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Achieving Sustainability in Non-ETS Sectors Using System Dynamics Modelling Practice

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The European Union (EU) has recently agreed on an ambitious framework for climate and energy policies by 2030. The new commitment foresees greenhouse gas (GHG) emissions reduction by 40 % compared to 1990. The part of these reductions is going to come from the EU Emission trading system (ETS) and other part from the sectors outside the EU ETS or, so called, non-ETS sectors: agriculture, transport, waste management and the part of energy sector and industry, which is not included in the ETS. As for now, much research has focused on studies relevant to the ETS; meanwhile, the largest part of GHG emissions in Europe is generated by non-ETS sectors. Therefore our study aims to strengthen the decision making capacity by providing the comprehensive modelling tool for policy analysis in non-ETS sectors. This tool is based on system dynamics modelling approach and encompasses the mathematical model for non-ETS sectors. With this model we analyse the effectiveness of various policy measures aiming to reduce GHG emissions in non-ETS sectors. The obtained results are compared with the benchmarks set by the EU climate and energy policy. Latvia is selected as a case study. We perform the analysis of baseline and green scenarios and test the model for sensitivity. The obtained results show that with the existing policy framework, in 2030, GHG emissions would increase by 19 % above the 2005 level. Since the developed model is white-box modelling approach therefore the dynamic relationships of driving forces behind the GHG emissions in non-ETS sectors can be transferred to other case studies and extended to the EU.

1. Introduction

Under the policy framework of climate and energy, the European Union (EU, 2014) has agreed to reduce greenhouse gas (GHG) emissions by 40 % until 2030 as compared to 1990. The part of these reductions is going to come from the EU Emission trading system (ETS) and other part from the sectors outside the EU ETS or, so called, non-ETS sectors; the non-ETS sectors covers 55 % of the total GHG emissions in the EU in 2013 (EC, 2013a).

Although much scientific research was done to analyse the performance of the sectors covered by the EU ETS (Pruse, 2012), little attention has been paid to studying the dynamic relations between and among the actors involved in the EU non-ETS sectors: agriculture, transport, waste management and the part of energy sector and industry, which is not included in the ETS.

The methods, used for setting specific targets for the non-ETS sectors in the EU, are analysed by Harmsen et al. (2011). The models, used for the allocation of cost optimal solutions for non-ETS sectors, are examined by Hast et al. (2013) for Finland and by Chiodi et al. (2013) for Ireland. Nevertheless these studies use linear programming techniques, where underlying, time dependent relations among involved parties, such as government, industry and general public, cannot be explored

Several authors, like Neufeldt and Schäfer (2008) for agricultural sector and Daly and Gallachoir (2012) for transport sector, have developed the tools for policy assessment within various non-ETS sectors, In the energy sector, modelling tools, such as, Markal/TIMES, GAINS and Primes are used to assist decision

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makers in selecting the appropriate policy measures. Still, these models are based on linear programming and rarely consider any non-linearities of energy, transport or agriculture sectors.

Therefore our study aims to strengthen the decision making capacity by providing the comprehensive modelling tool for policy analysis in non-ETS sectors. The novelty of the paper is in the development of this modelling tool, which is based on system dynamics modelling approach and encompasses the mathematical model for four non-ETS sectors: transport, energy (the part not covered by ETS), waste management and agriculture. Due to authors' knowledge, this is the first scientific article interlinking and modelling all non-ETS sectors at once using system dynamics model.

System dynamics modelling approach was chosen for this study due to its strength to represent and analyse complex system behaviour in time (Hjorth and Bagheri, 2006) and develop efficient policy strategies and scenarios (Sterman, 2000).

With this model we analyse the effectiveness of various policy measures aiming to reduce greenhouse gas (GHG) emissions in non-ETS sectors. The obtained results are compared with the benchmarks set by the EU climate and energy policy. Latvia is selected as a case study. This case is unique and of interest due to the high share – up to 75 % – of GHG emissions from non-ETS sectors in 2012 (LNIR, 2014).

We perform the analysis of baseline and green scenarios and test the model for sensitivity. The obtained results show that with the existing policy framework, in 2030, GHG emissions would increase by 19 % above the 2005 level. Since the developed model is white-box modelling approach therefore the dynamic relationships of driving forces behind the GHG emissions in non-ETS sectors can be transferred to other case studies and extended to the EU.

2. Background information

In Latvia up to 75 % of total GHG emissions are generated from non-ETS sectors: transport, agriculture, waste management and energy and industry not included in ETS. In 2012, the total amount of non-ETS GHG emitted in the country was 8.238 Mt CO_2 eq.

Transport and agriculture sectors were the largest emitters constituting to 33.9 % and 29.4 % of the total non-ETS emissions, respectively. The energy and industry sectors that are not covered by the ETS together composed 20.7 % of the total non-ETS emissions. 7.3 % of the GHG were emitted in the waste management sector. The remaining part of the Latvian non-ETS GHG emissions was generated by household activities and use of solvents and other products. The detailed data on the GHG emissions was obtained from the national GHG inventory data (LNIR, 2014).

For more detailed information on the final energy demand and share of renewable energy resources in Latvia's energy balance see Blumberga et al. (2014a).

Although Latvia has achieved a considerable reduction of emissions by 58.12 % since 1990 (LNIR, 2014), it is expected that till 2030 the emissions will rise again reaching 45 % increase as compared to 2005 (LV, 2013).

3. Methodology

System dynamics modelling approach was chosen for this study due to its strength to represent and analyse complex system behaviour in time (Hjorth and Bagheri, 2006) and develop efficient policy strategies and scenarios (Sterman, 2000).

3.1 Overview of developed system dynamics model

In order to understand the dynamic relationships of driving forces behind the GHG emissions in Latvian non-ETS sectors, a computer model based on system dynamics approach was developed.

The main target of using system dynamics is to trace the origin of GHG emissions in Latvian non-ETS sectors and to identify changes in the structure of the system, which will provide desirable solution – GHG emission abatement. A conceptual framework of the methodology is given in Figure 1.

The methodology follows the causal steps of building a system dynamics model: problem statement, hypothesis development, model formulation and simulation and scenario analysis. Model is adjusted and validated until it represents the historical development trends (Blumberga et al., 2011). The validation of the model is done twofold: behaviourally and structurally (Blumberga et al., 2015). The behavioural validation tests models ability to generate the systems' past behaviour. The structural validation is done to ensure the robustness of the model by preforming simulations for the variables with the extreme values (Barlas, 1996). The model was validated based on the national GHG inventory report (LNIR, 2014) for the period 2005 - 2012.

The model includes also various assumptions on the following trends: flues prices, population, policy enrolment, gross domestic product (GDP) and technology development represented as technology learning curves.

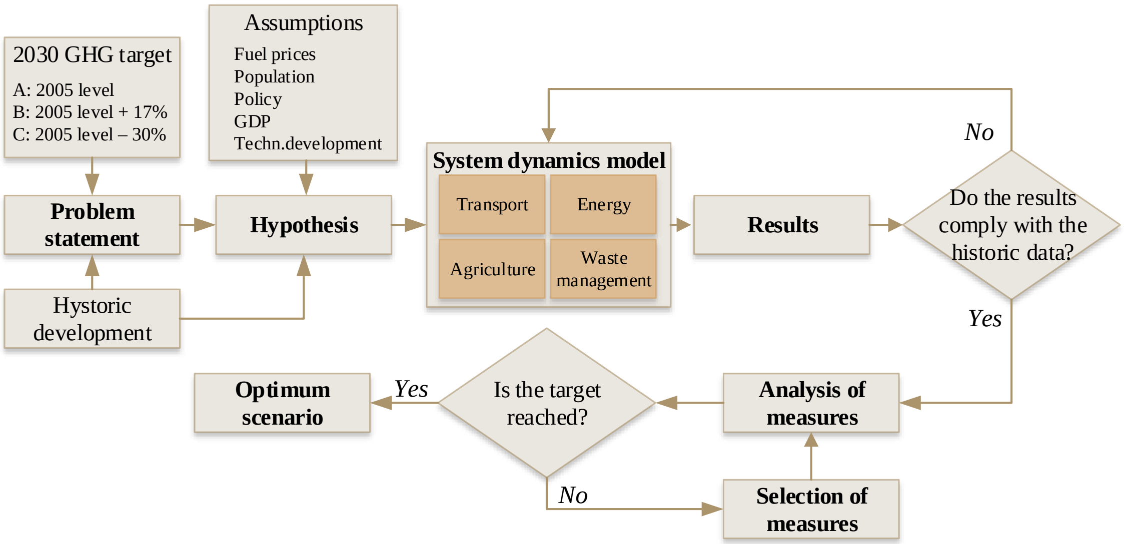

Figure 1: A conceptual framework of the methodological approach

After the validation is done the model undergoes sensitivity analysis (covered in this paper) and analysis of optimal policy measures (currently under development).
In order to create a quantitative system dynamics model, a stock-and-flow diagram has to be built by using the software tool. The diagram is built by four main building components – stocks (state variables in the system), flows (processes that change the state variables by inflows or outflows), auxiliaries (algebraic, graphical or fixed parameters defining the relationships among variables), and information links that serve as connectors among variables Blumberga et al. (2014b) (see Figure 2). The stock-and-flow diagram is a visualized system of differential equations. E.g. a stock is defined by the following discrete equation:

$$Stock_t = \int Flow_{(t,t-dt)} \cdot dt + Stock_{(t-dt)} \tag{1}$$

where $Stock_t$ – the stock level at time t; $Flow_{(t,t\text{-}dt)}$ – the flow rate influencing the stock during the time period from (t-dt) to t; dt – the time interval over which the equation spans; $Stock_{(t\text{-}dt)}$ – the stock level at the time (t-dt) (the initial stock).
The flow rates are characterized by the rate equations that relate the rates to the stocks of the system and, possibly, to exogenous conditions arising outside the system (Blumberga et al., 2011). All equations are solved via graphical simulation programs.

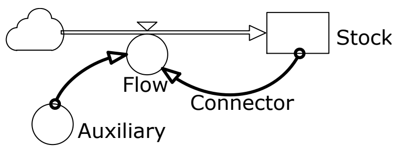

Figure 2: A simplified representation of stock-and-flow diagram

In our study, we used Powersim Studio 8 (2015) software environment to develop the model. The model consists of 4,700 interconnected elements. Modelling timeframe was chosen up to 2,030 to correspond to the new EU climate and energy policy framework.

3.2 Sensitivity analysis

A sensitivity analysis was used to determine, whether the established model is sensitive to parameter changes, and which of these parameters have the greatest impact on the simulation results. For sensitivity analysis, a set of 25 parameters whose values are most likely to change over the time were selected. These parameters included, for example, the macro-economic development rate given in GDP increase,

the growth rate of energy prices given as price increase rate for gasoline, diesel, natural gas, liquefied natural gas and electricity, fraction of biodegradable waste in waste stream, inconvenience costs, fraction of environmentally concerned persons in society, landfill limits, fraction of area for livestock feed, crops, and biofuels and policy support measures given as direct payments in agriculture and transport sector, subsidy for biomass fuel in households, tertiary sector and district heating.
To perform the sensitivity analysis, a risk assessment tool integrated in the Powersim Studio 8 software was used. The method of the Latin hypercube sampling was used to determine the variance of the dependent variable (the total non-ETS GHG emissions), taking into account the sensitivity analysis within the defined boundaries of the parameters used. The sensitivity analysis was performed for the time period from 2005 to 2030. The results are calculated taking into account probability theory and statistics-defined confidence limits.

3.3 Scenario description

To achieve the EU policy target in the short term the Member States have agreed to limit GHG emissions from non-ETS sectors on average by 10 % in 2020 as compared to the emissions in 2005 (EC, 2009). On the long term the EU's determination towards low-carbon economy (EC, 2013b) implies that by 2030 the GHG emissions from non-ETS sectors would be reduced by 30 %, compared to 2005 levels (EC, 2014).
Two scenarios are analysed in this paper (1) the baseline and (2) green scenario. The baseline scenario assumes that there would be no radical change in government policy, yet, considering that the policy is driven by international obligations.
To illustrate the potential of GHG emission reduction, a set of policy strategies were introduced to the baseline scenario: a) For energy sector the subsidies for renewable energy technologies, energy efficiency measures and information campaigns; b) For transport sector the increase of biofuel blend, subsidies for alternative fuel vehicle purchase, development of electric vehicle charging infrastructure, fuel taxes, information campaigns; c) For agriculture sector the grants for installation of manure management systems, subsidies for bioenergy, nitrogen tax, information campaigns; d) For waste management sector the increase of landfill tax, investment in waste sorting infrastructure, information campaigns (waste management sector). Thus, a set of regulatory, economic and informative policy instruments was tested.
The green scenario considered that the combination of policy measures in all sectors is implemented simultaneously, which can be considered the maximum reduction potential for GHG emissions.
The GHG emissions from non-ETS sectors in Latvia were compared to three different limiting targets or benchmarks for 2030: 1) 2005 benchmark where the GHG emissions remain at the level of emissions in 2005; 2) 2020 benchmark where the GHG emissions are increased by 17 % as compared to the level of 2005, which is the limit for the non-ETS sectors in 2020 in Latvia according to undertaken international commitments (EC, 2009); 3) 2030 benchmark where the GHG emissions are reduced by 30 % as compared to the level of 2005, which could be the limit for the non-ETS sectors in 2030 in Latvia according to the ongoing debate (EC, 2014).

4. Results and discussion

With the existing policies (baseline scenario) increase of GHG emissions can be expected; in Figure 3.

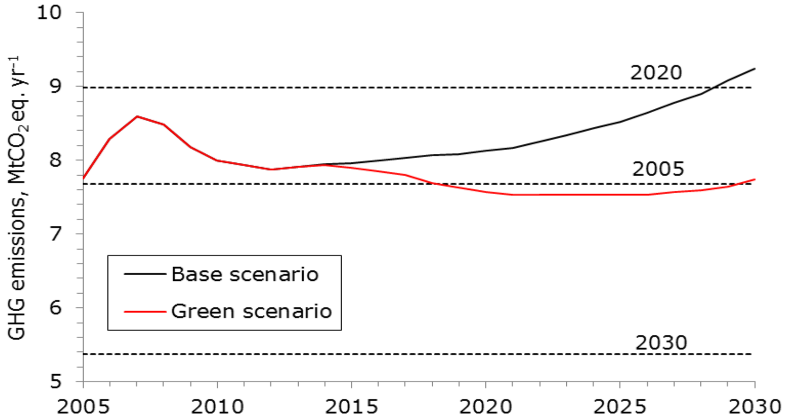

Figure 3: Simulation results for the GHG emissions from non-ETS sectors in Latvia with base and green scenario and the benchmark emission targets: 2005 (emission level the same as in 2005), 2020 (emission level by 17 % higher than in 2005) and 2030 (emission level by 30 % lower than in 2005)

In the baseline scenario, the GHG emissions increase by 19 % in 2030 as compared to 2005 level, thus exceeding the 2020 target or benchmark. The greatest increase of GHG emissions in next 15 years is expected from agriculture and transport sectors, mainly driven by the economic growth. In the waste management sector GHG emissions have no significant increase. In energy sector, on the contrary, GHG emissions are expected to decrease till 2027. The reduction of GHG emissions in the energy sector is explained by the achievements in improving energy efficiency of buildings, which is done by managing the available EU co-financing for energy efficiency measures. The additional driver is the increase in price for fossil fuel that enables the competitiveness of renewable energy sources. However, after 2027 GHG emissions in the energy sector start increasing because of the relatively low increase rate of the fossil fuel price. Thus in the time period from 2014 to 2020 the energy sector somewhat relieves the significant increase of GHG emissions from agriculture and transport sector. Therefore the total national GHG emissions will grow relatively slowly. As can be seen in Figure 3, under the green scenario it is possible to achieve a considerable reduction of total GHG emissions compared to the baseline scenario. In green scenario, the GHG emissions of non-ETS sectors fluctuate around the 2005 target level providing a 16.2 % reduction as compared to the baseline scenario in 2030.
The results of the sensitivity analysis show that uncertainty of the input parameters does not significantly influence the simulation results of baseline scenario; see Figure 4.

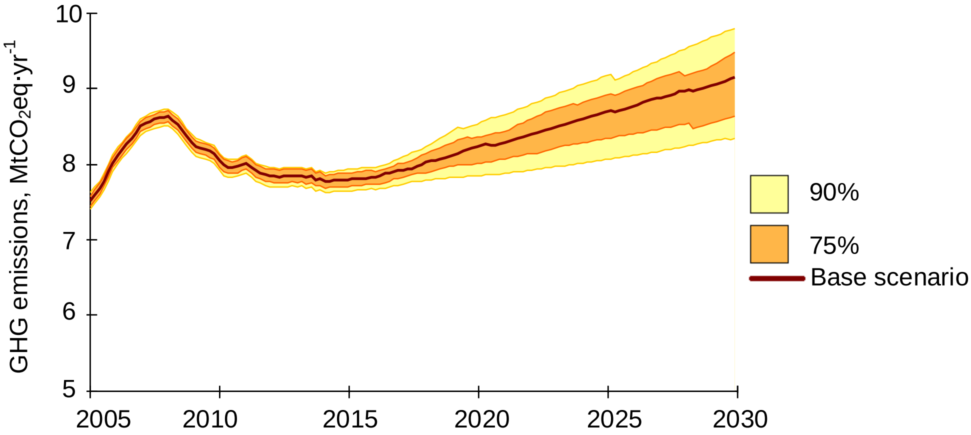

Figure 4: The results of sensitivity analysis results for the GHG emissions from non-ETS sectors in Latvia under baseline scenario

The sensitivity analysis shows that with the 90 % probability the GHG emissions from the non-ETS sectors in 2030 in Latvia will be between 8.1 MtCO2 eq. and 9.7 Mt CO_2eq. considering the uncertainty of 25 input parameters. Due to authors expertise the boundaries for sensitivity analysis are reasonable, since various uncertain parameters are modelled together. Moreover the aim of the system dynamics modelling is to depict the patterns of wide dynamic behaviour in the real system, not to give “point” projections (Sterman, 2000).The doubts for 75 % probability are narrower: from 8.5 Mt CO_2eq. up to 9.5 Mt CO_2eq. Thus, it can be considered that the model obtained is robust, results reliable and the developed model can be further used to assess the effect of various additional policy instruments and strategies to reach the 2030 target and to find out the economically, socially and environmentally optimal emission reduction strategy.

5. Conclusions

The mathematical model based on system dynamics modelling approach was used to simulate the effectiveness of various policy measures in the non-ETS sectors in Latvia until 2030. The obtained results were compared to the benchmarks set by the EU climate and energy policy. The results show that with the existing policy framework, in 2030, GHG emissions would increase by 19 % above the 2005 level.
In order to achieve GHG emission reduction, a proactive policy at the national level is required including such incentives as subsidies for renewable energy technologies and alternative fuel vehicles, revised tax policy, informative measures etc. However, even these measures are ineffective in front of the ambitious target of reducing non-ETS GHG emissions by 30 % by 2030 compared to the 2005 level. This finding suggests that more powerful policy measures need be found in order to decouple economic growth from environmental impact. The results of the sensitivity analysis show that the obtained model is robust and

results reliable. Therefore the developed model will be further used to assess the effect of various additional policy instruments and strategies to reach the 2030 target and to find out the economically, socially and environmentally optimal emission reduction strategy. Since the developed model is white-box modelling approach therefore the dynamic relationships of driving forces behind the GHG emissions in non-ETS sectors can be transferred to other case studies and extended to the EU.

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