CACTUS

STRENGTHENING CENTRAL AND EASTERN EUROPEAN CLIMATE TARGETS THROUGH ENERGY SUFFICIENCY

# Energy scenario models in Hungary and Lithuania and the impact of sufficiency

Supported by:

Federal Ministry for Economic Affairs and Climate Action

European Climate Initiative EUKI

on the basis of a decision by the German Bundestag

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CACTUS is a project on energy sufficiency and its integration into climate and energy strategies in the Central and Eastern European context funded by the European Climate Initiative EUKI.
It sensitises key scenario builders, policy makers and wider EU and climate and energy stakeholders on energy sufficiency, and explores its integration in Hungarian and Lithuanian scenario models.
Since the Summer 2020, the négaWatt association has been coordinating the implementation of the Cactus project with its partners REKK, LEI and the Fraunhofer ISI, and with the financial support of the EUKI fund of the German Ministry of the Environment BMU.

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# List of abbreviations

| Abbreviation | Definition |
|---|---|
| AFOLU | Agriculture Forestry and Other Land Use |
| BEV | Battery electric vehicle |
| CEE | Central and Eastern Europe |
| CHP | Combined heat and power |
| CNG | Compressed natural gas |
| EE | Energy efficiency |
| EPBD | Energy Performance of Buildings Directive |
| ETBE | Ethyl tertiary butyl ether |
| ETS | Emissions trading system |
| EUA | European allowances |
| FCEV | Fuel cell electric vehicle |
| GAMS | General Algebraic Modelling System |
| GDP | Gross domestic product |
| GHG | Greenhouse Gas |
| GUI | General user interface |
| HEV | Hybrid electric vehicle |
| HH | Household |
| IAEA | International Atomic Energy Agency |
| IEA-ETSAP | International Energy Agency - Energy Technology Systems Analysis Program |
| IND | Industry |
| IWW | Inland water ways |
| LEI | Lithuanian Energy Institute |
| LPG | Liquefied petroleum gas |
| MCA | multi-criteria analysis |
| MEPS | Minimum energy performance standard |
| MESSAGE | Modelling framework for energy system planning, energy policy analysis, and scenario development |
| NECP | National energy and climate plan |
| O&M | Operating and maintenance |
| PED | Primary Energy Demand |
| PHEV | Plug-in-hybrid vehicle |
| pkm | Passenger-kilometre |
| REKK | Regional Centre for Energy Policy Research |
| TIMES | The Integrated MARKAL-EFOM System |
| tkm | Tonne-kilometre |
| TRAN | Transport |
| WACC | Weighted average cost of capital |
| WTA | Willingness to accept |
| WTP | Willingness to pay |

# 1. Introduction

This report corresponds to the Activities II.4 and II.6 on modelling, of the CACTUS project, aiming at exploring the integration of energy sufficiency into scenario models of Hungary and Lithuania. The report first summarises in section 2 the process of preparing for the integration of sufficiency in energy system models, namely the selection of relevant indicators and defining the energy sufficiency assumptions in the Hungarian and Lithuanian context as explored in previous project activities. Section 3 is the core of this report and it provides an overview of the existing models in the partner countries Hungary and Lithuania. It addresses the Activity II.4 in the CACTUS project, analysing the status quo of the scenario models and aims at providing the first insights for the following activities (especially AII.5). Thus, the models are also analysed from a sufficiency perspective, identifying the potentials and barriers in the modelling approach. Section 4 illustrates the impacts of sufficiency and potential outputs of the models. This section addresses the Activity II.6 and aims at making the impacts of sufficiency measures visible in the target countries and initiating a joint dialogue with the policymakers and modellers. First, the quantitative and qualitative impacts of sufficiency are analysed, then some strategies for addressing not quantifiable impacts are recommended.

# 2. Integration of sufficiency in energy system models

## 2.1. Selection of relevant energy sufficiency indicators

Drawing on a previously established list of sufficiency-related indicators from (Marignac et al. 2021), a dialogue was started among the experts, considering the context of the target countries. The list included initially 35 indicators in the buildings sector and 25 in the transport sectors. The indicators listed were then organised by categories corresponding to various types of sufficiency drivers, e.g. social-related, infrastructures-related, description of needs, etc. Then, the usefulness of these indicators in elaborating, assessing and justifying assumptions quantitatively or qualitatively as well as the availability of required data were discussed. At this stage, indicators and levers for change were characterised, according to whether they are quantifiable or not, in the perspective of their integration into scenario models. The distinction was made between quantitative indicators for which quantitative data is available, and qualitative indicators which are expected to play a major role in explaining the various scenarios but cannot be implemented in models quantitatively (but rather as ratings, narrative-related indicators, or policies and measures-related indicators). This stage was complemented with data collection for each target country, identifying when quantitative data is missing or not consolidated enough. Here, the national context was taken into account in the great attention given to the local data availability and harmonisation was sought by selecting those quantitative indicators for which data were available in both target countries. Once indicators were organised by types of drivers and characterised as quantitative (technical) or qualitative (soft) ones, the interrelations and interdependencies between them were discussed – in light of national contexts – in order to identify which indicators (especially soft ones) may impact others (quantitative ones) when building assumptions. This work was carried out by mapping indicators and characterising their relationships and it highlights the useful underlying drivers that should be borne in mind when developing sufficiency assumptions.

## 2.2. Definition of energy sufficiency assumptions

After prioritising the sufficiency-related indicators, the potential of energy sufficiency in Hungarian and Lithuanian building and transport sector were addressed for these selected indicators. First the sufficient target levels were extracted from literature. Then the relevance of the approach and the suggested sufficient level for each indicator was further discussed taking into account the national socio-economic and cultural contexts of the target countries. In the last step the historical trends were gathered and analysed. This process resulted in the assumed sufficiency target levels for 2050 which are tailored to the national contexts and could be used as the basis for integrating the indicators in the energy models.
To explore the integration of these prioritised indicators in the energy system models of the target countries, in the next step the status quo of those models also from a sufficiency point of view was analysed.

# 3. Analysis of the status quo of scenario models

## 3.1. Overview of the models

To have a better overview of the potentials and challenges of modelling sufficiency, the existing tools and models in each partner country were analysed and compared. To this aim a template was developed based on Vethman et al. (2011), a study on energy models, covering key aspects of the models, including general information and general approach of the model, structure of the model in general and structure of each sector, inputs/outputs and data validation, policy consideration, decision-making logics of the model, flexibility and user-friendliness. The partners in the target countries were requested to answer the questions in the survey according to the models they use. The last section of the survey covered sufficiency aspect, by asking the partners to provide their opinions about what they consider the potential for addressing energy sufficiency in the building and transport sectors with their model, based on the characteristics of the models and their experience of working with the model. The template is provided as annex to this report. In the next sections the results of the survey are presented.
In total three models were introduced by the partners, and for each of them the questionnaire was completed. Hungary works with the HU-TIMES model, which covers the following sectors: Household, Tertiary, Industry, Transport and power sector. In Lithuania, two energy models are use, MESSAGE Transport Model for Decarbonisation Scenarios of Lithuania covering specifically the transport sector and LT-Energy, which can model the same sectors as HU-Times. Although the models have been developed in different environments (TIMES and MESSAGE), the structure, input/output and the potentials of the models are quite similar. One important aspect in the models is that none of them covers the whole demand side. Mostly the energy service demand is modelled externally, and the result is used as the input for the modelling. However, in the case of LT-ENERGY model the energy demand is given exogenously and mainly the supply side is modelled.
Table 1 provides a short and comparative overview of the main characteristics of these analysed models. A detailed and comprehensive description of the studied models is presented in Annex A: Results of the surveys.

*Table 1: Key features of the analysed models*

| Country | Hungary | Lithuania | |
|---|---|---|---|
| Name of the model | HU-TIMES | MESSAGE Transport Model for Decarbonisation Scenarios of Lithuania | LT-ENERGY |
| Developing environment | TIMES | MESSAGE | MESSAGE |
| Main owner/user of the model | REKK | LEI | LEI |
| Sectors covered | Household, Tertiary, Industry, Transport, Power system | Transport | Household, Tertiary, Industry, Transport, Power system |
| Model approach | Top-down/Bottom-up optimization | Bottom-up optimization | Bottom-up optimization |
| Geographical coverage | National | National | National |
| Potential outputs | Energy consumption, GHG emission, Costs and benefits, Energy supply, Imports and exports (Electric power only) | Energy consumption, GHG emission, Costs and benefits, Air pollution | GHG emission, Costs and benefits, Energy supply, Imports and exports, Energy balance, Air pollution |
| Usual time frame of the modelling | 2016-2050 | 2020-2050 | 2021-2050 |
| Usual time resolution | 5 years | 576 time slices per year | 600 time slices per year |
| Pint of view reflected in the modelling approach | End-user | Society as a whole, end-user | Entire energy sector |
| Policy considerations | Assessment, selection, development, improvement | Assessment, selection, development, improvement, combinations | Assessment, selection, development, improvement, combinations |
| Logic/assumptions in model | calculated internally/can be impacted by policies | calculated internally/can be impacted by policies | |
| Complexity of the modelling approach | high | moderate to high | moderate to very high |
| Main limitation for modelling sufficiency | inelastic demand curve | only adjusting the input using assumptions possible | only by providing dummy supply or reducing the input demand using assumptions possible |

# 3.2. Sufficiency approach

The present report has been considered as the basis for Activity II.5 in the project, addressing the potential suggestions for integrating sufficiency assumptions in the modelling approaches. To this aim, in this section we provide an overview of the modelling approach including both demand and supply sides and compare the followed approach in the available models at négaWatt and amongst other partners.

## 3.2.1. Modelling approaches in theory

Figure 1 presents an abstract and simplified approach of a comprehensive energy modelling, following the concept presented in négaWatt (2018). On the demand side the amount of the energy services is related to the input parameters and drivers as well as the user behaviour. This part of the energy system is where the sufficiency measures could have a direct impact, by changing habits of the consumers and potentially reducing the demand of energy services (e.g., kg of washed clothes per year). The energy services are then delivered by "demand side" technologies (e.g., washing washing), in which energy efficiency will affect the energy demand. The supply side cover the power and heat sector, and include the use of renewable energies, in order to reduce the primary energy demand.

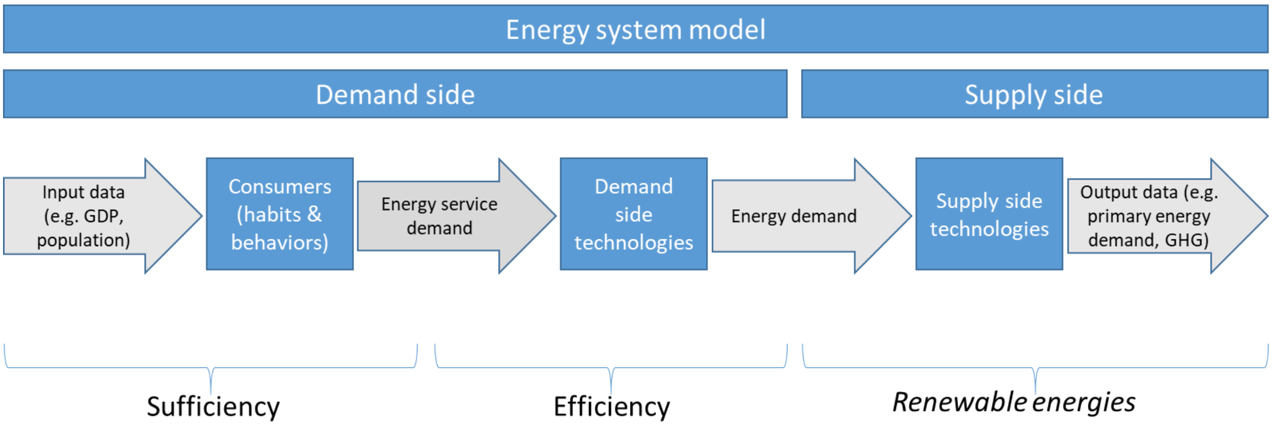


*Figure 1: Approach of a comprehensive energy system model*

The approach explained above is used to analyse and compare the available energy models in the partner institutes (REKK, LEI and négaWatt).

## 3.2.2. Modelling approach-REKK

The approach of the building sector used by REKK is illustrated in Figure 2. As seen here, demand side is partly covered by the model. The energy service demand is calculated exogenously using an econometric model (in Excel format). The calculation is based on a building stock database and provides the input for the model. The calculated baseline service demand serves as the input for the TIMES model and is optimized considering policies and measures (e.g., investment support for EE improvements) and according to the total cost of ownership. Taking the corrected energy demand as the input, the primary energy demand (PED), GHG, etc. are calculated on the supply side. Here also the policies (e.g., future $CO_2$ tax for non-ETS (Emissions trading system) heating plants) could be taken into account when choosing the technologies on the supply side.

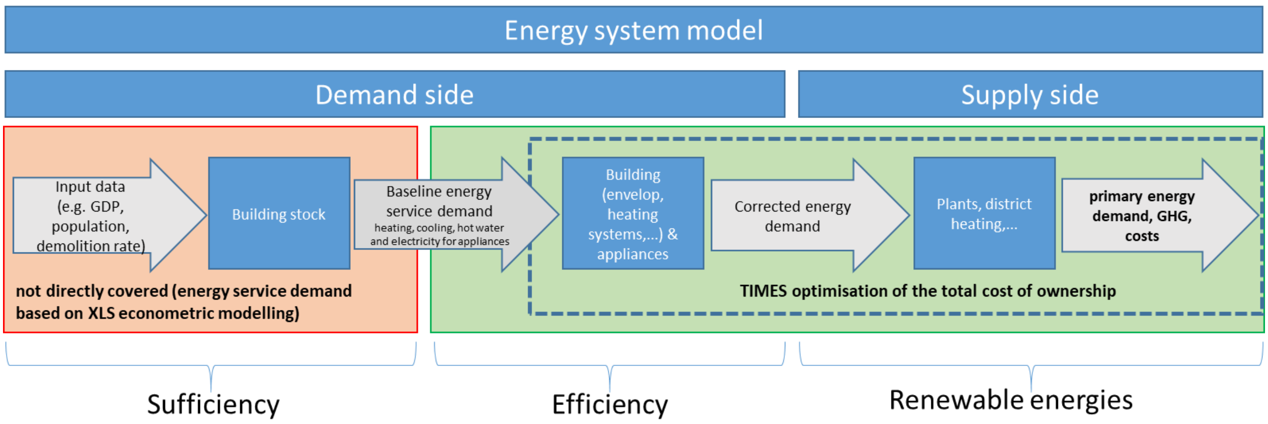


*Figure 2: Approach in the building model-REKK*

In transport sector, REKK follows a similar approach shown in Figure 3. Here again the econometric excel model is used to exogenously calculate the energy service demand in terms of pkm and tkm. The TIMES model uses the result as the input for decision makings on initially the transport technologies in long and short distances, and consequently the supply side technologies and their outcome (e.g., PED and GHG).

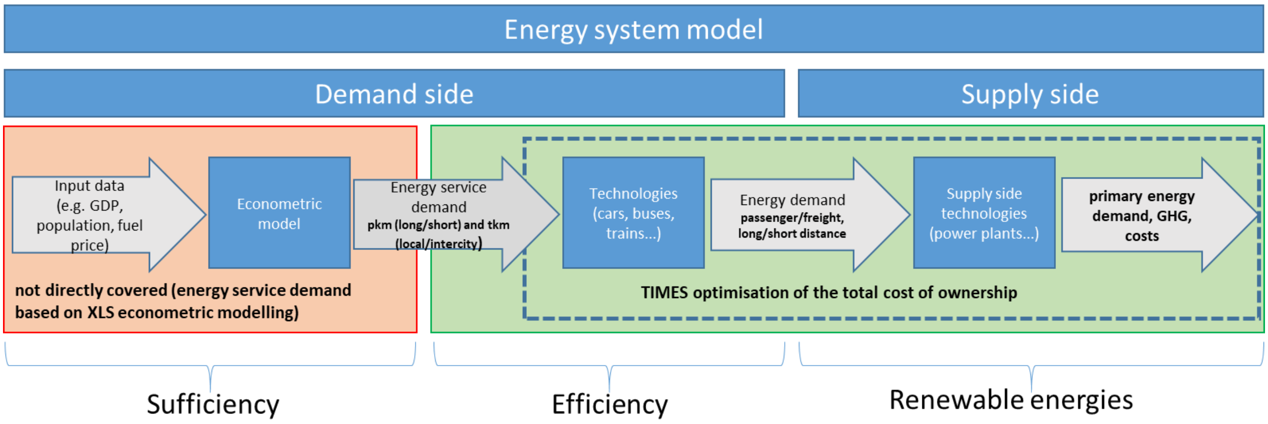


*Figure 3: Approach in the transport model-REKK*

In both building and transport models, the input parameters (e.g., GDP, population, demolition rate) are adjustable providing the flexibility to consider the sufficiency assumption as long as the underlying parameters are already considered in the modelling. Moreover, since the calculation of the based energy demand is trackable changes like adding parameters to include a new assumption in the model seem to be feasible. This will be studied more into detail in the next activity where the different possibilities of integrating sufficiency in the models are discussed.

### 3.2.3. Modelling approach-LEI

LEI follows in its transport model (shown in Figure 4), a similar approach as REKK. Calculation of the baseline energy demands is not directly covered by MESSAGE model but is carried out exogenously within an Excel model. Using a set of parameters, the pkm/ tkm as well as travel time budgets are calculated and consequently considered as the input for the model to define the technologies and calculate the energy demand for passenger and freight transport, in short and long distances. In selecting the technologies on both demand and supply side, the optimization of the total discounted costs is taken into account.

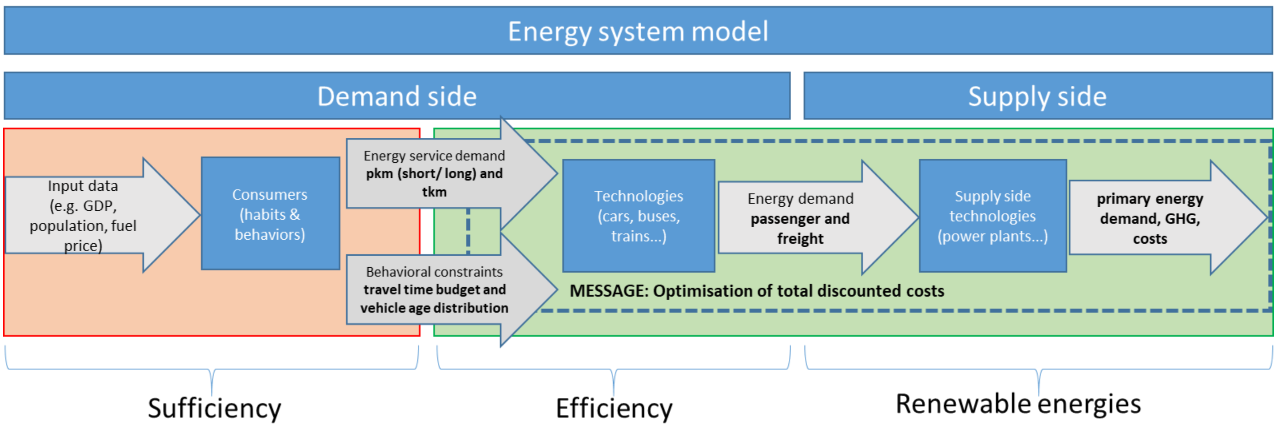


*Figure 4: Approach in the transport model-LEI*

In the LT-ENERGY model the demand side is not directly covered and therefore the final energy demand is only an external input for the supply side model, representing the "business as usual" demand. The model can however consider the changes in the demand side as a result of efficiency and sufficiency measures. This can be carried out by adding a virtual supplier on the supply side, representing the potential effects of a measure of energy saving. Based on the potential costs and energy savings of this virtual supplier, the model will decide for or against the intended measure and respectively optimizes or keeps the initially given final energy demand. The optimization process can consider the measure on both demand and supply side. An overview of the modelling approach is shown in Figure 5.

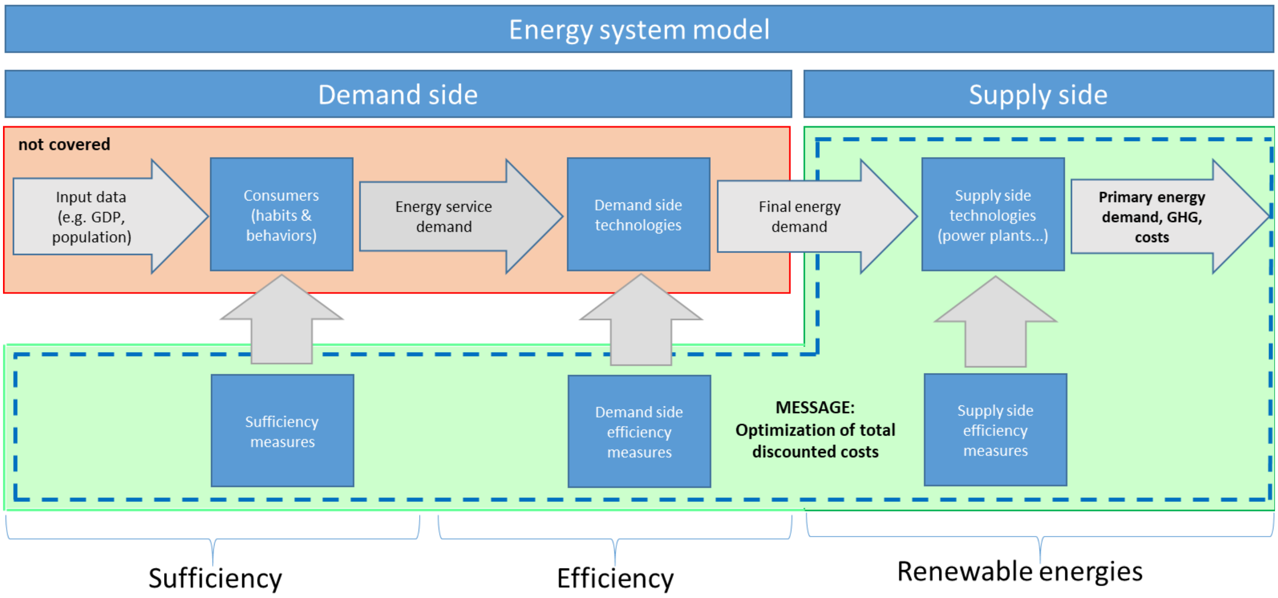


*Figure 5: Approach in the LT-ENERGY model*

## 3.2.4. Modelling approach-négaWatt

The modelling approach implemented by négaWatt, through an in-house dedicated model that has been developed and refined over the past 15 years, is based on the objective to explore and assess the potential for energy sufficiency, prior to and together with reinforced energy efficiency and substitution of stock-based energy resources (fossil fuels and nuclear power) by flow-based ones (renewables), as a global strategy towards sustainability.

The model is based on an incremental simulation approach which allows for describing, on a one-year steps basis, the evolution of the energy system. The modelling is focused on the nature and quantity of energy involved at all steps of the energy chains, which it tries to characterize through adequate physical indicators. This characterization starts with the end-use of energy services delivered to final users as heat (or cold), mobility and specific electricity in all sectors of the economy. The global need for energy services aggregates in a final energy demand for each of the sectors. The latter is met through secondary energy carriers, which in turn derive from primary carriers obtained, at the front-end of energy chains, through a primary energy demand tapping the various primary energy resources considered available.

The bottom-up characterization of energy services, through indicators such as heated square meters for buildings or passengers or tons per kilometre for transports, allows for introducing changes that reflect sufficiency assumptions. Those can be combined with efficiency assumptions regarding the type of equipment involved, such as heating systems or vehicles, assumptions on the final energy used by this equipment, and assumptions on substitutions between resources on the energy supply side depending on the demand by type of energy carrier.

For each year, the model integrates changes introduced through sufficiency and efficiency related assumptions, as well as assumptions on the development of renewables and the evolution of nuclear power, to calculate the energy balance, where the amount of fossil fuels used is adjusted to compensate for the residual difference between primary supply and demand. This yearly balance is completed, for the electricity sector, with a specific modelling of the hourly balance between supply and demand for the year.

Finally, the energy balance and the description of pieces of equipment and services that supports it are used as input to assess, through dedicated modules, some environmental and economic impacts. The former includes the overall greenhouse gas emissions (covering all gases and all sectors on a domestic perimeter), but also some assessment of the amount of raw materials used, or the transport and combustion related air pollution. The latter, calculated through a bottom-up aggregation of capital and operation expenditures over all the sectors covered by the model, include the total annual and cumulated costs and the total and per sector evolution of jobs.

## 3.2.5. Sufficiency and modelling approaches

**A specific sufficiency focus, difficult to translate to optimisation models**

The modelling approach developed by négaWatt is set to deal with sufficiency assumptions in a fairly straightforward way, by characterising them in terms of changes in the nature, amount or mode of energy services delivered. It allows to deal with various sufficiency leverages, from the level of use of equipment (e.g., duration of use of screens, speed limit for cars) to the average size of vehicles or dwellings, through car-sharing, shifting transport modes, or the impact of urban planning on distances covered, as long as these leverages can be related to the indicators of services covered by the model. The model therefore provides an assessment of the impact over time of such sufficiency-based changes on the overall energy balance and related primary energy needs, but also on greenhouse gas emissions or costs.

While this approach serves to identify the priority areas of sufficiency-driven policies and the leverage and effectiveness their design should target, it is the supposed impacts on sufficiency of such policies that the model uses as inputs, not the policies themselves. Therefore, the approach is conversely not fit to model the relationship between the design of sufficiency-related policies and their resulting effectiveness. For that purpose, other modelling approaches are needed.

There is a various range of cost and optimisation-based or agent-based models, which aim for describing the impact of changes in the societal, economic or regulatory framework on various players and components of the energy system. However, they tend not to consider sufficiency-driven options, at least not explicitly. One obvious reason is that few examples of explicitly sufficiency-driven policies exist to inform the modelling of their impact, especially when compared to the return of experience drawn from efficiency policies and measures in various sectors and economic contexts. Yet it should be noted that this is a self-sustaining situation, where the lack of field-evidence and the low information of policymaking about sufficiency by modelling tend to feed each other. There are, nevertheless, deeper methodological issues that need to be addressed.

One of the basic obstacles is that **these models sometimes lack the proper level of physical characterisation of energy demand through energy services**. This requires either to refine the descriptive part of the model to get down to that level, which might prove challenging or impractical, or to find indirect ways to represent the impact of sufficiency-based changes on the objects and indicators that are described in the modelling, which might be the source of bias.

Another strong obstacle, mostly found with **cost-based modelling approaches, is that it proves difficult to characterise the costs of sufficiency-based changes and describe them in adequate terms for the model**. This is particularly the case for optimisation models that try to minimise costs on a given perimeter and period. This relates to the difficulty of characterizing sufficiency in terms of prices and willingness to pay, as many of the energy services to be characterised are not what is directly paid for on modelled markets, and some of the concerned changes do not need to be paid for. It also, and possibly mostly applies to the issue of characterizing the economic impacts of changes, either on a micro or macroeconomic level: sufficiency has sometimes to do with potential co-benefits (or detriments) that are hard to characterise and even harder to monetarise in top-down modelling, from health to comfort or well-being. This is also a challenge, for similar reasons, for sufficiency to be integrated in a quantitative agent-based modelling that seeks for utility maximising. Nevertheless, this can be dealt with if finding appropriate indicators to characterize the utility in a way that relates to the energy service, such as the time budget in the case of mobility.

Although this remains limited in practice for the above reasons, implementing assumptions about sufficiency-driven changes in such models is possible in theory, and not of a different nature than implementing efficiency or energy substitution related assumptions, as a various combination of technical changes and players' decisions are in every case at stake. **Further understanding of sufficiency potentials and the way they can be levered can help to remove methodological barriers to better reflecting sufficiency in a various range of cost and optimisation-based or agent-based models.**

# 4. Possible impacts of energy sufficiency

## 4.1. Quantitative impacts

Energy sufficiency has multiple benefits, some of which overlap with the positive impacts of energy efficiency. **Direct effects include lower energy use and the resulting avoidance of air, soil and water pollution,** the amount of which can be relatively easily determined, but are difficult to quantify in financial terms. **Reducing energy demand can decrease the need for investment in energy systems, including electricity and heat generating assets, transmission capacity and other related infrastructure. Consumer costs decline** through reduced household energy bills and fuel costs, and savings can also be made on the purchase (or rental) price of smaller or shared dwellings, shared appliances, smaller vehicles, or the decision not to own a car. However, energy users might need to give up some comfort in their daily lives (for example door-to-door travelling by car, privacy in unshared rooms). Those are also difficult to express in monetary terms.

On the other hand, as a precondition for achieving sufficiency policy goals, **other types of investments may be needed, e.g. in the case of transport, achieving lower private car use presupposes the existence of adequate infrastructure** (safe and extended bicycle paths, railways, public transport improvements, redesigned road structures, etc.) and the wider availability of high quality public transport services.

The sufficiency indicators applied to incorporate sufficiency in scenario models (as introduced in chapter 2. ) might allow to check the quantitative impacts of some improvements. Heat and electricity consumption per capita can decrease as a result of lower floor area per person ($m^2$ per capita), which improves with larger household size (persons per dwelling) or smaller size of newly built dwellings. Shared rooms and appliances (serving more tenants with higher energy efficiency) can also lead to lower per capita energy use. A decrease in per capita energy consumption can result in reduced overall final energy use in the economy, unless offset by the effect of population growth.

In case of the transport sector, higher modal shares of public and non-motorized transportation (expressed as their share in total passenger kilometres) can be the result of a modal shift from individual car use. Higher vehicle occupation (more persons per vehicle) also reduces vehicle kilometres and fuel consumption. Higher rates of teleworking (percentage of people working from home) can be associated with a lower demand for transportation (passenger kilometres per capita).

Reduced dependence on fossil fuels due to reduced demand for energy services lead to savings in greenhouse gas emissions in both the buildings and transport sectors.

**In the framework of the CACTUS project, some impacts of the integration of sufficiency target levels were modelled.** The first scenario analysis in Hungary looked at the impacts of adjusting 3 demand inputs in case of the buildings sector, corresponding to assumed sufficiency levels: 1) 51% decrease in per capita cooking energy use, 2) 48% reduction in hot water consumption, and 3) limiting the per capita floor area to 35 $m^2$ in new buildings by 2050, compared to a reference scenario. According to the results, selected sufficiency improvements could result in around 8.5% decrease in energy consumption, and the reduced electricity demand could be met by deploying less power plant capacities, also reducing the required investments in new renewable electricity installations. The possible annual savings could amount to 247 million Euros.

In case of the Hungarian transport sector, the effect of inserting sufficiency target levels for two indicators were investigated: the per capita demand for car transport, and the per capita demand for total passenger transport, assuming again that their sufficient levels are approached by 2050. The modelling showed that a lower level of car use would result in around 2.6% lower energy consumption, happening through modal shift, while the reduced overall transport demand would lead to 10% reduction in energy use. The possible cost savings due to lower production capacity requirements could reach 1800 million Euros.

The amount of greenhouse gas mitigation resulting from reaching the sufficient consumption levels was not assessed at this stage of the modelling, as only the results for 2050 were analysed, for which year the model assumes net-zero emissions.

In the case of Lithuania, the first sufficiency scenario analysis looked at the impacts of nine selected social, housing and energy demand indicators of the buildings sector. Due to implementation of social policies is expected that the average household size trend could be stabilised and 2.2 persons would make a household in 2050. Due to the rapid decline of population in the country, the number of households declines. If energy sufficiency is implemented at a scale subject to which values of energy sufficiency indicators for 2050 are achieved, then consumption of energy would decrease in households by 18%, in comparison to levels assessed in one of the National Energy Independence Strategy (NEIS) scenario, without any energy sufficiency measures. This corresponds to expected changes in final energy consumption of 4% in 2050.

In case of the Lithuanian transport sector, the effect of seven quantified indicators were estimated. If energy sufficiency is implemented in transport at the level of the prioritised energy sufficiency target levels for 2050, energy and fuel consumption would decrease by 22% in passenger transport, in comparison to levels assessed in one of the NEIS scenario without any energy sufficiency measures. This corresponds to expected changes in final energy consumption of 8% in 2050.

The impact of energy sufficiency in buildings and transport sectors on the development of the energy sector was assessed using MESSAGE mathematical model. At the current stage, energy sufficiency measures were not modelled explicitly in this mathematical model. Therefore costs (if any) related to implementation of energy sufficiency measures were neglected. Energy sufficiency in mathematical model was represented by exogenously given correspondingly reduced final energy demand. Calculations were based on one scenario used for preparation of the current version of the NEIS. In this analysed scenario no bounds on $CO_2$ emissions were applied in order to better explore impact of energy sufficiency. However, it was taken that $CO_2$ price increases from 52 EUR/t in 2020 until 104 EUR/t in 2030, but later it stays constant. Energy sufficiency-based scenarios show reductions in consumption of oil products and other fossil fuel due to energy sufficiency in passenger transport sector, as well as reductions in biomass due to energy sufficiency in households for heat consumption. If energy sufficiency in buildings and passenger transport were implemented, the savings of GHG emissions could be achieved by 21% in 2050.

## 4.2. Qualitative impacts

Energy sufficiency actions will reduce energy and fuel price volatility and expectedly the fossil fuel price level. In combination with the reduced energy consumption this will cause lower energy bills. Therefore, the pattern of income distribution will change in directions from satisfaction of physiological needs to assurance of higher-level needs, including, self-actualization. Due to faster climbing of the Moslow pyramid up, the pattern of time use will change to in favour of more time spend for development of creativity, cognition of world and country, etc. More generally, this contributes to increasing the resilience of societies, which is particularly relevant in the current context.

Due to development of the sharing economy, the sense of commonality will grow stronger among residents, people will communicate more, neighbourhoods, green areas and common areas will become more liveable.

Reduced energy consumption will have an impact on GHG emissions and air pollution. Facilitated by the reductions of pollutions, the air quality will improve. In combination with used non-motorized transport modes (walking and cycling), the scale of the premature death will reduce and the health of humans will improve. This will require lower health expenditure as part of governmental and private expenditure.

Car sharing and use of the non-motorized modes will reduce traffic, which will lead to the reduction of investment intensity for the upgrade of the depreciating road infrastructure. The noise emitted by cars, especially during peak hours and in jams, will reduce.
It is expected that due to common use of appliances or machines which can be kept in common spaces the noise in dwellings will reduce too. Energy sufficiency in buildings will lead to smaller district heating and electricity infrastructure and, respectively, the reconstruction of existing one.
Current energy policies have been mostly focusing on the reduction of energy prices to increase competitiveness and tackle energy poverty rather than structural changes towards more efficiency and the apprehension of the need for behavioural change to avoid rebound effects.

## 4.3. Strategy for dealing with non-quantifiable impacts

Policy decision taken at all levels (national, regional and local) are shaping the strength of economic and social well-being. Ideally, policy makers consider most of the relevant costs and benefits when deciding about policy instruments, including not only the ones related to economic, but also those related to social and environmental impacts. The strength of the evidence base is the foundation of successful policy-making, along with its interpretation.
When deciding about whether or not to undertake a policy intervention or which policy option to choose from a set of alternatives, including the indirect impacts into the assessments requires that they are expressed in monetary terms. Environmental economic approaches to put a price on environmental services can be grouped in two main categories: the revealed preference methods and the stated preference method, depending on whether market prices can reflect a part of environmental value or not. For example, air pollution can influence real estate prices, and differences in market values can serve as a measure of how people value greener environments. In other cases, when prices cannot reveal preferences, (e. g. the value of having more public space on the streets due to restrictions on car traffic) the stated preference methods are applied, conducting surveys and asking people about how much they would be willing to pay or to accept (WTP and WTA) to achieve improvements or to avoid some negative impacts (Tietenberg 2014). These methods can also be applied for evaluating social impacts, e.g. change in well-being by using the value of time or medical costs as proxies, or surveying willingness to accept (e.g. related to switching from individual travelling modes to public transportation). Because of the complexity, cost and time requirements of carrying out such assessments, it is more common to rely on the result of studies investigating similar impacts and use their values in the context of analysis, the so called 'benefit transfer'. Related to the field of sufficiency, for example, Sovacool et al. (2021) provides a comprehensive research synthesis of externalities for energy and mobility, Sorrell et al. (2020) collects the current state of knowledge on rebounds and spill overs related to energy sufficiency.
Besides using social cost-benefit analysis, scenario modelling can contribute to evaluating the impacts of different policy options by incorporating such value estimations from literature or self-conducted surveys. If personal valuation related to changes in comfort or value of time costs can be attributed to behaviour change (e.g. switching to public transport or soft mobility instead of individual car use), some sustainability measures could be included in modelling competing with energy efficiency measures. However, to consider a wider range of externalities, rebound effects, and to analyse spill-over effects on other economic sectors, it might be necessary to extend the calculations of the currently used partial equilibrium models with general equilibrium modelling.
However, in spite of the extended literature on evaluations, there might be costs and benefits for which no empirical information is available, either because no related research results are yet available, or it is very difficult to measure or monetise the impact (e.g. strong neighbourhood cohesiveness). In that case, the conventional cost-benefit analysis and the other analytical instruments cannot be used on their own. Another factor to consider is that given the complexity of the natural and social environment, the determined values

can only capture a part of the true environmental and social values investigated, and some of them rely on subjective opinions (WTP, WTA values). This makes estimations uncertain, which might depend to a large extent on the opinions of different stakeholder groups. Therefore, some other qualitative techniques have also been elaborated and used for deciding among various policy alternatives.

One such method is the multi-criteria analysis (MCA), which allows selecting policy options that are supported by most stakeholders. This technique involves identifying the possible interventions, and then asking all potential stakeholders affected by the measures to evaluate them against some preselected criteria, chosen with their involvement, and ranked by them according to how important they are from their perspective. Finally, based on the grades of criteria and the ranking of stakeholders, a most preferred and least preferred policy option can be selected. MCA is useful to avoid uncertainties inherent in monetisation and can take into account different interests and numerous intangible criteria (NEF 2011).

It is also possible to combine the method with the modelling. For this, the impacts can be quantified by using a scale, for example giving the level of impact a number between 1 to 5 or a grade between ++ (+2) to -- (-2). Thus, if a measure has an intensive positive impact, it will get a high grade and if it has a minor positive effect, it receives a lower grade (e.g. contribution of aircrafts to noise could be assessed as '--', and that of bicycles '++'). These grades can be used as an input for the model. After grading all technologies involved and deciding about the weighting system (weighting according to the no of km / year, no of trips, etc.), it is possible to assess the overall impact (e.g. the results can show that the sufficiency scenario will be +1.7 regarding noise in the transport sector while BAU will be -1.8 and the efficiency scenario will be -0.5.) It is key to the approach to be transparent on the assumptions when quantifying the soft impacts (Lechtenböhmer et al. 2012).

Seeking to support decision making, the legislative requirement on types of indirect impacts to be included in the analysis of energy sufficiency policy and measures and in related programs should be set. The policy process has inter-linked and inter-dependent elements. The impact of policy decisions need to be anticipated, but it cannot be perfectly predicted, therefore feedback mechanisms are essential in order to perform corrections in direction or to determine the new paths. Furthermore, the parties that are most affected by policy decisions, particularly population and businesses, need to be active participants in the policy designing process. The strategy dealing with impacts of energy sufficiency could be an integral part of the European Green Deal[i], to recognise energy sufficiency as a supplemented key principle for clean energy transition, in addition to secure and affordable EU energy supply, fully integrated, interconnected and digitalised EU energy market, energy efficiency and renewable sources. The Strategy should aim at extraction of the discussed quantifiable and non-quantifiable impacts of energy sufficiency through a number of good policies, the examples of which are summarized in Table 2.

*Table 2: Examples of good policies or strategies dealing with the impacts of energy sufficiency*

| | |
|---|---|
| **Making the public transport (rail, buses / trolley buses) among the top considered solutions for travelling**:<br>– Permanent improvements in service quality (availability, accessibility, reliability, comfort, safety and security);<br>– Priority lines for buses in larger cities;<br>– Urban electronic tickets or smart tickets<br>– Advanced integrated ticket system for different transport modes (urban and inter-city distances);<br>– Ban on entering to the city centre by car. | **Renovation and building of infrastructure compatible to safety, adequacy and noise and vibration reducing criteria:**<br>– Programs to promote bicycling and develop pedestrian roads in urban environments;<br>– Infrastructure development for bicyclists and pedestrian – planned, constant, well financed, and well-connected;<br>– Bicycle and pedestrian masterplans guiding infrastructure investments. |
| **Developing the sense of communality between the residents:** | **Awareness raising, wide engagement and public acceptance becomes a vitally important for the policy package on energy sufficiency**: |

| | |
|---|---|
| – Creation and promotion of the market for rented appliances, machines, equipment, transport vehicles, etc. both at Community, local or national levels;<br>– Community promotion to buy appliances together and then sharing them;<br>– Information campaigns on values from buying things together for common use. | – Extensive content marketing campaigns utilizing individualized marketing decisions that consider individual preferences and works at its best promoting, engaging into long-lasting mutually beneficial relationships. These relationships, built on value and engagement, results into habitual behavioural changes, free-of-mouth referrals and therefore widely acceptable culture of consumption. |

# 5. Conclusion

Analysing the energy system models in Hungary and Lithuania provided useful insight into the potential of integrating energy sufficiency assumptions into these models. The models were analysed and their characteristics as well as similarities were assessed. Both countries use optimization models which minimize the total costs. While the HU-TIMES covers all sectors of Hungary, for Lithuania, two models are used: the LEI-Transport (MESSAGE based) model covers only the transport sector, other sectors are covered by the LT-ENERGY model.

Through defining the sufficiency-related indicators, the gaps and development potentials for the different models were identified. Considering the characteristics of the studied models (e.g. logic of the models, input/output and the covered indicators in the model), the inclusion of these sufficiency assumptions could vary from one model to the other. The LT-ENERGY model is a supply-side model in which the energy demand is given as the input. In this model the sufficiency measures could be only considered by either introducing a virtual supplier of energy savings, whose amount corresponds to the potential energy savings due to sufficiency measures or by reducing the demand which is used as the input for the model. Therefore, modelling sufficiency in the sense of using the built-in sufficiency assumptions in the demand-side modelling is not an option easy to implement for this model.

The HU-TIMES and LEI-Transport models do not cover the whole demand side and the energy service demand in these models is mostly calculated exogenously. However, in these models, the sufficiency-related indicators are already partly included. Hence, by introducing the sufficiency assumptions, the energy service demand reflecting the sufficiency-related impact could be calculated and used as the new input of the model. To integrate all the sufficiency assumptions, further model development, particularly including more sufficiency-related indicators or even new logic, should be carried out.

None of the three models explicitly consider the sufficiency aspects, however to have a rough estimation of the sufficiency impact on the energy saving, some initial modelling activities were carried out and preliminary results were drawn. Yet, energy sufficiency has several direct and indirect impacts beyond the energy dimension (savings and costs), which are important to consider when designing relevant policies. Although some of these impacts may be difficult to precisely quantify and/or to express in monetary terms, their omission from the costs and benefits can distort the decisions of policy makers. It is therefore essential to estimate them, for which the literature offers a number of methods. The approaches recommended in this report could be seen as an inspiration to facilitate the quantification of sufficiency impacts, for different actors in the field of sufficiency who aim at promoting the concept by communicating its various benefits for the society and the environment.

# 6. Annex A: Results of the surveys

## 6.1. HU-TIMES model

### 6.1.1. General information

- Name of the model:

  Long: Hungarian TIMES model
  Short: HU-TIMES

- Developing environment/ commercial modelling tool of the model:

  TIMES (developed by IEA-ETSAP, International Energy Agency - Energy Technology Systems Analysis Program). TIMES consists of VEDA Front-end and VEDA Back-end and GAMS (General Algebraic Modelling System) and Microsoft Excel.

- Programming language used for the model:

  GAMS

- Database used for the model (if applicable):

  Data gathered by REKK, based on primary and secondary research (mostly EUROSTAT and Hungarian Statistical Office data)

- Owner of the model:

  REKK

- Main users of the model:

  REKK

- Brief description of the modelling approach:

  HU-TIMES is based on social cost minimizing partial mathematical optimization. The social aspect is primarily due to the inclusion of externalities (Greenhouse Gas (GHG) emission cost) as well as the concept of meeting the exogenous end-use demands at a least cost way. Exogenous variables are provided for the model, e.g., macroeconomic assumptions (Gross domestic product (GDP) growth, population, European allowances (EUA) and energy carrier prices – except for electricity and district heat prices), end-use energy demand by sector (energy demand for industry, agriculture and building sectors, passenger- and ton-kilometres for transport sector). In addition to this, a detailed representation of currently available and future possible technologies that can satisfy the end-use demand are defined. The model chooses between the available technologies based on the exogenous end-use demands and also on the energy policies to be assessed.

- Relevant studies/projects in which the model was used so far:

  Hungarian National Energy and Climate Plan (in force), Hungarian 2050 Long-term Strategy – an economy with net-zero greenhouse gas emission (in planning phase – modelling work is finalized)

- Following references (papers / public reports...) describe the model:

- References (no description of the model included):
  Hungarian National energy and climate plan (NECP)[ii]
  Hungarian Long-term Strategy (in progress)
- Short descriptions[iii]
- Detailed description of the TIMES model (in general)[iv]

### 6.1.2. General approach

- Outcomes of the model:

☒ Energy use
☒ Policy effects
☒ Application of the technologies
☒ Technology change (some indicators for technology innovation or diffusion)
☒ Other: Greenhouse gas emission ($CO_2$, $CH_4$, $N_2O$)

- Potential output(s) of the model:

☒ Energy consumption
☒ GHG emission
☒ Costs and benefits
☒ Energy supply
☒ Imports and exports (Electric power only)
☐ Energy balance
☐ Air pollution
☐ Other environmental impacts
☐ Others

- Sectors covered by the model:

☒ Households
☒ Tertiary
☒ Industry
☒ Transport
☒ Power system
☒ Other energy supply sector Heating system (district heating as well)
☐ AFOLU (Agriculture, Forestry and Other Land Use)

- Geographical coverage aimed for / allowed by the model:

☐ Local (city-level or smaller)
☐ Regional (state-level)
☒ National
☐ CEE (Central and Eastern Europe)
☐ EU
☐ Global
☒ Other:
Electric power system for the entire EU and Balkan countries + Ukraine is to be included.

- Usual timeframe of the modelling:

  2016-2050 (2016 is the base year)

- Usual time resolution for modelling:

  5 years (2016, 2020, 2025, 2030, 2035, 2040, 2045 and 2050). Can be adapted (minimum resolution is 1 year period)

- Analytical approach of the model:

  ☒ Macroeconomic top-down:
  in some industrial sub-sectors (e.g., non-ferrous metals, mining) and agriculture (the energy consumption)

  ☒ Techno-economic bottom-up:
  most of the sectors (households, tertiary, transportation, industry: homogenous products, largest emitters)

  ☒ Somewhere between top-down and bottom-up, See above.

- Approaches followed by the model:

  ☐ Accounting
  ☐ Simulation
  ☒ Optimization
  ☐ (Techno-)econometric
  ☐ A combination, or other

- Possible driver for the abovementioned approach:

  It differs sector-by-sector. In case of:

  - Agriculture and Industry sectors: mainly GDP growth
  - Household and Tertiary sectors: population and GDP growth, underheating – which indicates by how much household consume less than adequate energy (i.e., they only heat part of the household, or they heat up for a lower temperature due to energy poverty not sufficiency)
  - Transport sector: mainly GDP growth (for freight transport) and population (for passenger transport)

- Possible "utility function" for the approach:

  It differs sector-by-sector. In case of:

  - Agriculture and Industry sectors: exogenous end-use energy demand
  - Household and Tertiary sectors: exogenous end-use energy consumption (for heating, cooling, hot water and other appliances)
  - Transport sector: passenger and ton kilometres

- Mathematical methods that the model apply:

  ☒ Analytical optimization
  ☐ Heuristic optimization
  ☐ Agent-based simulation
  ☐ Monte-Carlo simulation
  ☐ System-dynamics simulation

☐ Others

- Point(s) of view reflected in the modelling approach (considering costs, interest rates...):

☐ Society as a whole
☒ End-user
☐ Others (e.g., utilities)

### 6.1.3. Structure of the model

- Overview figures showing the structure of the model:

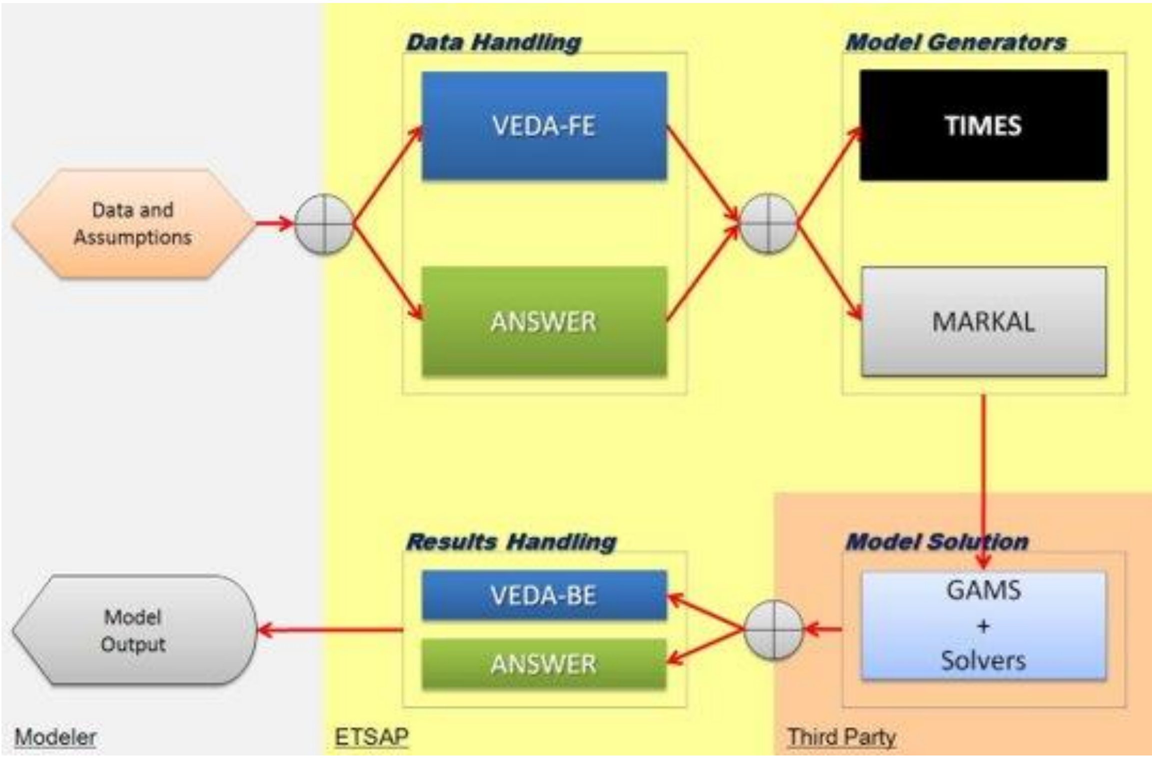


*Figure 6: TIMES software utilization*

- Following interactions are endogenously modelled:

  Electricity, heat and hydrogen consumptions are determined endogenously by the end-use energy demand of the different sectors (exogenous), the application of the different technologies (endogenous) and the policy measures (exogenous)

- Following intermediate calculation steps are explicitly accounted for, i.e., visible, in the model's (intermediate) output:

  The model considers the net present value of "costs": the main goal is to meet the exogenous demand in a least cost way. Therefore, the model takes into account all the costs of all the possible technologies (and their technology characteristics – e.g., efficiency, capacity constraint – as well) that appear throughout the modelling time horizon. Those costs that relates to the period after the modelling time horizon are deducted from the calculation, e.g., if there is an investment in a given technology in 2040, but its lifetime is 20 years, then the calculation only involves the depreciation only until 2050 (that is the end of the time horizon which is considered by our model).

### 6.1.4. Structure of building and transport sector

*Table 3: Energy services and indicators in the building sector-REKK*

| Sub-sector | Energy Service | Energy service indicator |
|---|---|---|
| Residential | Space heating, cooling, hot water; | PJ |
| | Other than space heating (aggregated): e.g., electricity appliances: fridge, refrigerator, washing machine, lightning, cooking, other appliances | PJ and lumen for lightning. |
| Tertiary | Space heating | PJ |
| | Other than space heating (aggregated): e.g., water heating, electric appliances, cooling | PJ |

*Table 4: Energy services and indicators in the transport sector-REKK*

| Sub-sector | Energy Service | Energy service indicator |
|---|---|---|
| Passenger transport | Motorcycle | Passenger kilometres |
| | Cars | Passenger kilometres |
| | Bus | Passenger kilometres |
| | Rail (Passenger) | Passenger kilometres |
| | Tram | Passenger kilometres |
| | Suburb train | Passenger kilometres |
| | Trolley | Passenger kilometres |
| | Underground | Passenger kilometres |
| Freight | Light commercial vehicles | Ton kilometres |
| | High duty trucks | Ton kilometres |
| | Rail (Freight) | Ton kilometres |
| | Pipeline transport | Ton kilometres |
| | Inland water ways (IWW) | Ton kilometres |

- Main input/output of the model:

**Building sector**

Main input and level of details:

End-use exogenous demand, technological and economic characteristics of technologies. Level of details: building type, age of the buildings.

Main framework input (energy prices, GDP...):

Energy prices, GDP, population, underheating

Main output and level of details:

Energy consumption, technology usage, investment and O&M (operating and maintenance) costs, GHG emission. Level of details: building type, age of the buildings.

**Transport sector**

Main input and level of details:

End-use exogenous demand, technological and economic characteristics of technologies. Level of details: demand segments – see Table 3 **Fehler! Verweisquelle konnte nicht gefunden werden.**and Table 4, energy carriers (e.g., diesel, electric, and hydrogen), ages: young, middle-aged, old

Main framework input (energy prices, GDP...):

Energy prices, GDP, population

Main output and level of details:

Energy consumption, technology usage, investment and O&M costs, GHG emission, shift in transport mode. Level of details: demand segments – see Table 3 **Fehler! Verweisquelle konnte nicht gefunden werden.**and Table 4**Fehler! Verweisquelle konnte nicht gefunden werden.**, energy carriers (e.g., diesel, electricity or hydrogen), ages: young, middle-aged, old

*Table 5: Level of details covered in the building sector-REKK*

| Sector | Building types | Age classes | Building elements | Technologies | Energy carriers |
|---|---|---|---|---|---|
| Residential | Family or terraced house (1-3 apartments)<br>Condominium (4-9 apartments)<br>Condominium (10+ apartments) | Based on building types we different age classes are defined (as it is determined in the official building typology).<br>Family or terraced:<br>-1944; 1945-1959;1960-1979;1980-1989;1990-2005;2006-2020;2020-.<br>Condominium (4-9ap.): -1945;1946-1989;1990-2005;2006-2020;2020-.<br>Condominium (10+ ap.): brick:<br>-1944;1945-1989;1990-2005;2006-2020;2020-.<br>panel: -1979; 1980-. | Not applicable. | heat pump; boiler (electric, gas-fired); district heating; | Coal (bituminous, sub-bituminous, lignite, brown coal briquette);<br>Oil (LPG – Liquefied petroleum gas);<br>Natural gas;<br>Primary solid biomass;<br>Solar;<br>Electricity;<br>Residential heating; heat pump |
| Tertiary | Health, social and accommodation;<br>Administrative and office;<br>commercial;<br>cultural;<br>Educational;<br>hospitals; sport facilities | -1900;1901-1945;1946-1959;1960-1979;1980-1989;1990-2006;<br>2006- | Not applicable. | heat pump; boiler (electric, gas-fired); central heating; | Coal (bituminous, sub-bituminous, lignite, brown coal briquette);<br>Oil (fuel oil, diesel, LPG);<br>Natural gas;<br>Bio (Primary solid biomass, biogas);<br>Geothermal,<br>Solar;<br>Electricity;<br>Residential heating; waste, heat pump |

- Does the model include a description of the building stock? If yes, does it also cover its geographical distribution?

  Yes, it does but there is no geographical distribution included.

*Table 6: Level of details covered in the transport sector-REKK*

| Sector | Modes | Infrastructures | Vehicles | Technologies | Energy carriers |
|---|---|---|---|---|---|
| Passenger transport | Road, rail, | not applicable | Motorcycles,<br>Cars,<br>Bus<br>Rail (Passenger)<br>Tram<br>Suburb train<br>Trolley<br>Underground | ICC, PHEV (plug-in hybrid), BEV (battery electric vehicle), HEV (Hybrid electric vehicle), FCEV (Fuel cell electric vehicle), CNG (Compressed natural gas) | diesel (fossil and bio), gasoline (fossil and bio), natural gas, electricity, hydrogen, |
| Freight | Road, rail, IWW, pipeline | not applicable | Light commercial vehicles<br>High duty trucks<br>Rail (Freight)<br>Pipeline transport<br>IWW | ICC, PHEV, BEV, HEV, FCEV, CNG | diesel (fossil and bio), gasoline (fossil and bio), natural gas, electricity, hydrogen, |

## 6.1.5. Input/output data

- Main problems or issues with the input data / data collection methods used for the model: (for building and transport sector)

  Data availability.

- Possible solutions the above-mentioned problem(s): (Building and transport sector)

  Detailed data gathering process, experts' assumptions

*Table 7: Categorization of the parameters include in the model-REKK*

| | Input | Intermediate | Output | Implicitly | Explicitly | Exogenously | Endogenously |
|---|---|---|---|---|---|---|---|
| Macro-economic data such as:<br>-Income/capita<br>-Growth/productivity/GDP | *X* | | | *X* | | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Demographic data such as:<br>-Population<br>-Number of households | *X* | | | *X* | | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Energy consumption of sector(s) | | | *X* | | *X* | | *X* |
| *If necessary, please explain:* | *Energy consumption of a sector depends on the exogenous demand and technologies to be used (their efficiency characteristics).* | | | | | | |
| Energy services | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | *HU-TIMES is based on the cost minimization approach where the exogenously determined end-use demands (services) have to be met.* | | | | | | |
| Societal costs and benefits<br>- employment<br>- life quality<br>- time consumption<br>- Others | | | *X* | | *X* | | *X* |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *If necessary, please explain:* | *The societal cost to be considered here is the GHG abatement cost.* | | | | | | |
| Environmental externalities<br>- $CO_2$ emission reduction effects<br>- Air pollution<br>- Others | | | *X* | | *X* | | *X* |
| *If necessary, please explain:* | *Environmental externalities to be considered are $CO_2$, $CH_4$, $N_2O$.* | | | | | | |
| Characteristics of energy techniques (e.g., capacity/ power, usage, efficiency factors or learning effect, or other) | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Energy prices or $CO_2$ prices | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Explicit specification and modelling of policies (e.g. subsidy levels, energy taxes, standards) | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Demand elasticities | | | | | | | |
| *If necessary, please explain:* | *Not applicable at the moment.* | | | | | | |
| Behaviour (purchase/choice of technologies) | | | | | | | |
| *If necessary, please explain:* | *Not applicable at the moment.* | | | | | | |
| Behaviour (use of technologies) | | | | | | | |
| *If necessary, please explain:* | *Not applicable at the moment.* | | | | | | |

### 6.1.6. Data Validation

- Methods used for calibration and validation:

  Comparing results with the actual base year data (2016).

- Available sensitivity analysis for the model results and the discussed parameters:

  Yes. It is possible to do with multiple (macro- and techno-economic) parameters

- Validation effort required in case the context of model changes:

  A calibration process (for the base-year, 2016) has to be implemented. We have done a greater validation process, when the building typology in Hungary has changed last year. The process required the re-calibration of the model, which took some workdays.

### 6.1.7. Policy consideration

- Analysis that is carried out / possible to carry out with the model?

☒ Policy assessment: several policies can be assessed (e.g., EUA price, taxes or subsidies)
☒ Policy selection
☒ Policy development
☒ Policy improvement
☐ Combination/others

- The following issues can be taken into account in the model:

☒ Policies impacting the technologies in the "stock":
Replacement of technologies (before they reached their lifetime: e.g., scrappage scheme), renovation/extension of a building...
Constraints can be built up on these technology characteristics (e.g.: whether gas boilers can be used in the new buildings after a certain point of time)
☒ Policies impacting the use of the technologies over the lifetime
Using economic incentives (taxes, subsidies) or technological constraints (i.e., a certain technology is not allowed).
☒ Policies impacting structures
See above.
☒ Standards (MEPS / labels)
☒ EPBD
(Energy Performance of Buildings Directive) and national standards for building
☒ Subsidies
☒ Taxes
☐ Soft policies (e.g., information based)
☒ Sufficiency policies,
Through applying bans on using given technologies or using incentives (taxes and subsidies)

### 6.1.8. Decision-makings in the model

**Building sector**

- Is the amount of energy service calculated/defined? If yes, based on which logic/assumption?

End-use demand is exogenously determined. End-use demand describes the gross energy demand for each segment (in PJ for heating, cooling, hot water and other appliances, except for lighting – that is measured in lumen[v]). Gross energy demand includes both the net – actual – energy demand and the avoided energy consumption due to energy efficiency applications. For each building type and age class, gross energy demand is based on the average specific energy consumption (PJ/m$^2$), the size of building (m$^2$) and underheating measures. Underheating describes the energy not consumed due to energy poverty (i.e., not the entire building is heated, or the temperature is below the expected level).

- Is the technology (are the technologies) to deliver the energy service chosen/defined? If yes, based on which logic/assumption?

Currently available and future technologies are defined, based on their technological and economic characteristics and development. The gross energy demand has to be met by the available or future technologies and by energy efficiency investments. The model chooses those technologies which can supply the energy demand in a least-cost way. When energy policies are applied (e.g., energy efficiency goals or renewable energy source share are defined), the model considers these and chooses the technologies in accordance with these policies and least-cost way approach simultaneously. Rebuilding is not an option, but renovation (i.e., energy efficiency) is available in the model.

- Is the use of the technology (or the technologies) decided/defined? If yes, based on which logic/assumption?

  The use of the future available technologies is not exogenously determined.

- The logic/assumption is:

  ☐ Exogenous
  ☒ Calculated internally
  ☒ Can be impacted by policies

- Costs that are input parameters for investment decision:

  Investment cost, weighted average cost of capital (WACC), expected return on investment, fix and variable operation and maintenance costs, energy carrier related costs.

- The way the costs are transformed into market shares:

  The model considers the net present value of "costs": the main goal is to meet the exogenous demand in a least cost way. Therefore, the model takes into account all the costs of all the possible technologies that appear throughout the modelling time horizon. Those costs that relates to the period after the modelling time horizon are deducted from the calculation, e.g., if there is an investment in a given technology in 2040, but its lifetime is 20 years, then the calculation only involves the depreciation only until 2050 (that is the end of the time horizon which is considered by our model).

**Transport sector**

- Is the amount of energy service calculated/defined? If yes, based on which logic/assumption?

- End-use demand is exogenously determined. Econometric models are built to predict the future demand, based on historical data (regression between ton-kilometres and GDP or passenger kilometre and population size and GDP).

- Is the technology (are the technologies) to deliver the energy service chosen/defined? If yes, based on which logic/assumption?

  Currently available and future technologies are defined, based on their technological and economic characteristics and development. The model considers the exogenous demand that has to be met by using available and future technologies in a least-cost way. Further energy policies (e.g., share of renewable energy sources, limit on GHG emission) can also be considered together with the least-cost way approach.

- Is the use of the technology (or the technologies) decided/defined? If yes, based on which logic/assumption?

  The use of the future available technologies is not exogenously determined.

- The logic/assumption is:

  ☐ Exogenous
  ☒ Calculated internally
  ☒ Can be impacted by policies

- Costs that are input parameters for investment decision:

Investment cost, WACC, fix and variable operation and maintenance costs, energy carrier related costs.

- The way the costs are transformed into market shares:

The model considers the net present value of "costs": the main goal is to meet the exogenous demand in a least cost way. Therefore, the model takes into account all the costs of all the possible technologies that appear throughout the modelling time horizon. Those costs that relates to the period after the modelling time horizon are deducted from the calculation, e.g., if there is an investment in a given technology in 2040, but its lifetime is 20 years, then the calculation only involves the depreciation only until 2050 (that is the end of the time horizon which is considered by our model).

### 6.1.9. Flexibility/complexity

- Flexibility of the model in terms of the changes in the modelling context? (e.g., changing the scale and/or scope of input and output)

From a modelling perspective (i.e., the way the model was built up) it is flexible, but from the data gathering point it is inflexible.

- Complexity of the modelling approach:

In terms of:

Conceptual complexity (the mathematical and logical difficulty level)

Less complex | More complex

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | X | | |

Detail complexity (the level of extensiveness of the model from included details)

Less complex | More complex

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | X | | |

- Trade-offs in case of increasing the complexity of modelling approach:

Increased model running time. On a 2016-2050 time horizon it takes about 7-8 hours to run a scenario.

### 6.1.10. User-friendliness and transparency

- Required efforts to make a complete model run:

Parameters and the modelling options have to be set

- Parts of the efforts that are not performed by the model itself, but outside the model:

Special knowledge is required to set the parameters and the modelling options.

*Table 8: Rating of user friendliness of the model-REKK*

| Aspects | Grade 1-10 (1: not user-friendly at all, 10: extremely user-friendly) |
|---|---|
| *Clarity* | |
| Meaning of results and inputs | *3* |
| Interface elements, guiding the user | *1* |
| Help function | *2* |
| *Generating results* | |
| Ease (number of user actions required) | *5* |
| Speed (calculation time) | *1* |
| Flexibility (capability of the model to run in different modes, or run for different data sections) | *10* |
| Formats (availability of predefined formats for various target groups) | *1* |
| *Analysis possibilities* | |
| Transparency of results and easy access to underlying data. | *8* |
| Graphical representation | *2* |
| Possibilities to perform analyses on the results in the model | *2* |
| Is it possible to generate reports on sections of results and inputs | *5* |
| Built-in sensitivity analysis | *2* |
| *Data management* | |
| Making modifications to inputs | *1* |
| Storing model runs integrally | *10* |
| Logging modifications | *10* |
| Sharing models with multiple users | *10* |

## 6.1.11. Sufficiency aspects

**Building sector**

- Feature(s) that could be interesting in the model approach in order to consider energy sufficiency aspects:

  Detailed building structure.

- Main strengths of the modelling approach when modelling sufficiency:

  Defining bans and economic incentives.

- Main limitations of the modelling approach when modelling sufficiency:

  Inelastic demand curve: due to inelastic demand curve, the model cannot capture changes in consumer behaviour (i.e., the end-use demand is fixed, which always has to be met).

- Expected improvement(s) to overcome the mentioned limitations:

  Including elastic demand curve: by including elasticity of demand, one can capture how the quantity demanded changes due to changes in (market) prices. With high elasticity one can capture the behaviour of a price sensitive consumer.

  Behavioural changes through usage of different technologies: by defining the "availability factor" for the existing and new technologies, the model might capture the changes of behaviour by allowing less availability for them. E.g.: if the availability of the washing machines is reduced. However, at the same time, alternative "technologies" – e.g., manual washing or using a share washing machine – has to be included in the model, thus the end-use demand can be met by these "technologies" as well. These could include the opportunity cost of spending time and energy on doing manual washing.

- An appropriate alternative modelling approach for the current model to consider sufficiency aspects.

  Considering detailed representation of the demand side.

- Advantages of a switch to this or these alternative(s):

  Wider range of aspects could be considered.

- Disadvantages or risks of a switch to this or these alternative(s):

  High modelling and data gathering requirement.

**Transport sector**

- Feature(s) that could be interesting in the model approach in order to consider energy sufficiency aspects:

  Modal shift.

- Main strengths of the modelling approach when modelling sufficiency:

  Defining bans and economic incentives.

- Main limitations of the modelling approach when modelling sufficiency:

  Inelastic demand curve.

- Expected improvement(s) to overcome the mentioned limitations:

  Including elastic demand curve: by including elasticity of demand, one can capture how the quantity demanded changes due to changes in (market) prices. With high elasticity one can capture the behaviour of a price sensitive consumer.

  Behavioural changes through usage of different technologies: by defining the "availability factor" for the existing and new technologies, the model might capture the changes of behaviour by allowing less availability for them. E.g. if the availability of cars is reduced. However, at the same time, alternative "technologies" – e.g., walking/biking – has to be included in the model, thus the end-use demand can be met by these "technologies" as well. These could include the opportunity cost of spending time and energy on doing walking/biking e.g., to the supermarket and carrying the grocery by hand/by bike.

- An appropriate alternative modelling approach for the current model to consider sufficiency aspects.

  Considering value of time, infrastructure.

- Advantages of a switch to this or these alternative(s):

  Wider range of aspects could be considered.

- Disadvantages or risks of a switch to this or these alternative(s):

  High modelling and data gathering requirement.

## 6.2. MESSAGE Transport Model for Decarbonisation Scenarios of Lithuania

### 6.2.1. General information

- Name of the model:

  MESSAGE Transport Model for Decarbonisation Scenarios of Lithuania

- Developing environment/ commercial modelling tool of the model:

  MESSAGE

- Programming language used for the model:

  GUI (General user interface) – Python, Tool Command Language
  Model – mostly C, Fortran

- Database used for the model (if applicable):

  A series of tables in MS Excel file are used as a database

- Owner of the model:

  Lithuanian Energy Institute

- Main users of the model:

  Lithuanian Energy Institute

- Brief description of the modelling approach:

  It is a bottom-up linear programming partial equilibrium optimization model created within MESSAGE modelling software, with aim to determine how the transport sector should develop to achieve set goals with the least possible costs. Calculations are based on minimization of total discounted costs.

  In the model, the demands are set exogenously for short and long-distance travel as well as freight delivery. To satisfy travel demands, the model can choose from more than 300 transport technologies based on vehicle type, class, fuel, and manufacture year. Each technology has different investments and maintenance costs, fuel consumption rate, occupancy rate, time consumption rate. Among vehicle types are personal cars, city busses, trolleybuses, intercity busses, passenger trains, freight trains and trucks. Modelled car classes are A-B, C-D, E-F, J-M. Modelled fuels include diesel, petrol, CNG, electricity, hydrogen, ETBE (Ethyl tertiary butyl ether), bioethanol, biodiesel. Biofuels and conventional fuels are blended in the model. To enable model shift travel time budget approach was implemented.

- Relevant studies/projects in which the model was used so far:

  Modelling potential Least-Cost Long-Term greenhouse Gas Emission Reduction Strategies for Lithuania (IAEA)

  An integrated modelling and analysis of the deep decarbonisation of the economy (Research Council of Lithuania)

  Integrated assessment of least-cost decarbonisation pathways of transport and energy sectors (Eimantas Neniškis PhD thesis)

- Following references (papers / public reports...) describe the model:

  Papers that describe the model are still being prepared.

  Key principles of the model were presented in International Association for Energy Economics webinar:

  DECARBONISATION OF THE ECONOMY: MODELLING AND PLANNING CHALLENGES http://www.iaee.org/en/webinars/webinar_neniskis.aspx

  Principles for modelling electric vehicles were published in journal Energetika: Neniškis (2019)

## 6.2.2. General approach

- Outcomes of the model:

  ☒ Energy use
  ☒ Policy effects
  ☒ Application of the technologies
  ☒ Technology change (some indicators for technology innovation or diffusion)
  ☒ Other

- Potential output(s) of the model:

  ☒ Energy consumption
  ☒ GHG emission
  ☒ Costs and benefits
  ☐ Energy supply
  ☐ Imports and exports
  ☐ Energy balance
  ☒ Air pollution
  ☐ Other environmental impacts
  ☒ Others:
  Transport modal shares; pkm/tkm (Passenger-kilometre per tonne-kilometre) by fuel used

- Sectors covered by the model:

  ☐ Households

☐ Tertiary
☐ Industry
☒ Transport
☐ Power system
☐ Other energy supply sector
☐ AFOLU

- Geographical coverage aimed for / allowed by the model:

  ☐ Local (city-level or smaller)
  ☐ Regional (state-level)
  ☒ National
  ☐ CEE
  ☐ EU
  ☐ Global
  ☐ Other

- Usual timeframe of the modelling:

  2020-2050, however it can be changed

- Usual time resolution for modelling:

  Each year is represented by 12 months, each month by typical workdays and off-work days and each of those have hourly time slices. In total 576 time slices for each modelled year.

- Analytical approach of the model:

  ☐ Macroeconomic top-down
  ☒ Techno-economic bottom-up
  ☐ Somewhere between top-down and bottom-up, please explain

- Approaches followed by the model:

  ☐ Accounting
  ☐ Simulation
  ☒ Optimization
  ☐ (Techno-)econometric
  ☐ A combination, or other

- Possible driver for the abovementioned approach:

  Demands: pkm and tkm

- Possible "utility function" for the approach:

  Total discounted costs

- Mathematical methods that the model apply:

  ☒ Analytical optimization
  ☐ Heuristic optimization
  ☐ Agent-based simulation

☐ Monte-Carlo simulation
☐ System-dynamics simulation
☐ Others

- Point(s) of view reflected in the modelling approach (considering costs, interest rates...):

☒ Society as a whole
☒ End-user
☐ Others (e.g., utilities)

## 6.2.3. Structure of the model

- Overview figures showing the structure of the model:

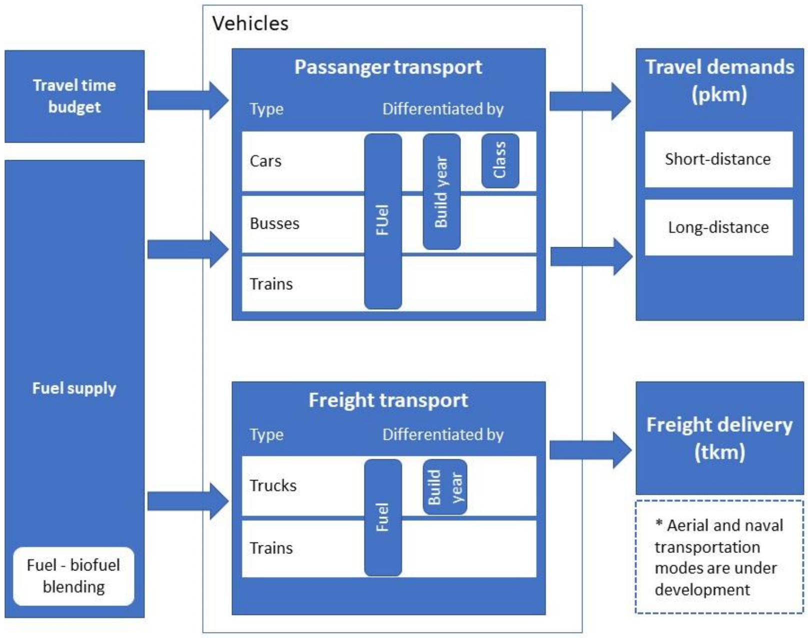


*Figure 7: Structure of the model-LEI*

- Following interactions are endogenously modelled:

Optimization. It means all interactions between all variables specified

- Following intermediate calculation steps are explicitly accounted for, i.e., visible, in the model's (intermediate) output:

None

## 6.2.4. Structure of building and transport sector

*Table 9: Energy services and indicators in the transport model-LEI*

| Sub-sector | Energy Service | Energy service indicator |
|---|---|---|
| Passenger transport | Short distance travel | Passengers x km |
| | Long distance travel | Passengers x km |
| | Travel time budget for short distance travel | hours |
| | Travel time budget for long distance travel | hours |
| Freight | Freight delivery | t x km |

- Main input/output of the model:

**Transport sector**

Main input and level of details:

Vehicle fleet data/fuel consumption by fuel and build year. For cars, also by class. Short and long-distance travel demands in Mpkm and freight delivery demand in Mtkm. Travel time budget in million hours.

Main framework input:

Vehicle purchase cost, fuel price, electricity price

Main output and level of details:

pkm and tkm by vehicle type, fuel, class
Fuel consumption
Emissions

*Table 10: Level of details covered in the transport sector-LEI*

| Sector | Modes | Infrastructures | Vehicles | Technologies | Energy carriers |
|---|---|---|---|---|---|
| Passenger transport | Road, Rail | - | Cars<br>Busses<br>Trains | Diesel car, petrol car, hybrid car, BEV, FCEV, diesel bus, CNG bus, BEV bus, FCEV bus, Trolley bus, diesel train, electric train. | Petrol<br>Diesel<br>LPG<br>CNG<br>Bioethanol<br>Biodiesel<br>ETBE<br>Electricity<br>Hydrogen |
| Freight | Road, Rail | - | Trucks<br>Trains | Diesel truck, CNG truck, FCEV truck, BEV truck, diesel train, electric train | Diesel<br>CNG<br>Biodiesel<br>Electricity<br>Hydrogen |

## 6.2.5. Input/output data

- Main problems or issues with the input data / data collection methods used for the model: (for building and transport sector)

  Lack of detailed enough data on how fuel efficiency and vehicle prices will change in the future; traffic volume distribution in time; hydrogen vehicles; trains…

- Possible solutions the above-mentioned problem(s): (Building and transport sector)

  Making assumptions and combining and processing data from multiple sources

*Table 11: Categorization of the parameters included in the model-LEI*

| | Input | Intermediate | Output | Implicitly | Explicitly | Exogenously | Endogenously |
|---|---|---|---|---|---|---|---|
| Macro-economic data such as:<br>-Income/capita<br>-Growth/productivity/GDP | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Demographic data such as:<br>-Population<br>-Number of households | *X* | | | *X* | | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Energy consumption of sector(s) | | | *X* | | *X* | | *X* |
| *If necessary, please explain:* | | | | | | | |
| Energy services | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Societal costs and benefits<br>- time consumption | *X* | | *X* | | *X* | *X* | *X* |
| *If necessary, please explain:* | *Travel time budget (input) is set exogenously, however time consumption per vehicle type (output) is determined endogenously. Time consumption is modelled to enable model shift.* | | | | | | |
| Environmental externalities<br>- $CO_2$ emission reduction effects<br>- Emissions<br>- External costs of emissions<br>- External costs of transport activities<br>- Other | | | *X* | | *X* | | *X* |
| *If necessary, please explain:* | *$CO_2$, CO, NOx, $N_2O$, $NH_3$, PM2.5 emissions based on emission coefficients for different technologies and the output of these technologies. External costs can be evaluated by adding costs on emissions or on activities of the technologies.* | | | | | | |
| Characteristics of energy techniques (e.g., capacity/ power, usage, efficiency factors or learning effect, or other) | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Energy prices or $CO_2$ prices | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Explicit specification and modelling of policies (e.g. subsidy levels, energy taxes, standards) | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | | | | | | | |
| Demand elasticities | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Behaviour (purchase/choice of technologies) | *X* | | | | *X* | *X* | |
| *If necessary, please explain:* | *Vehicle age distribution, car distribution by class, electric vehicle inconvenience cost* | | | | | | |
| Behaviour (use of technologies) | | | | | | | |
| *If necessary, please explain:* | | | | | | | |

### 6.2.6. Data Validation

- Methods used for calibration and validation:

  Comparison of model output with available data for historical year/years

- Available sensitivity analysis for the model results and the discussed parameters:

  Upon selection of model user

- Validation effort required in case the context of model changes:

  Comparison of model output with available data for historical year/years

### 6.2.7. Policy consideration

- Analysis that is carried out / possible to carry out with the model?

  ☒ Policy assessment
  Policy assessment can be performed by comparing scenarios with policies applied with base scenario. It is possible to model policies related to vehicle age distribution and car class shares by adjusting coefficients in corresponding relations; vehicle shares by fuel and modal shares by adding new relations; taxes/subsidies on fuel by adjusting fuel price; car registration tax and subsidies for sustainable cars by adjusting car purchase costs; car sharing by adjusting capacity factor; travel demands by changing the demand; fuel blending by changing blending proportions...

  ☒ Policy selection
  A target can be set, for example $CO_2$ reduction. Then, the model calculates how system should develop to reach set target. Another way is to compare the total costs of scenarios with different policies applied.

  ☒ Policy development
  Various parameters can be set to change throughout the modelling years. For example, subsidies for electric vehicles. Model solution shows whether set changes give expected results.

  ☒ Policy improvement

Various parameters can be set to change throughout the modelling years. For example, subsidies for electric vehicles. Model solution shows whether set changes give expected results.

☒ Combination/others

It is possible to assess a development of combination of policies and choose the best suiting one. Furthermore, a target can be set at the same time.

- The following issues can be taken into account in the model:

☒ Policies impacting the technologies in the "stock": replacement of technologies (before they reached their lifetime: e.g., scrappage scheme), renovation/extension of a building...

There is no way to remove the technologies from the stock before the end of their lifetime, however by adjusting vehicle age distribution constraints for pkm/tkm generation it is possible to achieve similar result.

☒ Policies impacting the use of the technologies over the lifetime

It is possible to limit the usage of certain technologies by setting constraints, e.g., pkm travelled by trains must exceed certain value.

☐ Policies impacting structures

☐ Standards (MEPS / labels)

☐ EPBD and national standards for building

☒ Subsidies

Subsidies can be implemented by changing input data (investment costs, fuel costs, variable or fixed costs).

☒ Taxes

Taxes can be implemented by changing input data (investment costs, fuel costs, variable or fixed costs)

☐ Soft policies (e.g., information based)

☒ Sufficiency policies

Modal shift to public transport, car sharing

## 6.2.8. Decision-makings in the model

**Transport sector**

- Is the amount of energy service calculated/defined? If yes, based on which logic/assumption?

  Travel/freight demands are set exogenously, and the model chooses the cheapest options to satisfy the demands, within given constraints (including travel time budget constraints)

- Is the technology (are the technologies) to deliver the energy service chosen/defined? If yes, based on which logic/assumption?

  Travel/freight demands are set exogenously, and the model chooses the cheapest options to satisfy the demands, within given constraints (including travel time budget constraints). Transportation options (technologies) are defined in such logic: technology uses fuel and time from travel time budget to produce travel (pkm). Technologies have defined investment and maintenance costs, fuel consumption rate, time consumption rate (speed), capacity factor (the rate of usage).

- Is the use of the technology (or the technologies) decided/defined? If yes, based on which logic/assumption?

  Decided. The model decides how much each technology has to produce based on satisfying the demands with least possible costs within set constraints, including travel time budget constraint.

- The logic/assumption is:

☐ Exogenous
☒ Calculated internally
The model decides how much each technology has to produce based on satisfying the demands with least possible costs
☒ Can be impacted by policies

- Costs that are input parameters for investment decision:

Vehicle purchase costs, maintenance costs, fuel costs, additional taxes, inconvenience costs for electric vehicles

- The way the costs are transformed into market shares:

The model decides how much each technology has to produce based on satisfying the demands with least possible costs.

### 6.2.9. Flexibility/complexity

- Flexibility of the model in terms of the changes in the modelling context? (e.g., changing the scale and/or scope of input and output)

Somewhat flexible

- Complexity of the modelling approach:

In terms of:

Conceptual complexity (the mathematical and logical difficulty level)

Less complex | More complex

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | X | | | |

Detail complexity (the level of extensiveness of the model from included details)

Less complex | More complex

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | X | | |

- Trade-offs in case of increasing the complexity of modelling approach:

For example, more or less transparency of the model. Please explain Increasing model complexity, increases optimization time. Furthermore, the model size is limited. The biggest problem with increasing complexity is data availability.

### 6.2.10. User-friendliness and transparency

- Required efforts to make a complete model run:

Minor effort is needed to run the MESSAGE model without making any changes. However, it might require quite some effort to make some changes. Data is managed in MS Excel file. After any change in the data, it has to be exported in required formats and pasted in certain places in specific files to apply it to the model.

- Parts of the efforts that are not performed by the model itself, but outside the model:

  The model was created within MESSAGE software and does not require any additional tool to complete a model run. However, model data is managed in MS Excel file. After any change in the data, it has to be exported in required formats and pasted in certain places in specific files to apply it to the model.

*Table 12: Rating of user friendliness of the model-LEI*

| Aspects | Grade 1-10 (1: not user-friendly at all, 10: extremely user-friendly) |
|---|---|
| *Clarity* | |
| Meaning of results and inputs | *8* |
| Interface elements, guiding the user | *7* |
| Help function | *1* |
| *Generating results* | |
| Ease (number of user actions required) | *8* |
| Speed (calculation time) | *8* |
| Flexibility (capability of the model to run in different modes, or run for different data sections) | *0* |
| Formats (availability of predefined formats for various target groups) | *10* |
| *Analysis possibilities* | |
| Transparency of results and easy access to underlying data. | *8* |
| Graphical representation | *8* |
| Possibilities to perform analyses on the results in the model | *8* |
| Is it possible to generate reports on sections of results and inputs | *8* |
| Built-in sensitivity analysis | *8* |
| *Data management* | |
| Making modifications to inputs | *5* |
| Storing model runs integrally | *10* |
| Logging modifications | *2 – modifications can be logged in MS Excel file, but the is no convenient structure developed* |
| Sharing models with multiple users | *1 – for working on the same case simultaneously*<br>*9 – for sharing a copy of a model* |

## 6.2.11. Sufficiency aspects

**Transport sector**

- Feature(s) that could be interesting in the model approach in order to consider energy sufficiency aspects:
    - Modal shift
    - Fuel shift
    - Travel demand
    - Load factor
    - Traffic distribution in time
    - Car sharing

- Main strengths of the modelling approach when modelling sufficiency:

  It is possible to evaluate how sufficiency measures, like modal shift to public transport, switching to smaller cars, car sharing, will affect the development of transport sector

- Main limitations of the modelling approach when modelling sufficiency:

  Sufficiency measures can be evaluated mostly through "what if" analysis, by adjusting input data.

- Expected improvement(s) to overcome the mentioned limitations:

  No improvements, regarding the sufficiency, are planned in the near future

- An appropriate alternative modelling approach for the current model to consider sufficiency aspects.

  Probably it would be a good idea to use agent-based model, where each agent has utility maximization objective function instead of cost minimization. Such model should include limited travel money budgets for each of the agent and a wide range of travel demands based on distance.

- Advantages of a switch to this or these alternative(s):
    - A better representation of behavioural choices, like transport mode selection, car purchase behaviour
    - It may allow to analyse questions/problems in a different way or take into account factors that cannot be taken into account in the current model version.

- Disadvantages or risks of a switch to this or these alternative(s):
    - Increased model size
    - It has not been tested yet, therefore it might be very difficult to implement
    - It is no longer possible to hard link it to the energy sector model, as energy sector model is based on cost minimization

# 6.3. LT-ENERGY model

## 6.3.1. General information

- Name of the model:

  LT-ENERGY

- Developing environment/ commercial modelling tool of the model:

  MESSAGE modelling package

- We have a detailed energy system model (Supply side model with partial integration of demand side) in which initial energy and fuel demands (without taking effects from future energy efficiency improvements or sufficiency measures on demand side) for HH, IND, TRAN…are calculated exogenously. We can say this demand represent future energy requirements which depend only on activity in demand side (increasing living space, increasing quantity of transported goods, etc.), but not taking into account any changes in lifestyle, consumers behaviour, transportation system and so one. Maybe we can use here naming "demand in business-as-usual case". This demand is as driving force for the supply model. Given demand should be satisfied in an optimal way looking from the supply side perspective. In addition, exogenously given demand can be changed by adding effects from energy efficiency or sufficiency measures in the demand side. This modelling mechanism in form of virtual energy suppliers is incorporated in the supply side model. However, these virtual suppliers model an effect that different efficiency or sufficiency measures would make in demand side. For example, if we have 100 MWh initial demand for gasoline in particular sector it is given for the model. However, if we estimate (or somebody else estimate and provide us this information) that due to possible implementation of energy efficiency measure in demand side which has a cost of 20 EUR/MWh we can save up to 10% of this demand we can activate on the supply side an additional virtual supplier of gasoline for this sector (for the demand sector!) which can supply up to 10 MWh of gasoline for the cost of 20 EUR/MWh and in such a way model implementation of that measure in demand side. In this case model will decide whether to use this energy efficiency measure in demand side and reduce energy supply from supply side or not.

- Programming language used for the model:

  Multiple languages: C, Python, Fortran

- Database used for the model (if applicable):

  Own data base of the model

- Owner of the model:

  Lithuanian Energy Institute

- Main users of the model:

  Lithuanian Energy Institute

- Brief description of the modelling approach:

  Bottom-up

  It is a bottom-up model, with aim to determine how the energy sector should develop to satisfy given demand with the least possible costs. It selects technologies for energy supply and chooses their operation regimes within a long-time interval (20-50 year perspective). It is an optimization supply side model. It is a linear programming model. Optimization criterion is minimization of total discounted costs within time interval under analysis.

Given demand should be satisfied in an optimal way looking from the supply side perspective. However, exogenously given demand can be changed by adding effects from energy efficiency or sufficiency measures in the demand side. For example, if we have 100 MWh demand for gasoline in particular sector it is given for the model exogenously. However, if we estimate that due to possible implementation of energy efficiency measure which has a cost of 20 Euros/MWh we can save up to 10% of this demand we can activate on the supply side an additional dummy/presumed supplier of gasoline for this sector which can supply up to 10 MWh of gasoline for the cost of 20 EUR/MWh. In this case model will decide either to use this energy efficiency measure or not and if yes at what extent from the range 0-10 MWh. In addition, model also evaluates how this change has affected remaining part of the supply system (how installed capacities and operations of other supply side technologies have changed, what effect was for overall system costs, emissions, etc.). So, it means that we can optimize supply side and additional possible measures on demand side.

- Relevant studies/projects in which the model was used so far:

Preparation of national energy strategy. Evaluation of economic attractiveness of capacity expansion at Kruonis Hydro Pumped Storage Power Plant.

- Following references (papers / public reports...) describe the model:

Research on development of the Lithuanian energy sector and formulation of Lithuanian National Energy Strategy (Ministry of Energy of the Republic of Lithuania, 2015-2016); Information can be found in http://old.lei.lt/main.php?m=580&l=3390&k=1

Socioeconomic costs and benefit analysis of Kruonis HPP capacity expansion. "Ignitis gamyba" JSC, 2019-2020. This report is confidential

## 6.3.2. General approach

- Outcomes of the model:

☒ Energy use
☒ Policy effects
☒ Application of the technologies
☒ Technology change (some indicators for technology innovation or diffusion)
☒ Other

- Potential output(s) of the model:

☐ Energy consumption
Exogenously specified demand is an input parameter for the model. However, demand changes can appear due to implementation energy efficiency or sufficiency measures (see above). So, demand is as an input parameter but also like an output result.
☒ GHG emission
☒ Costs and benefits
☒ Energy supply
☒ Imports and exports
☒ Energy balance
☒ Air pollution

☐ Other environmental impacts
☒ Others: Detailed allocation of all kinds of reserve capacities

- Sectors covered by the model:

☒ Households In form of externally given final demand
☒ Tertiary In form of externally given final demand
☒ Industry In form of externally given final demand
☒ Transport In form of externally given final demand
☒ Power system
☒ Other energy supply sector
☐ AFOLU

- Geographical coverage aimed for / allowed by the model:

☐ Local (city-level or smaller)
Model covers entire country with regional peculiarities, mainly relater to district heating. District heating systems in different towns are not physically interlinked. Therefore, in the model they are represented separately for each larger town but district heating as such is represented for entire country.
☐ Regional (state-level)
☒ National
☐ CEE
☐ EU
☐ Global
☒ Other Includes energy import-export links with other countries

- Usual timeframe of the modelling:

Changeable from current year until 2050 and more

- Usual time resolution for modelling:

5 seasons (1 season January-February, 2 season March-April, 3 season May-August, 4 season September-October, 5 season November-December. Splitting of the year is made in order to reflect in the best way variation in heat and electricity demand, water availability in rivers, etc.), 2 typical days within a season, 20 time slices within a typical day plus 3 wind probability conditions for each time slice. Totally 600 time slices within a year. 20 time slices in a day are chosen in order to reduce size of the model which already reaches maximum possible limits of the MESSAGE package. (Night hours were grouped into two time slices because there are no significant changes in parameters under consideration)

- Analytical approach of the model:

☐ Macroeconomic top-down
☒ Techno-economic bottom-up
☐ Somewhere between top-down and bottom-up

- Approaches followed by the model:

☐ Accounting
☐ Simulation
☒ Optimization

☐ (Techno-)econometric
☐ A combination, or other

- Possible driver for the abovementioned approach:

  Exogenously given demand for all energy and fuel forms in each branch of national economy including demand variation within a year, weak or day.

- Possible "utility function" for the approach:

  Discounted cost for energy supply side and additional measures that can be implemented on demand side within time period under analysis

- Mathematical methods that the model apply:

  ☒ Analytical optimization
  ☐ Heuristic optimization
  ☐ Agent-based simulation
  ☐ Monte-Carlo simulation
  ☐ System-dynamics simulation
  ☐ Others

- Point(s) of view reflected in the modelling approach (considering costs, interest rates...):

  ☐ Society as a whole
  ☐ End-user
  ☒ Others (e.g., utilities) Entire energy sector.
  Currently we use the same discount rate for energy sector and measures in demand sector. However, cost recalculation in order to take into account different interest rates/ discount factors in demand side sectors can be performed. This has to be done outside the model when preparing input data into model. Energy prices for demand sectors are not used in our model. We do not look to market equilibrium. Nevertheless, elastic demand can be also specified. This would allow searching for supply-demand equilibrium. This is not implemented because of lack of data for establishing of the elastic demand.

## 6.3.3. Structure of the model

- Overview figures showing the structure of the model:

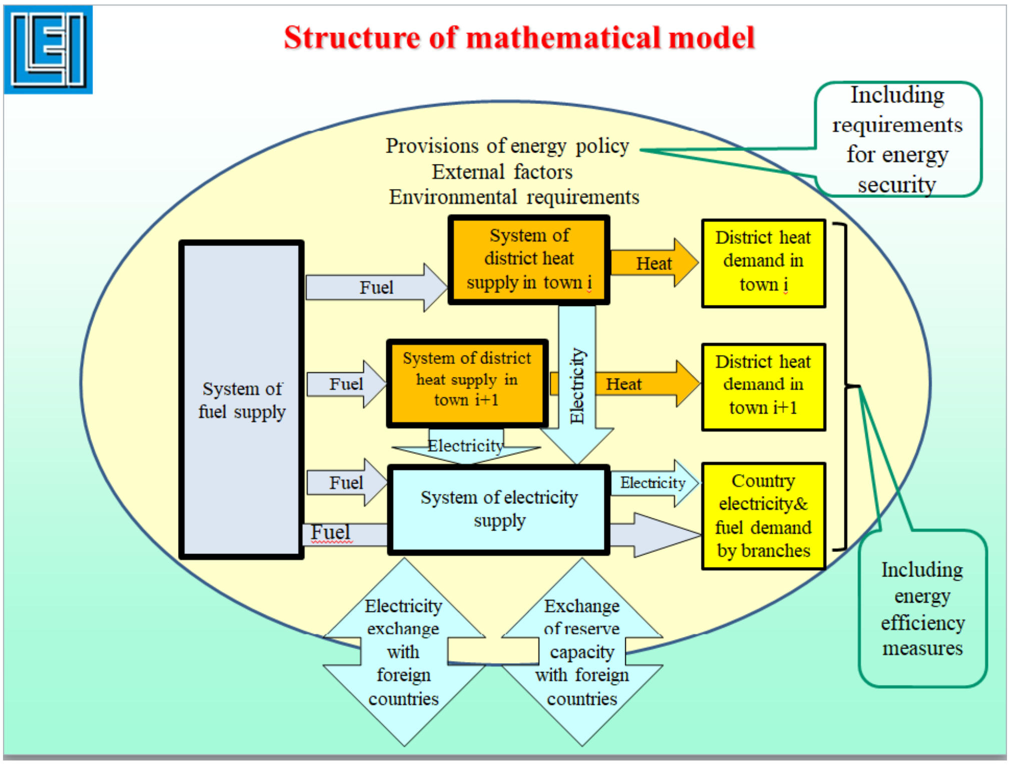


*Figure 8: Structure of the model-LT ENERGY model*

It is not possible to put into this file detailed supply chains that are used in all of these boxes. We attached only principal diagram illustrating modelling principles. In general, box "System of fuel supply" represents country chains of fuel supply to power plants, district heating boilers and all branches of national economy. Box "System of electricity supply" represents chains for electricity production and supply, including all existing and possible new power plants (with exception of CHP (combined heat and power)), electricity transmission and distribution grids in aggregated manner, electricity import-export links. Chain "System of district heat supply in town I" represents chains of district heat production and supply to consumers in town. Boxes representing demand includes exogenously specified demand for various energies and fuels and new possible measures for possible reduction of initially specified demand.

- Following interactions are endogenously modelled:

  Optimization. It means all interactions between all variables specified

- Following intermediate calculation steps are explicitly accounted for, i.e., visible, in the model's (intermediate) output:

  None

## 6.3.4. Structure of building and transport sector

*Table 13: Energy services in the building sector- LT ENERGY*

| Sub-sector | Energy Service | Energy service indicator |
|---|---|---|
| Residential | Final energy demand by fuel and energy types | |
| Tertiary | Final energy demand by fuel and energy types | |

*Table 14: Energy services in the transport sector-LT ENERGY*

| Sub-sector | Energy Service | Energy service indicator |
|---|---|---|
| Passenger transport | Final energy demand by fuel and energy types for entire sector | |
| Freight | | |

- Main input/output of the model:

**Building sector**

Main input and level of details:

Final energy demand by fuel and energy types with detailed variations within a time

Main output and level of details:

Demand reduction due to implementation of measures, cost for selected measures, changes in demand variation

**Transport sector**

Main input and level of details:

Final energy demand by fuel and energy types with detailed variations within a time

Main output and level of details:

Demand reduction due to implementation of measures, cost for selected measures, changes in demand variation

## 6.3.5. Input/output data

- Main problems or issues with the input data / data collection methods used for the model: (for building and transport sector)

  Data availability and consistency. Especially economic data

- Possible solutions the above-mentioned problem(s): (Building and transport sector)

  Not available

*Table 15: Categorization of the parameters included in LT ENERGY model*

| | Input | Intermediate | Output | Implicitly | Explicitly | Exogenously | Endogenously |
|---|---|---|---|---|---|---|---|
| Macro-economic data such as:<br>-Income/capita<br>-Growth/productivity/GDP | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Demographic data such as:<br>-Population<br>-Number of households | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Energy consumption of sector(s) | *X* | | *X (reduction of consumption)* | | | *X* | *X (reduction of consumption)* |
| *If necessary, please explain:* | | | | | | | |
| Energy services | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Societal costs and benefits<br>- employment<br>- life quality<br>- time consumption<br>- Others | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Environmental externalities<br>- $CO_2$ emission reduction effects<br>- Air pollution<br>- Other | | | *X* | | | *X for given demand* | *X emission reduction due to implementation of measures* |
| *If necessary, please explain:* | | | | | | | |
| Characteristics of energy techniques (e.g., capacity/ power, usage, efficiency factors or learning effect, or other) | | | | | | | |
| *If necessary, please explain:* | *We do not model explicitly building or transport sector.* | | | | | | |
| Energy prices or $CO_2$ prices | | | | | | | |
| *If necessary, please explain:* | *$CO_2$ price is used for emission trading sector. Building and transport sector is not emission trading sector. However, $CO_2$ prices can be easily introduced* | | | | | | |
| Explicit specification and modelling of policies (e.g. subsidy levels, energy taxes, standards) | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *If necessary, please explain:* | *Subsidies for demand reduction measures can be taken into account* | | | | | | |
| Demand elasticities | | | | | | | |
| *If necessary, please explain:* | *Elastic demand is not used because of lack of data.* | | | | | | |
| Behaviour (purchase/choice of technologies) | | | | | | | |
| *If necessary, please explain:* | | | | | | | |
| Behaviour (use of technologies) | | | | | | | |
| *If necessary, please explain:* | | | | | | | |

## 6.3.6. Data Validation

- Methods used for calibration and validation:

  Comparison of model output with available data for historical year/years

- Available sensitivity analysis for the model results and the discussed parameters:

  Upon selection of model user, i.e., sensitivity for all parameters used in the model can be performed

- Validation effort required in case the context of model changes:

  Comparison of model output with available data for historical year/years

## 6.3.7. Policy consideration

- Analysis that is carried out / possible to carry out with the model?

  ☒ Policy assessment
  Various policies can be introduced in a form of different constraints. For example, on use of renewables, on energy security, on efficiency improvements, etc. Solution shows whether policy measure gave expected result
  ☒ Policy selection
  Various policies can be introduced in a form of different constraints. Solution shows whether policy measure gave expected result. Having these results for various policies the best can be found
  ☒ Policy development
  Various policies can be introduced in a form of different constraints. Solution shows whether policy measure gave expected result. Having these results for various policies the best can be found
  ☒ Policy improvement
  Various policies can be introduced in a form of different constraints. Solution shows whether policy measure gave expected result. Having these results for various policies the best can be found
  ☒ Combination/others
  Various policies can be introduced in a form of different constraints. Solution shows whether policy measure gave expected result. Having these results for various policies the best can be found

- The following issues can be taken into account in the model:

  ☒ Policies impacting the technologies in the "stock": replacement of technologies (before they reached their lifetime: e.g., scrappage scheme), renovation/extension of a building...

Policies are formulated in form of various constrains and can be linked to selected variables. Remark: Given policy specification is rather soft. Therefore, answer is also soft. In principle we can reflect all or almost all policies which mathematically can be described in form of linear mathematical equations. Model allows entering additional user specified equations.

☒ Policies impacting the use of the technologies over the lifetime

Policies are formulated in form of various constrains

☒ Policies impacting structures

Policies are formulated in form of various constrains

☒ Standards (MEPS / labels)

Technologies that do not correspond to certain standards can be excluded from the set of possible technologies. Explicitly we consider technologies only in supply side. However, for example, introduction of A+++ fridges into HH sector we can model if we have data about electricity saving by these fridges in comparison with existing stock of fridges and overall electricity use by fridges in the country. Availability of data is the main problem.

☐ EPBD and national standards for building

Building stock properties can be taken exogenously by specifying final demand. For example, having information about existing building stock of certain quality we can specify heating demand more accurately. In addition, renovation of such buildings to reach certain standards can be also considered in the model as an optional efficiency measure.

☒ Subsidies

By changing input parameters or by entering additional relations

☒ Taxes

By changing input parameters or by entering additional relations

☒ Soft policies (e.g., information based)

Soft cost related bounds can be given. If policy is cost based and it can be described in form of linear mathematical bound violation of this bound can be foreseen by applying additional penalties or incentives.

☒ Sufficiency policies

We can model policies which can be specified in form of dummy supplier (see Figure 8) and model it as dummy supply that can be subtracted from energy or fuel coming from energy system.

### 6.3.8. Decision-makings in the model

**Building sector**

- Is the amount of energy service calculated/defined? If yes, based on which logic/assumption?

  Current version of the model does not represent details of building sector Final demand is given exogenously

- Is the technology (are the technologies) to deliver the energy service chosen/defined? If yes, based on which logic/assumption?

  No technologies inside of buildings are analysed in the current version of the model, however technologies that provide electricity or district heating are selected in energy production sector. For example, technologies for production of heat that are used for heating of buildings connected to district heating network are selected in supply side model. Selection is based on cost minimization criterion.

- Is the use of the technology (or the technologies) decided/defined? If yes, based on which logic/assumption?

No technologies inside of buildings are analysed in the current version of the model, however use of technologies that provide electricity or district heating are selected in energy production sector and their operation regime is found endogenously

- The logic/assumption is:

☐ Exogenous
☐ Calculated
☐ Can be impacted by policies

- Costs that are input parameters for investment decision:

No investments are modelled inside the building sector in the current version of model. However, we do modelling of measures that reduce demand in household. Their selection is cost based (investment, operation cost).

- The way the costs are transformed into market shares:

We do not model these technologies in our model

**Transport sector**

- Is the amount of energy service calculated/defined? If yes, based on which logic/assumption?

If you have in mind energy that drives vehicles, it is produced in energy production sector. Refinery is also part of energy production sector. If you mean mobility service, it is not analysed explicitly in the current version of model

- Is the technology (are the technologies) to deliver the energy service chosen/defined? If yes, based on which logic/assumption?

If you have in mind energy that drives vehicles, these technologies are chosen in energy production sector. If you mean mobility service, selection of these technologies is not analysed explicitly in the current version of model

- Is the use of the technology (or the technologies) decided/defined? If yes, based on which logic/assumption?

If you have in mind technologies that produce energy for vehicles their use is selected in energy production sector. If you mean mobility service, these technologies as well as their use are not analysed explicitly in the current version of model

- The logic/assumption is:

☐ Exogenous
☐ Calculated internally
☐ Can be impacted by policies

- Costs that are input parameters for investment decision:

No explicit technology representation is used in the current version of the model. Therefore, no cost is used for transport sector

- The way the costs are transformed into market shares:

### 6.3.9. Flexibility/complexity

- Flexibility of the model in terms of the changes in the modelling context? (e.g., changing the scale and/or scope of input and output)

  Flexible

- Complexity of the modelling approach:

  In terms of:

  Conceptual complexity (the mathematical and logical difficulty level)

  Less complexMore complex

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | X | | | |

  Detail complexity (the level of extensiveness of the model from included details)

  Less complexMore complex

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | X | |

- Trade-offs in case of increasing the complexity of modelling approach:

  Complexity has an impact to the model size. It has limitation.

### 6.3.10. User-friendliness and transparency

- Required efforts to make a complete model run:

  Minor, if no changes in data are required and no additional outputs is necessary to get from solution file

- Parts of the efforts that are not performed by the model itself, but outside the model:

  All these changes have to be performed by model user and inserted into the model.

*Table 16: Rating of user friendliness of the LT-ENERGY model*

| Aspects | Grade 1-10 (1: not user-friendly at all, 10: extremely user-friendly) |
|---|---|
| *Clarity* | |
| Meaning of results and inputs | *8* |
| Interface elements, guiding the user | *8* |
| Help function | *0* |
| *Generating results* | |
| Ease (number of user actions required) | *8* |

| | |
|---|---|
| Speed (calculation time) | *8* |
| Flexibility (capability of the model to run in different modes, or run for different data sections) | *0* |
| Formats (availability of predefined formats for various target groups) | *10* |
| *Analysis possibilities* | |
| Transparency of results and easy access to underlying data. | *8* |
| Graphical representation | *8* |
| Possibilities to perform analyses on the results in the model | *8* |
| Is it possible to generate reports on sections of results and inputs | *8* |
| Built-in sensitivity analysis | *8* |
| *Data management* | |
| Making modifications to inputs | *8* |
| Storing model runs integrally | *10* |
| Logging modifications | *8* |
| Sharing models with multiple users | *10* |

### 6.3.11. Sufficiency aspects

**Building sector**

- Feature(s) that could be interesting in the model approach in order to consider energy sufficiency aspects:

  We cannot highlight any feature. It is modelling trick that can be used in many other cases

- Main strengths of the modelling approach when modelling sufficiency:

  It is possible to evaluate detailed impact of sufficiency measures used in demand side to the supply side, as well to find corresponding price changes that are applicable to demand side. We model explicitly the entire energy sector. Sufficiency is human made decision and nobody models this decision-making process. What people do in their models? They represent human made decisions and look what impact it has to the system that they model. For example, car sharing. It is only possible to assume that people may make such decision and then it is possible to evaluate how utilization of cars has changed, analyse how much stock of cars can be reduced and how much this reduces production amount of car industries, etc. But this is only consequences of human made decision regarding sufficiency. Similarly, we analyse consequences of human made decision on development and operation of energy system. Yes, we do not analyse changes in car industry but we analyse changes in energy sector in details. In addition, we take cost into account and try to make optimal decision.

- Main limitations of the modelling approach when modelling sufficiency:

  Sufficiency in building sector can be taken in two ways:

a) By providing dummy supply which corresponds to energy saving due to sufficiency measures (cost can be taken into account as well. Cost in this case may correspond to willingness to reduce demand). Various sufficiency measures can be represented by corresponding dummy supplies.

b) By exogenously given reduced demand. (We have models for estimating demand, but they are not adjusted for explicit modelling of sufficiency measures. We can make some assumptions about this but usually we forecast demand without sufficiency measures. Because of this sufficiency measures as well efficiency measures, we model in supply model. Nevertheless, option for giving exogenously reduced demand exist).

- Expected improvement(s) to overcome the mentioned limitations:

  First it is necessary to find real limitations, formulate reason why these problems have to be solved in this model. Only then it is possible to say what improvements should be done.

- An appropriate alternative modelling approach for the current model to consider sufficiency aspects.

  Enhancement of sufficiency modelling can be done by adding explicit modelling of building sector to the current version of the model. But first of all, it is necessary to justify rationality of such enhancement. Here we have in mind rationality of putting everything into one model. Our approach is rather good and fit with the size limitations of the software. Technical potentials of sufficiency measures can be also estimated in other models and our model can be used for economic analysis of such measures and estimation of impact to energy system and to emissions from fuel burning.

- Advantages of a switch to this or these alternative(s):

  It may allow to analyse questions/problems in a different way or take into account factors that cannot be taken into account in the current model version.

- Disadvantages or risks of a switch to this or these alternative(s):

  Increased size of the model.

**Transport sector**

- Feature(s) that could be interesting in the model approach in order to consider energy sufficiency aspects:

  We cannot highlight any feature. It is modelling trick that can be used in many other cases

- Main strengths of the modelling approach when modelling sufficiency:

  It is possible to evaluate detailed impact of sufficiency measures used in demand side to the supply side, as well to find corresponding price changes that are applicable to demand side.

- Main limitations of the modelling approach when modelling sufficiency:

  Sufficiency in building sector can be taken in two ways:

  a) By providing dummy supply which corresponds to energy saving due to sufficiency measures (cost can be taken into account as well. Cost in this case may correspond to willingness to reduce demand). Various sufficiency measures can be represented by corresponding dummy supplies.
  b) By exogenously given reduced demand

- Expected improvement(s) to overcome the mentioned limitations:

First it is necessary to find real limitations, formulate reason why these problems have to be solved in this model. Only then it is possible to say what improvements should be done.

- An appropriate alternative modelling approach for the current model to consider sufficiency aspects.

  Enhancement of sufficiency modelling can be done by adding explicit modelling of transport sector to the current version of the model. But first of all, it is necessary to justify rationality of such enhancement. Secondly it would be necessary to reduce complexity of energy sector model in order to size of the model.

  We started development of transport model having an idea to make hard linking with energy model but realized that model size will be too big. Now we are working on household, industry and agriculture models as well on methods and ways how to link them into one system.

- Advantages of a switch to this or these alternative(s):

  It may allow to analyse questions/problems in a different way or take into account factors that cannot be taken into account in the current model version.

- Disadvantages or risks of a switch to this or these alternative(s):

  Increased size of the model

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[iv] https://iea-etsap.org/index.php/documentation
[v] For lighting, lumen demand is considered.