Understanding the gaps and addressing the potentials of energy sufficiency in "catching-up" European economies

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Abstract

While the role of energy sufficiency as an essential driver towards reaching climate goals has been discussed in the European context for a few years, it still faces obstacles to making its way towards policy agendas. On one hand, existing policies tend to focus on energy efficiency and the development of renewable energies, which are more clearly identified, thoroughly assessed and integrated into available scenarios. On the other hand, energy sufficiency is commonly perceived as a limitation to individual needs and thought of in terms of willingness for behavioural change, although the concept has also to be considered at the policy level, resulting in infrastructural changes. This paper addresses reasons and ways to bridge this gap in understanding energy sufficiency and its role in strengthening the climate mitigation actions, with a focus on two "catching-up" economies in Central and Eastern Europe: Hungary and Lithuania. It summarises results from the CACTUS project, which analyses the integration of sufficiency in the sectors with the highest energy consumption shares, namely building and transport. First, the paper examines the potentials of energy sufficiency regarding energy and climate policy goals in the transport sector and discusses the building of energy sufficiency assumptions in the perspective of a European convergence. Then, considering the crucial role that scenario development plays in framing climate policies, it analyses the methods and challenges for integrating these assumptions in scenario models. The paper also explores the path towards more ambitious mitigation strategies by providing exploratory quantitative and qualitative analysis of sufficiency potentials. The results of the project are expected to pave the way for the development of sufficiency policies by raising the awareness of policymakers on the sufficiency concept and its mitigation role.

Introduction

In the past 20 years, consumption patterns in the building and transport sectors have often offset successful energy efficiency policies. In the transport sector, cars can be a good example of this, with constant progress in the efficiency of vehicles, offset by an increasing number of cars, of their sizes, weight, power, and travelled distances (EEA 2019). This is particularly true in Central and Eastern European (CEE) countries, where "catching-up", i.e. reaching an average economic development, and thus consumption level of other European Union (EU) member states has been the priority of the past decades. In these countries, the building sector has remained a key emitting sector while transport has become the largest emitting sector with an increasing trend. Between 2004 and 2019, final energy consumption in the transport sector increased by 65 % in Lithuania and 36 % in Hungary, as a result of economic and freight growth, growing car ownership and increasing distances travelled, and related greenhouse gas (GHG) emissions had an increase of 58 % in Lithuania and 32 % in Hungary (Eurostat 2021a).

There has been little room for questioning whether those increasing trends were tailored to actual needs, or they may have been the result of unsustainable consumption patterns, with no dedicated reflection on the dimensioning or level of use of the actual services delivered through energy consumption. Such questions have not been integrated into the energy and climate modelling work that has been the basis for these countries' climate and energy strategies. Yet, energy sufficiency by reducing the level of energy services could play an important role to achieve climate neutrality by 2050 at the EU level (EU 2021) and on the path of deeper sustainability, beyond just climate aspects. The integration of sufficiency in energy modelling is still in its infancy, and there are significant modelling challenges to such integration, e.g. the need to apprehend soft factors and their relation to technical ones, which are of particular significance in the CEE region. This paper aims at addressing this policy and modelling gap, by analysing energy sufficiency in the CEE context with a view to supporting its integration into climate and energy scenarios of Hungary and Lithuania. It builds upon the results of CACTUS, a capacity-development and technical-dialogue project between energy sufficiency experts from France and Germany, and key scenario builders from Lithuania and Hungary (Association négaWatt 2020).

Energy sufficiency

There are various understandings of sufficiency in literature. They mostly relate to the purpose of setting living standards on a sustainable level and can refer both to the situation of meeting such a balance between nature and society (Sachs 1995) or the process to get to that balance (Fischer et al. 2013) and the strategy to implement that process (Thomas et al. 2017). Moreover, sufficiency could have the following approaches: a capping approach in relation to limitation of resources of various kinds and planetary boundaries (Rockström et al. 2009), a threshold approach in relation to the satisfaction of decent living standards (Rao et al. 2018) or a combination of both to set the reflection on energy sufficiency as the search for a level of energy services which meets both a floor related to individual needs and a ceiling related to collective limits (Darby et al. 2018; Spengler 2016).

On this basis and for the purposes of this paper and the capacity dialogue which it builds upon, which focuses on energy sufficiency as a leverage rather than a status, energy sufficiency can be defined as follows: energy sufficiency aims at keeping energy consumption at a sustainable level through an action on the services, such as the size of the car, its sharing or the shift to other modes, or the distances covered. It is mostly related to satisfying a decent minimum energy service level for everyone while keeping this level within limits that do not endanger the carrying capacity of the Earth. In OECD economies, energy sufficiency mostly aims at curbing the overall demand for energy services while generally improving the well-being of consumers, although that might challenge the relationship to well-being, focusing on the quantity rather than the quality of services accessed and goods accumulated, and require to aim for some redistribution of those services, considering the current inequalities.

In CEE countries, relatively moderate "living standards" may correspond to more sufficient patterns of consumer behaviour compared to those in Western European countries (e.g. higher reliance on public transport). Sustaining those services at such a level while aiming for higher consumer satisfaction could help avoid unfavourable developments (e.g. a general move towards higher distances travelled in individual transport modes). Sufficiency could also help address energy poverty issues and facilitate the path to higher energy independence. In 2017, 28 % of the Lithuanian population was unable to keep their home adequately warm (Eurostat 2022b), and 14 % of Hungarian energy consumers had arrears on utility bills, compared to the EU average of 7 % (Eurostat 2022a).

Starting from this perspective, the paper explores the potential for developing the role of energy sufficiency in the climate and energy strategies of countries such as Lithuania and Hungary, through its integration into the modelling of such strategies, with a focus on the transport sector. Following the guidance provided by literature on the different steps to be taken (Förster et al. 2019; Toulouse et al. 2019), the paper addresses:

- the need to start with formulating the potential and justification for sufficiency, through an analysis of the status quo of energy consumption patterns and existing policies and measures that could relate to sufficiency in the two countries, allowing for a better understanding of the possible gap to be bridged;
- the identification of relevant parameters or indicators relating to the measure of energy sufficiency levels and their possible evolution in those specific national contexts;
- the efforts to integrate corresponding sufficiency-related assumptions in existing scenarios that are used to elaborate long term energy and climate strategies in the two countries, and the methodological issues arising from the recalibration or adaptation of models to fit that purpose;
- the lessons to be learnt from this integration regarding the chain of impacts of sufficiency and the capacity of models to characterize them to better inform policymakers on needs and potentials for energy sufficiency measures.

When considering energy sufficiency as a mean, or a leverage to meet sustainability objectives such as reduction of GHG emissions, the scope of actions envisioned mostly lies in the following distinction between changes that can occur in the energy chains that draw energy services from energy resources: sufficiency relates to changes in the level of energy services to be delivered, as opposed to energy efficiency, which relates to changes in the performance of delivering a certain level of energy service with the least resources (Association négaWatt 2017). This is not always straightforward, as some actions might affect both the performance of delivery and the quality of energy services: for the purpose of the project, we tend to consider them as part of a sufficiency approach. More concretely, in the transport sector, energy sufficiency encompasses the reduction of mobility services (e.g. smaller vehicles, fewer trips, shorter distances), while energy efficiency corresponds to consuming less energy for the same service (more efficient vehicles).

In contrast to energy efficiency, which is more traditionally recognised as a positive leverage to reduce energy and GHG footprints while bearing social and economic benefits, energy sufficiency is often perceived as a restriction to individual needs and wants without clear benefits or even a challenge to social welfare or economic prosperity (Toulouse et al. 2019). Moreover, sufficiency is often wrongly understood as being only determined by individual behavioural changes and willingness, and therefore difficult to handle in models, scenarios and policymaking, when it actually also relates to policies and infrastructural changes. In the CEE region, while it could be a chance to not copy unsustainable practices, it could also be perceived as a barrier to development and catching up. By researching the sufficiency potential in the Hungarian and Lithuanian context and raising its visibility with key scenario builders and policymakers, the project is also raising awareness on the benefits that can arise from sufficiency.

CEE context

The first step of any work on sufficiency potentials and the assessment of their possible impact in climate and energy strategies is to characterize the status quo of energy consumption, identify its drivers and question these in regard to existing or projected policies relating to energy sufficiency leverages. This is particularly important in the specific context of countries like Hungary and Lithuania, where the level of energy services could be regarded as lagging behind sufficient levels for part of the population but driven by trends that might not fulfil sustainability objectives.

ENERGY CONSUMPTION AND ECONOMIC CONTEXT OF CATCHING-UP ECONOMIES

The economic development of catching-up economies, Lithuania and Hungary, is faster than the EU-27 average in terms of increase in the gross domestic product (GDP) and energy consumption in the transport sector (Figure 1 a). While the GDP grew by 20 % in EU-27 during 2005–2019, the increase was about 29 % in Hungary and 48 % in Lithuania (Eurostat 2021b). The increase of final energy consumption by transport was only moderate in EU-27 (3 %), but rather steep (26%) in Hungary and even steeper (55 %) in Lithuania (Eurostat 2021c). Since 2013, the growth of GDP has been accompanied by faster energy consumption for transport in Lithuania, but the increase of energy consumption by transport slightly lacked behind in Hungary. The EU-27 economies demonstrated some decoupling of growth of GDP and energy consumption by transport over that period.

The improving living standards (GDP per capita) is understood to be the main driver of the increased sub-sector of passenger cars as well as travelling and related distances in passenger-kilometres (pkm) per capita (Figure 1 b). Over 2005–2019, the inhabitants of Lithuania travelled, on a yearly average, slightly longer distances (11,749 pkm per capita) than the average in the EU-27 in general (11,278 pkm per capita), while those of Hungary covered shorter distances (8,416 pkm per capita). Regarding modal split of passenger transport, catching-up and EU-27 economies have similarities, being dominated by passenger cars, followed by buses and trains. The share of cars in total passenger transport was the highest in Lithuania (91 % in 2019), but it increased the most in Hungary (from 64 % 2005 to 72 % in 2019) mostly to the expenses of trains and, partly, buses. In 2019, the relevant modal share of coaches and buses in Lithuania (8 %) was almost at the level of EU-27 (9 %) and less than half of the share in Hungary (20 %). Hungary sustained some favourable patterns of consumer behaviour, such as the higher reliance on public transport and lower car use (compared to the average EU-27 levels). In Lithuania, travelling by bus is not popular, as buses are considered old and inconvenient. Instead, people use their own cars. In 2019, 536 passenger cars per 1,000 inhabitants were registered in Lithuania, compared to 390 in Hungary. Although both countries have their own characteristics, a common feature is that energy demand in Lithuania and Hungary is growing faster than in the EU-27, and it appears to be driven, especially in the transport sector, by unfavourable trends regarding sufficiency leverages such as the distances covered or the share of modes. As this evolution of consumption is not in line with the energy and climate objectives of those CEE countries, it is relevant to question the energy sufficiency potentials for curbing these trends.

RELEVANT STRATEGIES AND POLICIES IN THE TRANSPORT SECTOR

The long-term climate and energy targets of Lithuania and Hungary, set out in their National Energy and Climate Plans (NECP) and Long-Term Strategies (LTS), are similar. Both countries aim for energy independence and wish to achieve net-zero emissions by relying mostly (90 %) on renewables (Hungarian Ministry of Innovation and Technology 2020a, 2020b; Ministry of Environment 2019). In addition to the large-scale electrification of the economy, which would be based in Lithuania exclusively on renewables and in Hungary partly on nuclear energy, energy efficiency improvements would also play a significant role. Decarbonisation of transport is planned mostly through electrification and

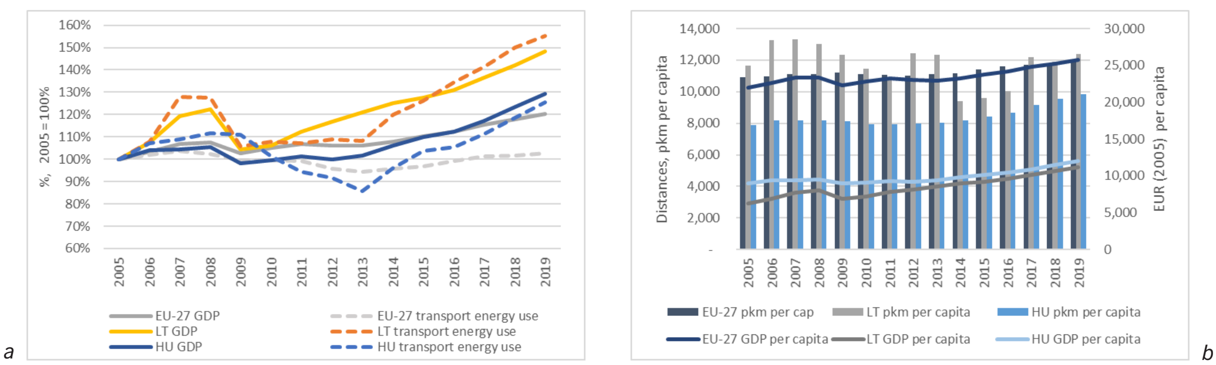

Figure 1. Key statistics of catching-up and EU-27 economies (DG MOVE 2021; Eurostat 2021b; 2021c).
a: Index of GDP and energy use in transport in Lithuania, Hungary and EU-27, % (2005=100 %).
b: Distances travelled in relation to living standards.

the deployment of new and more efficient technologies in both countries. Lithuania aims to phase out fossil fuels in the medium term (2040) including road transportation (Seimas 2021). In the short-term, public taxis and ride-sharing services shall switch to using renewables, and the electrification of railways is expected. The policy measures in Hungary mainly target electrification in public and individual transportation, modal shift, and the development of intermodal transport by providing tax advantages for combined freight transport. In the longer run, the Hungarian LTS envisages the increased role of hydrogen use as a fuel, especially in the long-distance freight and passenger transport segments.

Some measures, which can correspond to the sufficiency approach outlined, are also included in the strategies, such as encouraging the reliance on public transport, biking and walking, the promotion of car-sharing, car-pooling, bike-sharing and more efficient transport planning. The Lithuanian NECP refers to changing consumer behaviour also in relation to eco-driving and promotion of inland waterway transport. The Hungarian Energy Strategy emphasises that the promotion of telework can contribute to the reduction of transport energy use (Hungarian Ministry of Innovation and Technology 2020c). Policies aiming at reducing private transport demand through improving the quality of service in public transport, and the support of soft mobility by providing better infrastructure and creating low-traffic zones also appear in related strategies (BKK Centre for Budapest 2015).

Nevertheless, sufficiency, as a policy objective and as a means to question the overall level of service demand, has not yet appeared on the Lithuanian and Hungarian agendas. Accordingly, sufficiency has not been integrated into climate and energy models used to elaborate the national decarbonisation strategies of both countries. Hungary's NECP, albeit stressing the importance of decoupling economic growth and energy consumption, even states that economic growth should not be constrained by limiting energy use in the transport sector.

Highlighting the role of sufficiency as a key driver next to efficiency and renewable energies may be essential to estimate its potential in the local context and to explore its consideration into climate and energy scenarios of the two countries. Eventually, sufficiency could help to achieve decarbonisation faster and at lower costs, and ensure that the additional emissions from the ever-increasing demand do not offset the gains from the efforts of greening the sector.

Preparing for the integration of sufficiency in energy system models

Energy system models are used to project the energy demands and to explore the potential paths towards the reduction of energy consumption and GHG emissions. In contrast to energy efficiency, which is already widely integrated in energy models, energy sufficiency is still finding its way into energy modelling. It was first introduced and discussed through aggregated simulation models, such as in the French négaWatt scenario (Association négaWatt 2017), which uses an ad hoc model designed in a way that fits the building of sufficiency assumption. It is more challenging but crucial to discuss the way sufficiency could be introduced in models that have historically not been designed with that specific focus. This may be particularly far reaching for complex macro-economic models. Previous analysis suggests that such integration into more widespread types of models used to develop national scenarios, such as object-oriented cost-optimisation models can be done, but is not straightforward.

In this project, we have explored the potential strategies for integrating sufficiency in the existing models. The most direct one is to change parameter settings (e.g. ownership rate) to reflect evolutions related to sufficiency leverages. As this is dependent on the existing structure, deeper changes would call for a logic upgrade to integrate additional sufficiency aspects. Finally, the integration of sufficiency might need the implementation of a completely new logic, at least in some parts of the model, when its current logic does not allow to properly reflect some sufficiency-related aspects. This paper focuses on the first approach, as its depth of implementation fitted the limited and exploratory scope of the project. It consists in generating sufficiency-related leverages in scenarios by integrating energy sufficiency assumptions that could translate in the terms of the existing parameters.

In this approach, two main difficulties need to be overcome. First, sufficiency-related assumptions must be described in terms that fit the logic of the models, which mostly means in terms of equipment, such as vehicles and the related infrastructures and, if the model allows for it, intensity and/or duration of use. This is an objective of the selection of indicators, as discussed in this section. But also, the assumptions need to be introduced, either exogenously or through some internal build-up, in a way which must be consistent with the cost optimisation approach – whereas the cost or cost-implications of some sufficiency options, such as reducing the distances travelled, are not easy to grasp.

SELECTING RELEVANT ENERGY SUFFICIENCY INDICATORS

Within this work, a bottom-up approach was followed to discuss the fundamentals and overall key considerations for including sufficiency assumptions in energy and GHG models and scenarios. Prior to developing quantitative and qualitative reasoning, to project sufficiency oriented evolutions and discussing how they could be reflected in models, indicators are needed. As the purpose of the project was not to discuss per se sufficiency levels through the definition of decent living standards (e.g. in the sense of Rao, 2018) but to explore the potential for sufficiency leverages to contribute to the objectives of sustainable energy and climate strategies, the indicators sought for are meant to describe the evolution of energy services delivered through mobility, both in quantitative (e.g. pkm per capita by distance) and qualitative terms (e.g. reason for travel), and the related evolutions of mobility patterns (e.g. development of teleworking or local tourism).

The selection of relevant sufficiency indicators thus appears as preliminary work to further assess sufficiency potentials and build the associated assumptions, identify socio-political drivers and justify the feasibility of the projected changes. Such a process allows for considering the national context at each stage but also bearing in mind the issue of energy poverty.

Reasoning on sufficiency implies examining energy services, which can lead to work on new indicators and result in bringing to light new drivers and levers. The first stage of a bottom-up approach consists in identifying, discussing and selecting a series of indicators to be used in elaborating sufficiency assumptions. The project drew on an initial list of sufficiency-related indicators, previously established within a larger network of partners around a European sufficiency-based scenario (Marignac et al. 2021), that was used as a starting point for this project. This list was derived from reflections on how one can differentiate energy sufficiency from energy efficiency, in order to make energy sufficiency explicit in scenarios. In addition, beyond the obvious end-use parameters, the reflection was motivated by the desire to study the obstacles and levers as well as the framework conditions. This initial list was discussed with the partners in the light of target countries' contexts. The list included 25 indicators both for passenger mobility and, to a lesser extent, for freight. The indicators were then organised by categories corresponding to various types of sufficiency drivers they could relate to, ranging from the evolution of needs (e.g. the number of trips, or the number of telework days) to the equipment and level of use (e.g. number of persons per car), the enabling infrastructures (e.g. kilometres of bike paths), the incentives and regulations (e.g. tax break for commuting) and even social perceptions (e.g. violence in public transports).

Then, the usefulness of these indicators in elaborating, assessing and justifying assumptions as well as the availability of required data was discussed in a technical dialogue with all partners. At this stage, indicators and levers for change were characterised, according to whether they are quantifiable or not, in the perspective of their integration to form assumptions into scenarios. The distinction was made between quantitative indicators for which data might be available (e.g. number of persons per vehicle) and qualitative indicators, which are expected to play an important role in shaping assumptions and explaining the various scenarios but cannot be implemented in models quantitatively. This stage was complemented with data collection for each target country, identifying when quantitative data is missing or not consolidated enough.

Once indicators were organised by types of drivers and characterised as quantitative (technical) or qualitative (soft), the interrelations and interdependencies between them were discussed – in light of national contexts – in order to identify which indicators (especially soft ones) may have an impact on others when elaborating 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. This theoretical work was preliminary to the modelling work. Although the structure of the models used in Lithuania and Hungary, and the way they could accommodate with these indicators, was part of the background discussion, this first step was carried out independently of the features of existing models in order not to restrict the thinking. It mostly served to prioritise indicators for the quantitative phase of assumptions building described in the next section, in the sense of choosing those indicators that would best fit for this purpose while capturing, through the identified interrelations, the broader picture of sufficiency leverages possibly at play.

DEFINING ENERGY SUFFICIENCY ASSUMPTIONS IN THE HUNGARIAN AND LITHUANIAN CONTEXT

The potential of energy sufficiency in the Lithuanian and Hungarian transport sector was then discussed based on a selection of prioritised quantitative sufficiency indicators from the list previously established, for which data was available and integration in scenarios were thought to be manageable in a relevant way. Target levels for selected indicators were derived from the combination of three perspectives:

- At first, theoretical sufficiency potentials were analysed through characterisation of possible level ranges of energy services for 2050, as described through the chosen indicators. These "sufficient target levels" were extracted from literature, mainly stemming from the main 1.5 degree international decarbonisation pathways without large-scale artificial negative emissions or significant temperature overshoot (Grubler et al. 2018; Kuhnhenn et al. 2020; Millward-Hopkins et al. 2020) and made explicit in a detailed dashboard. Assumptions and drivers justifying those levels were detailed in the dashboard, when available, together with the corresponding key enabling policies, taken from those scenarios but also relevant literature (e.g. Thomas et al. 2019 and Mattioli 2016).
- These levels and the approach taken by the different sources, sometimes leading to wide ranges, were then discussed together with the detailed assumptions justifying them with regards to their relevance in the national context. While some of the theoretical target levels were country specific, none of the sources had an explicit country specific analysis and the justifications and drivers remained often theoretical, with few best practice examples. Levels and assumptions were also compared with those for France and Germany from the major sufficiency-based scenarios for these two countries (respectively Association négaWatt 2017, and UBA 2020). In those two pieces of work, the rationale behind assumptions was much more detailed and adapted to the national context, allowing for experience from those exercises to be shared with local scenario builders from Hungary and Lithuania.
- Finally, the historical trends for each indicator for Hungary and Lithuania were gathered and analysed with regards to the local socio-cultural and economical context, with a view to projecting possible trends and discussing the potential for sufficiency-based evolutions.

Theoretical target levels characterized through the first steps and assumed target levels stemming from the detailed dashboard and technical dialogue are explicit in Table 1.

As a result, it is assumed that by 2050, the total transport demand could increase in both countries compared to 2017, reaching about 15,000 pkm per capita. The assumed value is close to identified theoretical sufficiency levels from literature (Table 1). A similar process was carried out for all transport modes in each country. Through this process, 2050 sufficiency target levels tailored to the national context of each country for each prioritised sufficiency indicator could be proposed as the basis for integration within local scenarios. A more detailed description of forming the assumptions for the specific indicators are described in Konstantinaviciute et al. (2022) and Bartek-Lesi et al. (2022).

It is important to stress that these values are the first assumptions, which could be further refined through the analysis of the applicable policies and their estimated impacts on passenger transport demand, which could be the subject of future research. However, these values can be used in the scenario mod-

Table 1. Selected energy sufficiency indicators for the transport sector and assumed target levels for 2050.

Indicator	Sufficient target levels for 2050 based on literature	Lithuania		Hungary	
		Base year (2017)	Assumed target level for 2050	Base year (2017)	Assumed target level for 2050
Number of persons/car	2 – 3 [a, b, d]	1.35	1.6	1.5	1.7
Number of cars/capita	0.34 [b]	0.48	0.5	0.22	0.3
Pkm/capita	LT: 16,218 [b], HU: 17,935 [a]	12,208	15,000	9,341	14,499
Pkm by car/capita	LT: 8,674 [b] HU: 1,077[5, b] – 7,526[5, c], 1,710[6, b]-23,878[6, c]	11,088	11,500	1,415[1] 4,774[2]	988[1] 5,181[2]
Pkm by motorcycles and scooters/capita	473 – 560 [b]	Not available	Not available	183	255
Pkm by bus/capita	LT: 1,968 [b] HU: 2,154[5, a], 3,420[6, a]	602[1] 367[2]	1,500	477[1] 1,392[2]	706[1] 2,897[2]
Pkm by rail/capita	LT: 1,366 [b] HU: 2,154[5, a], 3,420[6, a]	150	700	311[3] 789[4]	951[3] 2,521[4]
Pkm by air/capita	581 [c] – 1,841 [b]	628	1,000	Not available	1,000
Pkm/capita for non-motorised mobility	Not available	Not available	200	Not available	564

Note: 1 Local, 2 Long-distance, 3 Tram/Metro, 4 Rail, 5 Urban, 6 Rural.

Sources: a) Millward-Hopkins et al. 2020, b) Grubler et al. 2018, c) Kuhnhenn et al. 2020, d) Association négaWatt 2017.

els (possibly combined with sensitivity analysis) to have an idea of the scale of possible savings sufficiency can bring, both in terms of energy consumption and carbon emissions.

Building energy efficiency assumptions in scenarios

The next step consists in discussing the way the sufficiency-related assumptions and 2050 target levels on sufficiency-related indicators developed in the previous stages could be introduced in existing models. These models have been used or could be used to build the scenarios backing national climate and energy strategies in each of the partner countries such as the NECPs as previously described. The discussion starts with an overview of the status quo of the tools and models used by partners and available for such scenarios in Lithuania and Hungary from a sufficiency perspective. The analysis focuses on two bottom-up, optimisation models, where end-use demand is mostly exogenous, allowing for considering sufficiency-related changes in this demand and their handling by the models and identifying the potentials and barriers to the introduction of sufficiency assumptions in the modelling approach. This analysis is followed by subsections presenting the integration of the assumptions and the lessons learnt.

STATUS-QUO OF THE ENERGY MODELS IN LITHUANIA AND HUNGARY

In Lithuania, a linear-programming partial equilibrium optimisation model developed with MESSAGE modelling software was used for the transport sector. This bottom-up model aims to determine how the transport sector should develop to achieve a set of goals with the lowest costs (Neniškis et al. 2021). The model was designed to be integrated into an overall energy sector model but can also work alone. Calculations are based on the minimisation 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. Modelling vehicles by manufacture year gives the ability to account for the changes in vehicle age distributions. 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. In addition, cars are differentiated by size, based on the Euro Car Segments. Fuels include diesel, petrol, CNG, electricity, hydrogen, ETBE (ethyl tert-butyl ether), bioethanol and biodiesel. Biofuels and conventional fuels are blended in the model. To enable modal shift, Daly's travel time budget approach is implemented, which is based on Zahavi's idea that on average people spend a fixed amount of time for travelling, through history and societies. The travel time budget is modelled as a resource required by vehicles in addition to energy to produce trips (Daly et al. 2014).

In this modelling approach, the travel time budget could be seen as a proxy for articulating energy consumption and mobility services. However, whether shifting to more sufficient mobility patterns is consistent with the constant travel time budget conjecture or not (through changes such as telework) is a matter for discussion: the model, therefore, relies on the need to make an exogenous assumption on the evolution of this time budget (constant or not) instead of allowing to question it.

Beyond this intrinsic methodological issue, the model is currently limited in the assessment of sufficiency or the level of energy services due to the lack of details regarding sufficiency-related parameters – especially compared to technology and efficiency-related ones. The choice of vehicles is primarily determined by two factors: cost-effectiveness and travel time budget limitations. Furthermore, spatial resolution is limited to one node, i.e. only travel within the country as a whole is considered, without any disaggregation, apart from short and long-distance travel. Such disaggregation, though it requires major modifications of the model, which fall out of the scope of the project, is nevertheless possible. For instance, higher spatial resolution would allow for the introduction of differentiated assumptions on the evolution of pkm depending on the various lengths and purposes of the trips. However, there is a trade-off, as to increase the spatial resolution, the level of details has to decrease somewhere else since the model size is already at software limitations.

Nevertheless, the impact of some sufficiency assumptions on fuel consumption, GHG emissions and transport expenditure can be investigated with this model. This could be done through the effects of car-sharing (by changing the vehicle occupancy rate), using vehicles for longer time (by adjusting the vehicle age distributions), modal shift (by adjusting the travel time budget), choice to drive smaller cars (by adjusting constraints on car classes) and less commuting (by reducing travel demands).

The HU-TIMES model, used in Hungary, is based on social cost minimising partial equilibrium mathematical optimisation (Loulou et al. 2016). The social aspect is primarily dealt with through the inclusion of externalities (GHG emission costs) and to the fact that the exogenous end-use demands must be satisfied at the least cost over a long-term time horizon. The model represents the national energy system including all energy resources, technologies for the supply side as well as for the demand side, which provide energy services, e.g. vehicles in case of transport. Exogenous variables are provided for the model, such as macroeconomic assumptions (e.g. European allowances).

As in the Lithuanian model, the demand for different transport segments (e.g. local passenger transport or large-distance freight transport) is met by the lowest cost technologies belonging to various transport modes. However, there are two main differences. Firstly, the Hungarian model does not incorporate the travel time budget concept; secondly, it defines two freight transport demand categories. Thus, in the case of the HU-TIMES model, transport requirements are assigned to four aggregate transport demand categories:

- local passenger transport (motorcycles, private cars, buses, trolley buses, trams, metro, suburban trains),
- long-distance passenger transport (motorcycle, car, coaches, train),
- short-distance (<50km) goods transport (light commercial vehicles (LCV) and heavy duty vehicles (HDV) with a maximum gross vehicle weight of less than 7 tons) and
- long-distance (>50km) goods transport (freight trains, LCV and all sizes of HDV).

Within the transport modes, a detailed representation of currently available and future technologies that can satisfy the end-use demand is defined, differentiated by fuel type, propulsion system and age group. The technologies are described by their year of entry (in case of new technologies), lifetime (determining the turnover of the vehicle stock), capacity, energy efficiency, and load factor (also taking into account return journeys without a load in case of freight transport). The model chooses between the available technologies based on the exogenous end-use demands and the energy policies to be assessed. Modal shift is possible up to a certain level, as a minimum and maximum range is determined for each transport mode within a demand segment. Since the HU-TIMES is based on total cost minimisation, while the sectoral end-use demand is given exogenously, decisions about future technology deployment are mainly decided by techno-economic attributes (i.e. costs and efficiencies) and socioeconomic constraints (possible share of a transport mode). Although the model does not include data on existing and future transport infrastructure, the technologies it selects provide some orientation as to what infrastructure developments will be required (e.g. additional EV chargers, hydrogen fuelling stations, etc.).

Like the Lithuanian model, the capacity of this Hungarian model to cope with the sufficiency-related assumptions is technically dependent on the level of disaggregation of the description of mobility that it contains (i.e. the nature, distance, mode etc.) so as to integrate detailed changes through differentiated leverages. There is no limitation in principle to develop the model in that direction, although such significant work was out of the scope of this project. Nevertheless, a more fundamental question lies with the proper accounting of sufficiency-based options in the objective function used for the optimisation: since this is based on a cost minimisation approach, the issue is whether the benefits and detriments of sufficiency leverages could be reflected in a way that is consistent with how other options are dealt with through an appropriate scope of costs and positive and negative externalities.

The two considered models, although tailored to specific needs and adjusted to national contexts, are based on more generic tools (respectively MESSAGE and TIMES) that are broadly used and representative of the modelling approach used for the development of energy and climate strategies in many, if not most countries. The introduction of sufficiency-related assumptions in the two considered models could therefore bear fruitful lessons on a broader level. It is however likely to raise much deeper methodological questions than tuning the models to reflect the assumed target levels on the selected indicators can answer. It is nevertheless useful, as a starting point, to test concretely the way the two models react to such a set of sufficiency assumptions.

INTEGRATION OF SUFFICIENCY ASSUMPTIONS AND PRELIMINARY RESULTS

The models have been designed to assess long-term energy scenarios and assist in setting up least-cost decarbonisation pathways, used in national energy strategy planning. Figure 2 presents an abstract and simplified overview of both energy system models, which are close to the concept of *sufficiency-efficiency-renewable energies* presented by Association négaWatt (2018). Both models have similarities: 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 assumptions could have a direct impact, reflecting the modified habits of the consumers and potentially reducing the demand for energy services. The energy

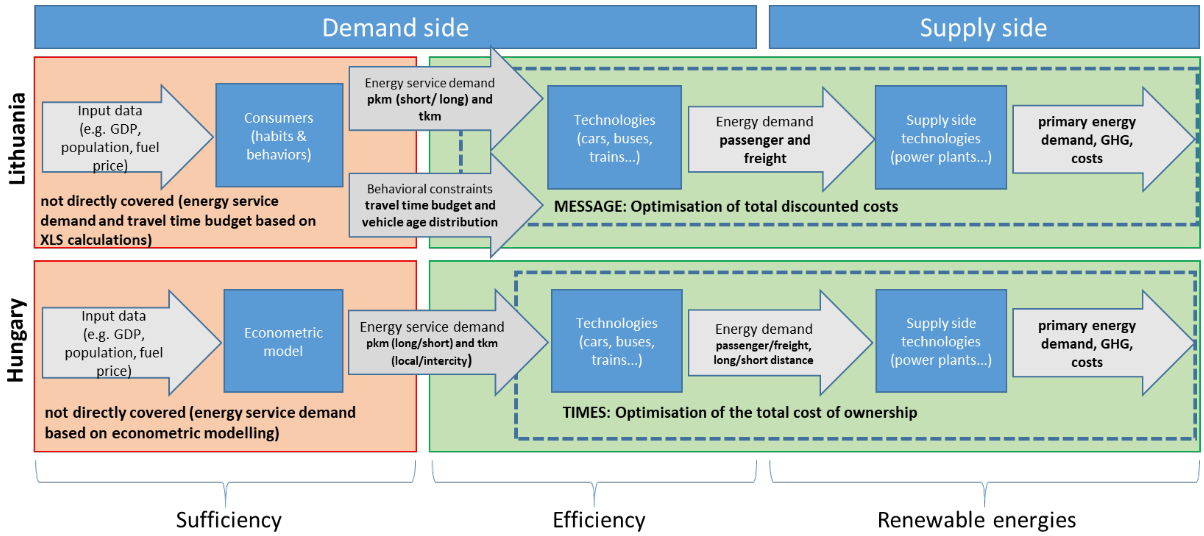

Figure 2. Approach in the transport model in Lithuania and Hungary.

services are then delivered by "demand side" technologies (e.g. cars, buses), in which energy efficiency has an impact on the energy demand. The supply side includes the use of renewable energies, to further reduce the primary energy demand and its carbon intensity.

Since none of the two models systematically covers the demand side, the results of the work on indicators, sufficiency leverages and target levels can be used to build a trajectory of demand related to the considered mobility services, then introduced as an external input for the modelling. In the case of Lithuania, the output of the transport model was used further as input of an optimisation supply side model (LT-Energy).

Integrating the possible impacts of changing consumption patterns (at the individual or societal level) into these models would require additional input regarding the internal drivers of the models, beyond the external estimate of possible sufficiency targets to set parameters changes. When the models are designed to reflect changes in the stock and use of equipment that could result from policy changes, such deeper implementation would require some mapping of the relevant policies and the estimation of demand reductions they can result in, so that they could be introduced in a similar way to existing efficiency or substitution options (e.g. the incentive to shift from a thermal to an electric car, that could be tuned through a subsidy level). Additional agent-based modelling might also be needed. Furthermore, to allow for these sufficiency-related changes to be comprehensively reflected in the optimisation sought for by the models would require some assessment of the corresponding costs and benefits, including the personal costs of behaviour change and the costs and benefits of policy implementation (e.g. improvement of infrastructure) and externalities, at least in a way that is similar and consistent with that of other leverages.

At this stage of the research, modelling sufficiency assumption in this manner could not be realised. Thus – as a first step – sufficiency "scenarios" were created through simple excel models to exogenously adjust energy service inputs from the models, based on the assumed sufficient target levels presented above e.g. in terms of pkm and tonne-kilometre. The models then used 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. In both models, the input parameters are adjustable thus providing the flexibility to consider the sufficiency assumptions, as long as the underlying parameters are already considered in the modelling.

In Lithuania, the preliminary estimations, taking into account only prioritised energy sufficiency indicators, show potential energy savings resulting from energy sufficiency implementation in transport sectors. If energy sufficiency is implemented in transport at the level of the prioritised energy sufficiency target levels for 2050 (shown in Table 1), energy and fuel consumption would decrease by 22 % in passenger transport, in comparison to levels assessed in one of the National Energy Independence Strategy (NEIS) scenario without any energy sufficiency measures.

In the case of Hungary, with the HU-TIMES model being a cost minimisation driven mathematical optimisation model, the costs associated with applying sufficiency measures – the willingness to accept and to pay for these measures, where relevant – should be incorporated into the model to endogenise energy sufficiency. As such cost data are not currently available, further studies would be required to monetise the additional costs, which might sometimes be zero or irrelevant (e.g. the cost of attending a meeting online). The analysis conducted in the project points both to the potential for such a development and its limitation. On one hand, it seems to some extent possible to improve the characterisation and assessment of some of the direct or indirect costs and benefits associated to sufficiency options. Though this would require dedicated economic or field studies and could only be integrated through some extensive development of the model to take these costs and benefits into account (e.g. the health benefits of modal shift to soft modes), some issues are bound to remain. For instance, the model would still fall short of integrating some aspects that would resist monetarisation, such as the change of urban environment that some of the sufficiency options could lead to. It would also struggle to deal with some macro-economic effects that would arise from deep changes in consumption patterns and levels.

The first calculations made so far had the goal to discover the magnitude of potential energy and GHG savings from selected sufficiency target levels that could be easily included in the model. These are the sufficiency assumption for total motorized passenger transport demand (e.g. through promoting teleworking), and policies shifting demand from individual car use to public transport modes (e.g. by reducing car traffic through the introduction of congestion charging, creating low traffic zones or car access restrictions). While the target level of overall transport demand would save 10 % of the energy consumption in 2050, the assumed shift from cars to public transport would result in a 2.5 % reduction in the final energy use. This is to be explained by the features of the model: since the HU-TIMES model is set to meet the requirement of nearly zero emissions in 2050, lower car transport entails a switch from individual electric cars to electricity and hydrogen fuelled buses and trains. Thus, although the electricity demand for cars reduces, the increased hydrogen consumption of (long-distance) public transport vehicles offsets much of the achieved energy savings, due to the high electricity demand for green hydrogen production. Typically, a more integrated framing of sufficiency, efficiency, and fuel switch assumptions upfront, which the model shows no obstacle to, would be needed to further assess the potential respective role of each of these all required leverages. Moreover, the development of such a model to cover the calculation of other externalities, such as raw materials that are a core issue regarding the cumulative consumption of the vehicles fleet, could be envisioned to bring additional useful information. While the analysis suggests that such developments could be implemented based on the tools and models tested in the project, it would require extensive work.

LESSONS LEARNT: GAPS, CHALLENGES AND POTENTIALS

Energy sufficiency could be found as a complementary driver to wider use of renewable energies, and to improve energy efficiency, in order to reach climate neutrality. However, further modelling work is needed to holistically assess the potential impact of energy sufficiency.

The work undergone in the project paved the way for a practical first step of integration of sufficiency-related assumptions into classical object-based, cost optimisation models through changes in parameters setting that reflect evolutions towards target levels for some indicators of energy services. This approach is dependent on the adequacy of the model's parameters to the object-oriented description of changes related to sufficiency leverages, an adequacy that could be improved through in-house modifications of the objects described and parameters in the models. However, as mentioned above, deeper integration and assessment of the possible impacts of sufficiency measures into the scenario models of the two countries require deeper implementation, that would need to be informed upfront by further research, including a thorough literature review of implemented sufficiency policies and their impacts to have a view on the possible demand reductions they can result in, as well as the relevant research in agent-based modelling. The assessment of the corresponding costs and benefits is also required to incorporate sufficiency measures in the models as mitigation options, and to assess the effects on total decarbonisation costs. Furthermore, it would be relevant to perform a more detailed assessment of the energy sufficiency potential and its impact on the energy supply sector. For this purpose, it is necessary to expand energy sufficiency research for all economy sectors in both breadth and depth, taking into account the individual characteristics of different consumer groups and the feasibility of sufficiency measures.

The literature related to mitigation potential assessments of sustainable user practices suggests that the task is challenging and further research is required to develop the existing models. Research to date has mainly focused on demand reductions at the global or multi-national level. However, exploring demand reduction opportunities at the national level is essential to support the development of energy and climate strategies and formulating national policies (Barrett et al. 2021). The experience gained within this project and through the exchange with other partners, allows expanding the scope of energy sufficiency research and increasing its efficiency.

In the modelling exercise presented in this paper, the exogenously determined sufficiency indicators were used to lower the projected demand trajectory for the transport sector in the models. Therefore, at this stage of the research, it was possible to study the scale of reductions that selected sufficiency target levels could facilitate on the energy demand and future technology need. The results for Hungary in the year 2050 suggest that the targeted passenger transport demand could result in remarkable cost savings compared to the reference, due to the lower number of vehicles needed to be put into operation and the avoided investments in RES-E capacity as a result of lower energy requirement. Although these comprise only a fraction of the total costs and benefits as they do not yet consider the above-mentioned social costs and benefits, this finding is in line with the results of Grubler et al. (2018) and Barrett et al. (2021) suggesting that lower demand for energy services can moderate the necessary expansion of electricity systems, making the transition cheaper and quicker, and can also help avoiding the need for risky and costly carbon removal technologies.

Discussion and future work

Exploring the integration of energy sufficiency assumptions into scenario models in Hungary and Lithuania provided useful scenario and policy insights. Analysing the relevant sufficiency indicators in the transport sector, as a key consumption sector and a particularly relevant area from a sufficiency perspective, revealed that efforts to preserve some favourable consumer habits by introducing relevant policies and providing higher quality services can help avoiding the expansion of unsustainable behavioural patterns and might lower the costs of meeting decarbonisation goals. Although some of the indicators suggest more sustainable consumption patterns compared to the EU average economic development, rising welfare is leading to higher demand for energy services, which might substantially reduce the gains from costly energy efficiency improvements. This is particularly the case for Hungary. Hence, it is important to further and more systematically investigate the role of demand for these services and the possibilities of influencing the way they are used to avoid unfavourable tendencies.

The possible effects of energy sufficiency policies can be analysed, to form a basis for further projection, only if relevant statistics are available. This would require the systematic collection and publication of data, such as the modal share of active mobility according to types of settlements, pkm for two-wheelers and air transport that are consistent with GHG emission statistics, or the number of hours worked in home office. Other important factors such as the spatial distribution of access and use of mobility services and its possible change are important but complex. This change should take into account the willingness and capacity to change of individuals, together with the relationship between these factors and the existence of needed infrastructures, whether hard (e.g. bike lanes, charging points for EVs) or soft ones (e.g. incentives, conditions of safety and security). Although the approach to sufficiency integration in existing models such as those examined in Hungary and Lithuania is very much focused on sufficiency as a leverage for change than as a pre-defined level to reach, research on the relationship between the foreseen sufficiency policies and issues of needs, wants and well-being also needs to be developed so as to reinforce the understanding of the potential for change.

The deployment of energy sufficiency measures is largely determined by consumer behaviour, which is influenced by many different factors under which infrastructure plays a key role in the mobility sector. Often these factors and consumer choices defy the economic logic that underpins choices in classical energy sector modelling. In order to more thoroughly and objectively assess and reveal the sufficiency potential in Lithuania, it is envisaged to further analyse the energy demand side and scope for implementing energy sufficiency measures in individual energy consumption segments for all economy sectors. In the nearest future, an analysis of energy sufficiency in electrical appliances and lighting is planned. From a longer-term perspective, firstly it is foreseen to continue the analysis of energy sufficiency in the transport sector by including more of the energy sufficiency indicators identified earlier (see also Marignac et al. 2021). For this purpose, it is necessary to survey the travelling needs and habits of the Lithuanian population as well as to collect the missing statistical information on non-motorised transport such as bikes. Secondly, a more detailed disaggregation of energy consumers according to various parameters is foreseen with an important role for differentiation of households according to income level and other living conditions. Once the full energy sufficiency potential is revealed, it could be integrated into the national decarbonisation strategy more systematically.

The modelling framework in Hungary also needs to be improved in order to consider a wider range of sufficiency measures. While the supply side of the HU-TIMES model is enriched with detailed representation of both transformation and end-use technologies, the demand side should be more representative to be able to model further sufficiency measures, to quantify more of the associated costs and benefits (including e.g. the decisions of consumers), and to learn from experiences on the effectiveness of related policy interventions. The first stage of modelling focused on the results for the year 2050, when the model assumes net-zero carbon emissions. However, it is also important to analyse the effects on the results for the years between 2020 and 2050, as demand reduction can bring about high fossil fuel and GHG emission savings before the net-zero energy system is reached. Furthermore, the HU-TIMES is a partial equilibrium model, where the end-use demands are determined based on exogenous macro parameters (e.g. population). However, some of the sufficiency measures can influence the macro parameters, therefore indirectly alter the end-use demand. Therefore, an expansion of the partial equilibrium towards a general equilibrium perspective would be necessary.

The initial modelling analysis in the target countries showed that sufficiency could contribute to reducing emissions by providing relatively low-cost emission mitigation options.

Conclusion

Although energy sufficiency has first emerged as a specific topic in research and scenario building practices in the context of the most advanced European economies, where discussing the ecological footprint of consumption patterns and the inequality of access to them was the most obvious, it has a broader relevance. Both from an environmental and social point of view, the notion of action on the level of energy services as a leverage to satisfy individual leaving conditions while remaining within planetary boundaries should make sense in any context. The analysis of sufficiency potentials in the specific case of catching-up economies like Hungary and Lithuania has therefore important value well beyond its national outcomes.

The work implemented through the project illustrates how the level of energy services delivered in the transport sector, although limited by lack of detailed data on some aspects, could be analysed. It could first be characterised and its past evolution could be described, and how this can lead to discussing its possible future, taking into account ecological and social factors, demographic conditions as well as the specific political or cultural contexts. The identification and selection of practicable sufficiency-related indicators, and the collective mind-mapping of the way they are interrelated and the levers of change they could evolve with, proved an effective way to elaborate on possible curbing from past increasing trends and discuss their feasibility and acceptability. This work was supported by detailed literature research, as well as a broader review of sufficiency target levels for 2050 that were also discussed in the larger network of partners of a sufficiency-based European scenario, ensuring that the possible levels of energy services assumed for 2050 in Lithuania and Hungary are consistent with converging levels assumed in various European countries. The 2050 sufficiency target levels were estimated on the basis of international literature often related to 1.5 degree pathways without negative GHG emissions. However, those pieces of work remain very generic. The sufficiency target levels, which are tailored to the national context of catching-up economies in CEE complement this work. They take an international relevance beyond Europe, particularly in emerging economies, which are also catching-up and looking for ambition decarbonisation pathways.

This eventually allowed for introducing context-tailored sufficiency assumptions in the modelling of national trajectories, touching on methodological issues regarding the consistency of doing so in object-oriented, optimisation models historically mostly developed to describe the supply side. The characteristics of the models (e.g. covered indicators, logic of the model, and consideration of policies) show some limitations in the type and range of sufficiency assumptions that could be included and the right representation of their impacts – which calls for deeper improvements of and reflection on the models that is way beyond the scope of this project. Nevertheless, the identification of these limits is a very important step towards better integration of energy sufficiency assumptions in existing models, and therefore also in future scenarios, which will provide information on the evolution of national energy and climate strategies in European countries.

The use of existing trajectories to assess the sensitivity of their results to the introduction of such sufficiency assumptions already provides interesting results. However, since these assumptions only cover some specific aspects of sufficiency potentials and, in the case of Hungary, were introduced in trajectories that already meet climate objectives, these results measured in 2050 remain short of reflecting the full impact over cumulative emissions of sufficiency-related options, compared to other leverages. The European scenario project, being currently developed by a network of partners led by Association négaWatt, aims for a more comprehensive representation of the full potential of sufficiency. It builds upon the findings of this project at all levels, from the identification of relevant sufficiency indicators and their inter-relations to the proposal of sufficiency levels in the form of corridors, and the building of assumptions adapted to various national contexts.

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