the final results, would generate a more accurate image perspective.
- To facilitate the implementation of GHG forecasting models at national level, it is important to develop sectoral strategies based on resources and development options so that Romania can achieve convergence to EU values: sustainability, competitiveness and security.
- The results of this research study can help to generate a GHG emissions perspective, which can be taken into account by decision-makers.

This research study:

- used a recent bibliography to provide updated documentation on the climate change topic;
- achieved a detailed documentary study on GHG emission forecasting models used at international level;
- identified/used relevant selection criteria to select the most appropriate forecasting model that can be applied at national level;
- developed a complex database to run the selected model that can be easily customized and exported;
- analyzed and presented the most appropriate methods, in order to reduce GHG emissions at national level;
- highlighted the national and European policies in force for the 2050 time horizon;
- developed three scenarios on Climate Change Impact Policies (BAU, OPT and PES) over the 2050 time horizon;
- identified specific national parameters, which must be considered for the elaboration process of a dedicated national forecasting model;
- identified risks, associated with climate change at national level;
- addressed ethics issues, related to the international environmental protection policies elaboration process.

0.7. Author Comments

The research assumptions were mainly structured based on the strategic and scientific documents on climate change, GHG projection models and environmental policies available at global, European and national levels.

As a result of the research conducted (during the study elaboration), a number of inconsistencies were observed which generated a series of uncertainties regarding the analysis of the environmental legislation from the ethical principles perspective:

Political involvement in global research groups created at the global level to study different aspects related to the climate change phenomenon.

- Preferential application and subjective approach of climate change policies at international level, not following the proportionality principle, especially for vulnerable groups.
- Promoting large-scale RES use as the optimal alternative, without taking into account the lack of absorption capacity of the national electricity system at this point, the emissions resulting from the installations production process used, the dependence on the import of these equipments, and the issues related to impacts on land use, natural habitats, and microclimate change.

  It is also neglected the fact that, in order to allow the injection of E-RES (electricity produced from Renewable Energy Resources) into the National Electricity System, flexible back-up capacities (on natural gas) are required, thus replacing a nuclear group (non-CO_2). Thus, the overall amount of CO_2 at national level increases.

Therefore, the ecologist trend promoted internationally in the last period does not necessarily comply with the imperative fundamental ethical principles.

Rational use of all available energy resources at national level in a fair, efficient, environmentally-friendly and cost-effective manner, taking into account social components such as migration and the employment rates (including professional reconversion/relocation), is the most sustainable approach to manage emissions from energy field, the most polluting sector identified at national level.

In order to achieve this goal, particular attention should be taken to stimulate innovation and to develop new technologies, as well as encouraging investments to improve energy efficiency across the energy resources - production - transport - distribution – consumption trajectory, given that energy continues to be the most important component of the economic growth for ensuring a high standard of living.

These new challenges identified are the bases for new pursuit subjects and possible future study directions.