Integration of sufficiency into energy modelling tools.

WP3 report from “Integrating Energy Sufficiency into Modelling of Sustainable Energy Scenarios

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Project overview:
Integrating energy sufficiency into modelling of sustainable energy scenarios

The project was funded by the Baltic-Nordic Energy Research Program and took place 2020-2022. The project partners were Green Liberty (Latvia), INFORSE Europe (Denmark), Lithuanian Energy Institute (Lithuania) and Aalborg University (Denmark). The project was coordinated by Aalborg University. The project had an observer group with members from AirClim (Sweden), Finnish Nature Conservation Society (Finland), Naturvernforbundet (Norway), Association négawatt (France), and Stockholm Environmental Institute (Tallinn Office, Estonia).

The project objectives were:

1. Integrate sufficiency aspects into energy modelling tools applied for development of sustainable energy scenarios
2. Develop modified Danish, Latvian and Lithuanian national sustainable energy scenarios, which build upon the combination of sufficiency, efficiency and renewable energy
3. Create national policy dialogues among public and private actors in the Nordic and Baltic countries about energy scenarios that include energy demand changes from a sufficiency perspective and discuss the feasibility of these scenarios and the possibilities and limitations for socio-economic and regulatory changes enabling transition towards these scenarios
4. Disseminate the methodology for integration of sufficiency into energy modelling tools and development of scenarios, and disseminate the experiences with developing and applying these tools and scenarios to Nordic and Baltic stakeholders and to scientific journals

The following reports are available from the project:

Systematisation of experiences with energy sufficiency initiatives (Work package 2):
The report presents the applied understanding of energy sufficiency in the project and gives a literature-based overview of energy sufficiency actions within energy consumption in households and within mobility respectively. Furthermore, the report presents data, which enables integration of sufficiency actions into energy modelling.

Integration of sufficiency into energy modelling tools (Work package 3):
The report describes how sufficiency-based changes in energy demand within energy consumption in households and within mobility can be quantified at national level and can be included through exogenous and endogenous modelling approaches in EnergyPlan and MESSAGE modelling tools.

Development of adjusted national sustainable energy scenarios (Work package 4):
The report analyses how much energy sufficiency measures can contribute to the reduction of national greenhouse gas emissions. The report presents revised national sustainable energy scenarios for Denmark, Latvia and Lithuania based on the EnergyPlan and MESSAGE modelling tools with the integration of energy sufficiency.

National policy dialogues (Work package 5):
The report presents the developed concepts for national policy workshops aiming at exploring how policy measures can influence preferences for sufficiency-based reductions of energy consumption. Furthermore, the report presents the experiences from the national policy dialogues organised in Denmark, Latvia and Lithuania.

Dissemination to other Nordic and Baltic countries (Work package 6):
The report presents the experiences from a two-day workshop with dissemination of perspectives on and methods within energy sufficiency to Baltic and Nordic countries that were developed in the project. Furthermore, the report presents the joint cross-national discussions and experience sharing among the participants at the workshop. Finally, the report presents ideas for further research and knowledge development within energy sufficiency.

The reports can be requested by sending an email to the project coordinator Michael Søgaard Jørgensen, Department of Planning, Aalborg University, Denmark at msjo@plan.aau.dk

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1.0 Introduction

The report has been written as part of the project “Integrating energy sufficiency into modelling of sustainable energy scenarios”, which is funded by The Baltic Nordic Energy Research Programme. The project is coordinated by Aalborg University and conducted in collaboration between Aalborg University, INFORSE-Europe, Lithuanian Energy Institute and Green Liberty Latvia. The aim of the project is to contribute to the development of more advanced strategies for systemic, sustainable transition of energy production and use, based on new social practices that reduce energy consumption. This contribution is met through developing new, improved national 2030 energy and climate scenarios based on the feasibility of reaching a net-zero emission and 100% renewable energy system by 2050. Besides building upon existing national sustainable energy scenarios, the new scenarios developed in the project integrate experiences from recent national sustainable energy practice initiatives within the categories; household energy consumption and mobility.

This report is a deliverable of work package 3 “Integration of sufficiency into energy modelling tools”. It describes how sufficiency-based changes in energy demand within energy consumption in households and within mobility can be quantified at national level and can be included in an exogenous energy modelling tool (EnergyPLAN) and an endogenous modelling tool (MESSAGE). Furthermore, the report presents a survey on the willingness to reduce energy consumption among Lithuanian citizens.

In this report, we will narrow down the analysis of sufficiency actions reported in work package 2: “Systematisation of experiences with energy sufficiency initiatives”, to actions, where we can quantify the results on energy demand with reasonable certainty on national level and where we can propose measures to implement them. We will also describe how to include sufficiency actions in energy models. Examples are provided in EnergyPLAN and MESSAGE, including the quantified sufficiency actions and for MESSAGE also a survey on the willingness to reduce consumption. This quantification of sufficiency and integration in energy models give the basis for the national energy scenarios with sufficiency presented in the work package 4 report: “Development of revised national sustainable energy scenarios for Denmark, Latvia and Lithuania”.

In addition to the authors, this report is based on inputs and comments from professor Henrik Lund and associate professor Iva Ridjan Skov, Aalborg University, in particular regarding the IDAs Klimasvar and input data for EnergyPLAN.

In this report’s chapter two, we present briefly the definitions of sufficiency with particular focus on energy sufficiency, and describe the principles for integration of sufficiency in energy models with respectively exogenous and endogenous modelling of energy demand.

In chapter three, we present the quantification of selected sufficiency actions described in the work package 2 report “Systematisation of experiences with energy sufficiency initiatives” on national scale, assuming national policies to implement them. The selection is made using the criteria of ability to quantify based on available information and the presence of known policies to implement them, but we do not describe the policies in detail. The selected sufficiency actions are not an exhaustive list of possible sufficiency actions on a national scale, but are only a selection of actions, where we have the necessary information to fulfil our selection criteria. We have also limited the actions to household energy use (heating and electricity use) and personal transport.

In chapter 4, we briefly describe the EnergyPLAN model, and present the energy demand-side inputs in the EnergyPLAN model for the sectors covered by our proposed sufficiency actions. These are space and water heating, electricity use, and transport. We then use the quantified sufficiency actions as examples of modifying input data from an existing energy scenario for Denmark with high efficiency where there is less focus on energy sufficiency.

In chapter 5, we present examples for including energy sufficiency actions and proposals in the MESSAGE modelling tool with inclusion of measures as well as survey results in a scenario for Lithuania.The MESSAGE modelling tool is very flexible in its energy demand inputs, allowing optimisation across various sectors and measures depending on user choices. Thus, energy demand measures can be included both endogenous and exogenous in the model optimization. In this report, we present examples of integration of sufficiency in energy scenarios with the MESSAGE tool, but given the character of the tool, it is not an exhaustive list of all options for this integration.

2.0 Integrating sufficiency in energy modelling

To include energy sufficiency in energy modelling, quantification on the level of the models is crucial. For national models, quantification has to take into account local/national conditions. The basis for this is experiences from energy consumption initiatives, past experiences, surveys, and how they will interact on a national scale with the socio-economic and regulatory context, including the role of rebound effect, energy poverty and others. This can, among others, be based on microdata analysis as surveys and “living labs” to see how much room for sufficiency different societal groups in the different countries have. It can also be based on macro-level analysis, using past experiences as the basis.

Quantification of energy sufficiency is also a discussion about where we should reduce and how we can do it, what is technically feasible vs what is socially acceptable. To succeed in development of constructive and informative energy models with energy sufficiency included, it is important to make it transparent that modelling is political and value based. This includes to indicate the values chosen for each specific scenario.

2.1 Definition of energy sufficiency

The following table presents an overview of the different energy sufficiency definitions presented and used in this project. More in-depth discussions of energy sufficiency definitions and definition elements can be found in the work package 2 report “Systematisation of experiences with energy sufficiency initiatives”:

Source	Energy sufficiency definition	Focus points
Darby and Fawcett (2018) and Vadovics and Živčič (2019)	The ENERGISE project defines energy sufficiency as “a consumption that ensures that everyone has access to a sufficient amount of energy to satisfy their basic needs in a way that respects the ecological limits of the planet”.	- Social and environmental factors - Basic needs as well as ecological limits - A global level of consumption ensuring sufficiency
Sahakian et al. (2019)	“Energy sufficiency which accounts not only for absolute reductions in resource usage, but also changes in everyday and habitual practices – which implies challenging collective conventions around energy usage in the home, as well as setting upper limits to consumption.”	- Social and environmental factors - Action / practice oriented
The Enough network	The Enough network defines sufficiency as a term that “encompasses efforts to rethink and	- Social and environmental factors

	redesign collective and individual practices in line with the planetary limits and people's aspirations for better lives”.	- Better lives as well as ecological limits - Action oriented
Moser et al. 2015	“Energy sufficiency refers to changes in individual behaviours that lead to lower demand for energy services [emphasis added]”	- Upper limits (environmental) and reductions - Action oriented
Sorrell, Gatersleben and Druckman, 2020	“Energy sufficiency involves reducing (voluntary or compulsory) consumption of energy services in order to minimise the associated environmental impacts [emphasis added]”	- Upper limits (environmental) and reductions - Action oriented
The European Council for an Energy Efficient Economy (ECEEE)	Energy sufficiency as “a state in which people’s basic needs for energy services are met equitably and ecological limits are respected”.	- Social and environmental factors - Basic needs as well as ecological limits - A state of affairs
négaWatt, (Marignac, 2019)	“Energy sufficiency, as a means to rethink and redesign individual and collective practises to favour activities and services that are intrinsically low on energy use, can be a key further leverage to enable deeper decarbonisation pathways” - Focus on ensuring adequate energy services for everyone - Focus on unconscious, routine nature of many activities associated with energy consumption; - Focus on lifestyle changes and macro level / system changes	- Social and environmental factors - Basic needs as well as ecological limits - Action / practice oriented - Systemic changes

As the table demonstrates, there are several definitions, some with varying focus areas. For the project, no single definition has been formulated or chosen, and the table above thus serves as an overview of factors to take into consideration in relation to energy sufficiency. The overview has factored into the energy scenario modelling of the project, where the focus has been on how different factors can be included. The quantification of the effects of the sufficiency actions is not trivial, and must include physical potentials as well as structural limits in the society as well as lifestyle preferences. The quantification of lower and upper limits also pose a significant challenge which varies according to the level at which the model operates (e.g. national, global etc.). A factor such as consumption needed for good lives, or even basic needs, are philosophical and somewhat context dependent. The upper limit of consumption is defined by a combination of available technologies, resources and environmental limits. Both sets of limits (environmental upper limits and social lower limits) are, however, immensely important. . Lastly, the limited amount of research on sufficiency actions and the quantification herof also poses challenges in energy sufficiency modelling.

2.2 Modelling energy sufficiency

The purpose of energy scenarios models is to determine costs, environmental effects etc. of an energy system that will supply a given society with one or more forms of energy. This will require inputs as energy supply options as well as energy demands. The energy demands can be described either with a set pre-defined level of energy consumption or with a set of data that allows the model to optimise the energy efficiency level.
To include energy sufficiency measures in energy scenarios models, it is necessary to evaluate their potential effects on future energy consumption. To do this, we evaluate the effect of sufficiency on energy service demand. From the changes in energy service level, we then determine the changes in energy demand. In the simpler analysis (exogenous modelling of energy sufficiency and energy efficiency, see below), there is a 1:1 relation between the energy service level and the energy demand once the energy efficiency level is determined. In more advanced modelling (endogenous modelling of energy service level and energy efficiency), energy sufficiency is included in the optimisation together with energy efficiency.

For example with space heating: the combination of the floor space, the heating (temperature) level and other indoor climate parameters (as air exchange rate) determines the energy service demand for space heating of a building/dwelling. Then the energy service demand multiplied by the specific energy demand in space heating (including ventilation) determines the total energy demand for space heating.

To include energy sufficiency in energy models, we need:

- Knowledge of effects of energy sufficiency actions, for instance from micro-level analysis as living labs or from macro-level analysis of potentials for energy sufficiency derived from past experiences, combined with knowledge of behavioural changes and user choices;
- Knowledge of abilities to scale up results from micro-level analysis of smaller-scale practices . This includes knowledge of policies for energy sufficiency and the estimated effects of these policies in the societies analysed, synergies between policies, rebound effects, etc.. For some energy models, also costs, acceptability, and other details of sufficiency policies are needed;
- Knowledge of the fraction of energy consumption that is covered by the scaled-up energy sufficiency actions, for instance heat demand of dwellings as part of total heat demand of a country. This is often available from statistics.

For the energy scenarios, we have in this project included sufficiency actions, where we have knowledge of opportunities to scale up to national levels, as we want to integrate energy sufficiency in national energy models, and ultimately in national energy plans. For the documentation of the scaling-up, we have included studies on energy sufficiency on EU and national level, as well as studies and estimates on energy sufficiency on smaller scales combined with documentation of scale-up from other sources.

For instance, for space heating we have included reduced indoor temperatures based on living labs and reduction of dwelling sizes based on German documentation, but we have for instance not included reduction of dwelling sizes with a change to tiny houses. For the first two sufficiency actions, we have documentation of their effects on a smaller scale and estimates for scaling up. For the tiny houses, we have no evidence for how much the well-documented interest in tiny houses could actually reduce sizes of new build houses, if the barriers against tiny houses were removed. For this reason, increased use of tiny houses is not included.

2.3 Endogenous vs exogenous

Energy sufficiency can be included in energy models as exogenous parameters that simply reduce the energy demands or energy service demands in the input data. The exogenous approach uses assumptions that are defined before modelling. Thus, the model has no impact on the assumed role of sufficiency. Sufficiency role in the scenario is an assumption that is made before running the model. Sufficiency can also be included in an endogenous way, where the model can include energy sufficiency measures in the model’s optimization. In this case, the model considers sufficiency as a possible (but not obligatory!) part of the future energy scenario. It may (or may not) be chosen depending on its fit to the scenario and attractiveness compared to other options. If the endogenous approach is employed, sufficiency role in the scenario is a result of modelling.

In this project two energy system modelling tools have been used with the purpose of exemplifying integration of sufficiency measures in both exogenous and endogenous ways of modelling. EnergyPLAN exemplifies exogenous models (see chapter 4) and MESSAGE exemplifies endogenous modelling (see chapter 5).

Compared to the traditional modelling of energy development scenarios, the integration of sufficiency and endogenous modelling of sufficiency measures requires a more detailed representation of energy users and energy services they use. Therefore, the modelling tends to cover more demand-side details in addition to the traditional focus on the supply side. Another important issue is that energy sufficiency goes hand in hand with energy efficiency. In some cases, efficiency and sufficiency can be seen even as competing sets of measures to reduce primary energy consumption. Thus, energy sufficiency has to be reflected along with energy efficiency. In this way, the endogenous model chooses appropriate measures in optimization.

Both efficiency and sufficiency can be reflected using the usual technology notation. However, simultaneous modelling of energy efficiency and sufficiency requires a new understanding of issues reflected in a model. The main issue is that demands are described by energy services instead of amounts of energy to be consumed. For example, in the case of heating, the demand is reflected not as a certain amount of heat needed to ensure buildings‘ thermal comfort but as the area to be heated (in square metres) multiplied by heating degree days (HDD). The latter is defined by climate conditions in the geographical area considered and the usual temperature level. Actual energy consumption is reflected by competing technologies that reflect different energy efficiency levels and investments needed to reach higher efficiency.

3.0 Brief overview of examples of sufficiency initiatives and changes in social practises

In this chapter, we will present different ways of incorporating energy sufficiency with energy consumption reduction initiatives, within household energy consumption and personal mobility practices. To ensure the credibility of scenarios, we include measures that not only can be quantified with reasonable certainty, but where we also can propose softer political measures to realise the quantified sufficiency on a national level. The softer measures include information, assistance, and balanced economic instruments that contribute to a more just society with more equal opportunities for instance in mobility.

In this chapter we also explore how energy sufficiency measures can reduce energy demand and in this way be incorporated into an exogenous energy model like EnergyPLAN. . The selected sufficiency measures that we include in the examples are additional to an existing, ambitious Danish energy scenario: IDAs Klimasvar[1] that includes energy efficient technologies, efficient use of technologies and shift to renewable energy .

Sufficiency based Sustainable Energy Consumption Initiatives (SECIs), derived from the ENERGISE database

In ENERGISE, a typology related to sufficiency was developed to help identify sufficiency aspects of Sustainable Energy Consumption Initiatives. The Resource Consumption Typology (RCT) definition primarily orients itself towards absolute reductions. SECIs that have been characterised as sufficiency SECIs according to the RCT, are SECIs that to some extent deal with absolute reductions in energy consumption reductions.

Two examples from the ENERGISE SECIs that were categorised as sufficiency-based initiatives are included in the following proposals for sufficiency actions to be integrated into energy models. Other proposals for sufficiency actions are from studies of possible actions

[1] IDAs klimasvar is developed by IDA (Danish Society of Engineers) and Aalborg University. https://ida.dk/om-ida/ida-mener/klima-energi-og-cirkulaer-oekonomi/klimasvar

and combinations of potentials and previous experiences with energy sufficiency on a larger scale.

3.1 Households

3.1.1 Reduced Laundry of Clothes

In regard to energy reductions within households one sufficiency aspect derived from ENERGISE is concerned with laundry practices. The aim was to investigate if clothes are used longer before being washed and the washing machine is filled, the number of laundry cycles can be reduced and electricity consumption reduced.

ENERGISE - an innovative pan-European research initiative - developed, tested and assessed options for a bottom-up transformation of energy use in households and communities across Europe. ENERGISE developed two prototype ‘ENERGISE Living Labs’ (ELLs) designed to capture dynamics of (changes in) individual and collective energy consumption. The Danish ELLs consisted of a total of 37 participating households with a household size ranging from one person to more than four persons. Participants of the two prototypes of ELLs Danish households were asked to engage in two different challenges, one that dealt with absolute reductions related to heating the home (further explained in section 3.1.2 Reduced Indoor Temperature), and one that dealt with reductions related to laundry. Learnings from the latter will briefly be presented in the following and further descriptions of the findings from ENERGISE Living Labs can be found in work package 2 report “Systematisation of experiences with energy sufficiency initiatives” section 5.1 ENERGISE Living Labs.

In the challenge related to laundry reduction, households were asked to halve their number of weekly laundry cycles, e.g. households that would normally do 8 weekly cycles were asked to reduce the number to 4. The average amount of weekly laundry cycles varied a lot - e.g. between 1.5 and 7 cycles for households with 3 members. The households’ additional practises for keeping clothes clean were examined (e.g. airing out clothes, brushing off stains or avoiding stains all together), as were the parameters they used to determine when clothes were in need of washing. These aspects were examined prior to, during, and after the challenge.

Empirical experiences

Though participants did not manage to reduce their number of laundry cycles entirely by half, they did reduce their number of laundry cycles by 35-39% during the challenge period.

Many of the participants started doing fuller loads and several participants developed new ways of keeping used clothes in circulation. This was combined with the uptake of airing out clothes. Some participants challenged the social norms (or at least their own experiences of these) around wearing the same clothes for two consecutive days. Although smell was a common criteria, prior to the challenge, to determine whether clothes should be washed, it seemed in general, like the participants became more sensorial (using senses like seeing and smelling) in order to judge when their clothes were dirty enough to be put into the laundry basket.

Before the challenges, most of the participants determined whether items needed to be washed based on the length of wear, and only a few mentioned stains to be a criteria.

After the challenges, length of wear is still the most dominant reason for washing a piece of clothes, although it has been reduced.

Impact from proposed sufficiency measure

To use results from ELL for modelling of possible large-scale developments, it is important to consider typical constraints that experimentations face when aiming to upscale. Four of these are described in the WP2 report, section 5.1.1:

1. “Fragmented established institutional arrangements with expert driven ways of thinking, and powerful lobbies”;
2. “Obdurate urban assemblage (infrastructural/technical, legal, financial; spatial, social etc.)”;
3. “No consensus on the merits of the outcomes of the innovation experiment beyond those involved” and
4. “Limited representativeness: results of innovation experiments are only limited applicable to large scale”.

To overcome these constraints, several approaches and actions are relevant, as described in the WP2 report section 5.1.1. This is measures such as:

- Integrating multiple perspectives by taking a multi-actor/stakeholder approach. Including and engaging diverse groups of actors, cross institutionally, as well as future users and policy makers is beneficial and critical to understanding the diversity of participants along with the (social) context of experimentation, the conditions and limitations.
- Developing participatory visions through co-creation with heterogeneous stakeholders through Transitions Management methods;
- Carrying out successful and convincing pilot projects, and framing the experiment in ways that avoid immediate dismissal. E.g. framing the issue with a focus on health as well as climate;
- Focusing on behavioural measures that trigger structural change - i.e. the new and innovative practices should be embedded in daily lives of existing communities; community engagement with collective ‘sense making’ makes the move beyond individual behaviour change to structural behaviour change more likely.
- Scale jumping - i.e. when social groups move to higher organisational levels, by linking up with actors in other areas and at other scales, in order to achieve their interests.

These approaches and measures should be considered to use the results from modelling with inputs from ELL in the development of policies to realise the modelling results on a larger scale, such as on national scale.

If the results are used internationally, it is necessary to convert the Danish effect from the ELL to other countries, analysing laundry practice in the respective country/ies, and determine if they are similar to Danish practice.

Since experiences from the ELL showed a reduction in the number of laundry cycles by 35-39%, and we find that the households involved in the ELL are representative for Danish laundry[2], in Denmark we can expect an average reduction of 37% in laundry cycles, if measures are introduced considering above constraints and proposed actions. This reduces electricity consumption for washing and drying by 37%.

The input data needed for modelling the action exogenously is the reduction in electricity demand. The reduction in electricity consumption from reduced laundry cycles is included in section 3.1.7 Electricity Sufficiency in households.

3.1.2 Reduced Indoor Temperature

The second living lab of the ENERGISE project was a thermal comfort challenge. In this challenge, households were asked to reduce the indoor temperature of their houses to a fixed level (18ºC), regardless of prior preferences. In the ELLs, 21-22ºC were the preferred temperatures for the living room area (in some cases slightly lower or higher). Participants shared a preference for colder temperatures in bedrooms, though with a range of stated temperatures varying from 15 to 23ºC.

Participants were generally confident that they could easily reduce indoor temperatures by one degree, but all found it unacceptable to feel cold in their own home, or invite guests into a cold house. It is clear that participants carry with them learned ideas and memories about appropriate (or inappropriate) ways of heating the home. Generally speaking, comfort usually trumped economic and/or environmental considerations when it came to the heating challenge.

Furthermore, the access to regulate the different heating systems play a significant impact on the households commitment to reduce their everyday consumption. Therefore the infrastructure and technical solutions play an important role in reducing the indoor temperature.

Empirical Experiences

The heating challenge started on November 5th and ended on December 2nd. Participants indicated preferred temperatures for their living rooms in the exit survey of about 0.5ºC lower than what they indicated in the baseline surveys. It is important to note that 0.5ºC is based

[2] According to ElmodelBolig: Nyhedsrapport 2018, p 37 https://statistic.electric-demand.dk/, the average number of washing cycles per year was 244 in 2018, equivalent to 4.7 cycles per week, which is similar to the 1.5-8 cycles found in the families that took part in the ELL.

on averages, and that some participant answers may show bigger variations between baseline and exit answers, and some may show a smaller variation. Also it is important to note that the sample size is smaller for the exit survey responses than for the baseline survey responses. It is also important to note that some participants had started the heating challenge earlier than the official start of the challenge, which means that T1 does not necessarily represent temperatures that participants would have had at the same time of the year, if they had not been involved in the project.

The exit surveys showed that in one group of families with in average more than 21ºC before the challenge, the families had in average maintained a temperature 1ºC below the previous temperature (0.8ºC lower in living rooms, higher reductions in sleeping rooms) while in another group of families with lower indoor temperatures, there was very little change after the challenge (0.1-0.2ºC reduction).

The relatively small variation between baseline and exit survey responses reflects what the participants also stated during the exit interviews and focus groups: several participants had found the heating challenge too difficult, some had given up, some had found it unbearable with the colder temperatures, and some had not been able to reduce their temperatures significantly because of infrastructural/material reasons (heating systems that did not work or reacted unexpectedly, and/or too well insulated houses). Most participants did however say that they could probably live with a 1-degree reduction in general, but not a lot more. Some of the changes that came around during the challenges have, however, persisted and continued.

Impact from proposed sufficiency measure

To use results from this ELL, it is important to consider the typical constraints, as described in section 3.2.1 above as well as approaches and action to mitigate them.

To convert the results from the Danish ELL for other countries, it is further necessary to look at climate and heating practices, and determine if they are similar to Denmark.

In Denmark we can expect an average reduction of 1 degree for all households with temperatures above 21ºC based on results from the ELL, but no reduction in temperatures for families with lower indoor temperatures. One degree lower temperature results in 5% lower heat demand for the average Danish climate. A survey by Bolius[3] regarding indoor temperatures showed that 35% of the families have more than 21ºC in the main part of the dwelling (living room etc.). Thus we conclude that in average the temperatures can be reduced with 1/3ºC in Danish homes with a campaign with information similar to the one in the living lab. This will reduce heat demand in dwellings with one third of 5% equalling 1.7%.

The input data needed for an exogenous energy model is the reduction in heat demand.

The net heat demand for dwellings (space heating and hot water) in Denmark in 2018 was 140 PJ (38.9 TWh). Following IDAs Klimasvar[4], in 2030 heat demand will be 11% lowered

[3] https://www.bolius.dk/fileadmin/user_upload/Boligejeranalyse/Rumtemperatur_december_2016.pdf
[4] IDAs Klimasvar 2030. https://vbn.aau.dk/ws/portalfiles/portal/332267652/IDAs_klimasvar_2030.pdf

because of energy savings while new buildings will add 6 PJ, giving a net heat demand for dwellings of 130 PJ (36.1 TWh). The net heat demand will then be reduced with 1.7% of 36.1 TWh = 0.61 TWh.

The heat demand input in EnergyPLAN is final energy for heating, but as the boiler loss is just 1% of final energy in the scenario, the difference is negligible.

In section 3.1.6 is proposed how to combine the heat savings proposed and in chapter 4 is proposed how to divide them in the different sources of heat.

3.1.3 Reduced living space

The German Umwelt Bundes Amt (Federal Environmental Agency) has commissioned a number of studies on integrating energy sufficiency in energy planning and strategies. Six reports were published 2018-2020[5]. Further description of the findings can be found in work package 2 report "Systematisation of experiences with energy sufficiency initiatives" section 5.2.1 Space Saving – German Analysis.

This section deals with the finding of the report of space-saving living through sufficiency policies (Flächensparend Wohnen).

Despite a more or less stagnating population, the living space in Germany significantly increases every year and leads to growing living space consumption per capita. A further increase is expected in long-term scenarios and will make sustainability, energy, and climate targets in the building sector much more difficult to reach. It also causes a growing use of space and resources, as well as enormous infrastructure costs. In Germany there is a growing awareness of this problem, especially on a regional level and in some towns. In this study, the vast potential of a reduced living space per capita is estimated. The most promising target groups are identified that use living-space far above average and might be interested in reducing it. Retirees and households that face a break in their routine of life such as reaching retirement age or families whose children are moving out are among those target groups. For these target groups specific barriers against the reduction of living space are analysed.

The study also takes a closer look at actors such as policy makers, associations, and the housing sector, and their specific obstacles and motivations to address the problem. To support households to reduce their living space, a mix of policy instruments are found to be necessary, consisting of both informational and financial instruments. Existing approaches are analysed and a set of novel instruments to support households of the target groups to reduce their living space is created. The impact of these instruments for energy consumption and emissions of the target groups is calculated. Furthermore it is analysed whether or not these measures are attractive from the point of view of a household taking into account costs and benefits and show likely distributional effects.

[5] https://www.umweltbundesamt.de/publikationen/flaechensparend-wohnen. Tabelle 6 - p.35, p.62-74.

Empirical Experiences - Studies

The study proposes a number of measures to realise lower living space:

Financial instruments to stimulate the division of single-family houses into more dwellings. One of the target groups for this measure is retiring people that want to stay in their house. The financing needs identified are for planning and constructing the division of the dwelling into two. The study finds that out of target groups of 2.57 million families in Germany, 10% could divide their house until 2030 (from 2020) and reduce the average living space per person from 90 m^2 to 54m^2.

Municipal advice centres for efficient use of dwelling space. The target groups are seniors/retired people and others living with large living space per person. The advice centre should:

- assist people with large dwellings per person to find smaller dwellings, organise the moving and clarify legal issues, economic effects etc. The study finds that out of target groups of 6.4 million families, 2.5% could move to smaller houses and flats 2020-2030, reducing their average size of dwelling per person with 33 m^2
- Assist people renting out rooms. The study finds that out of a target group of 6.4 million families, 7.5% could rent out a room and reduce living space per person with 20 m^2

Fitnescheck for political and commercial changes. Based on the finding that German housing policies have no focus on limiting living space per person, the proposal is to integrate sufficiency of living space in German housing policies including advice services. The study has not been able to quantify the effect of this measure and it is not included below.

Impact from proposed sufficiency measure

To convert the German effects to other countries, the first question is how relevant the measures are for the country in question. For Denmark, the issues with some people living in much larger houses that they need or want is similar to Germany, and therefore we can assume that the effects can be the same. Also the division of people in age groups in Denmark is similar to Germany, so the target group can be expected to be the same relative to the population.

Based on a total of 42 million households in Germany and an area of 3,900 million m^2, the target groups (share of dwellings) and the effects can be calculated for Denmark. This is presented in table 3.1 and shows a total reduction in heat demand to be 0.28 TWh in 10 years, in Denmark. The input data needed for exogenous energy modelling is the reduction in heat demand. In section 3.1.6 is proposed how to combine the proposed heat savings.

Measure	Financial instruments to stimulate the division of single-family houses	Municipal advice to help moving to smaller dwellings	Municipal advice to help to rent out rooms
Number of dwellings that has acted with this measure until 2030	2.57 mill *10% = 0.257 mill.	6.4 mill *2.5% = 0.16 mill.	6.4 mill *7.5% = 0.48 mill.
Reduction of living space for families that acted per person	90-54 = 36 m^2	33 m^2	20 $m^{2<}$
Persons per dwelling	1.63	1.55	1.55
Reduction per dwelling	59 m^2	51 m^2	31 m^2
Reduction of total living space	15.2 mill. m^2 = 0.39%	8.2 mill. m^2 = 0.21%	14.9 mill. m^2 = 0.38%
Heat consumption in Denmark in 2030 households IDAs Klimasvar without this measure	130 PJ including hot water of which space heating, 80%= 104 PJ		
Heat saving with measure	0.39+0.21+0.38 = 0.98% of 104 PJ, equal 1.02 PJ = 0.28 TWh		

Table 3.1 Calculation of reduction in heat demand in Denmark when reducing living space

3.1.4 Water Saving Showerheads and Taps

With labelling of showerheads and taps consumers can be expected to use the labels and choose appliances with less water consumption. No standardised labelling or regulation on water consumption for appliances are in effect in the EU at the moment. The EU Commission is considering introducing labels that inform consumers of the water consumption levels of taps and showerheads.

Empirical Experiences - Studies

The EU Joint Research Center has evaluated the effect of a proposed labelling scheme for taps, showerheads etc.[6] The evaluation shows that the labels will make consumers save 27% hot water and cold water on average, simply because many consumers and designers will use the labels when they select new appliances. The savings will only be realised with the change of taps and showers; therefore the effect will appear gradually. With the assumption that the label will be agreed in 2021 (which, however, was not realised), 75% of the 27% savings will be realised by 2030, equal to 20% savings in energy use for heating water.

Impact from proposed sufficiency measure

We use the 20% saving in 2030. To calculate the savings the average hot water consumption for the country is needed.

In Denmark the water usage in households is 101 litres per person per day. Approximately 35% of this is hot water[7]. Thus the annual Danish hot water consumption is 12.9 cubic metres per person - or 74.8 million cubic metres in total. In Denmark hot water is 55 degrees Celcius when delivered from the heating system whereas cold water is 8 degrees. Hence, water is heated 47 degrees. The energy used for heating 12.9 m^3/person of water 47 degrees is 4.1 TWh/year[8] in total for the country. In addition to this there are losses in the hot water system (storage tank, etc.).

The annual heat demand for hot water in households can be estimated to 26 PJ (7.2 TWh) in 2030 as 20% of the heat demand for households that is estimated to 130 PJ if the proposals in IDAs Klimasvar are followed. This gives losses of 7.2 - 4.1 = 3.1 TWh/year in the hot water production, however not all of the losses are influenced by the hot water consumption. We assume that half of the losses are saved when hot water consumption is reduced. This results in savings of 20% of 5.65 TWh = 1.13 TWh (4.1 PJ) in 2030.

In section 3.1.6 is proposed how to combine the proposed heat savings.

3.1.5 Shorter and fewer baths

In relation to the use of water saving showerheads and taps (presented in section 3.1.4) hot water use can also be decreased by taking fewer and/or shorter showers.This will moreover be healthier for the skin. See work package 2 report “Systematisation of experiences with energy sufficiency initiatives” section 5.3.2 Water Saving with Lifestyle Changes for further information.

[6] Follow-up of the MEErP Preparatory Study on Taps and Showers - Final Report], Mauro Cordella, Javier Sanfelix, and Oliver Wolf, May 2019, https://www.researchgate.net/publication/331687273_Follow-up_of_the_MEErP_Preparatory_Study_on_Taps_and_Showers_-_Final_Report

[7] https://sparenergi.dk/forbruger/varme/varmt-vand

[8] 47 deg. x 4.18 kJ/deg/litre x 1000 litre/m3 / 3,600 kJ/kWh = 54,6 kWh/m3.
74.8 million m3/year x 54,6 kWh/m3 = 4.1 TWh/year.

A major part of hot water use is for hygiene, primarily for showers[9]. The average Danish person showers every day and some take long showers. Physical and dirty activities can make showers necessary. A long shower can also provide comfort on a cold day,

Campaigns focussing on the health benefits can support shorter baths. The change of habits to take fewer baths and showers is most likely to occur if there is a convincing combination of reasons, such as health, time savings, energy savings, and water savings, and that each of these reasons are known and understood.

Empirical Experiences

Experience has shown that Danish people are willing and able to save water. Increased concern for water use resulted in a reduction of residential water use in Denmark due to increased information on water as a scarce resource and information campaigns on how to save water.
Residential water consumption was reduced from 60 m^3/person annually in 1987 to 40 m^3/person in 2012, a 33% reduction over 25 years equal to 1.3% per year. The reduction was most significant in the first 15 years (1987-2002), where it was 1.7% per year[10].

Impact from proposed sufficiency measure

Based on the historically positive response to water savings, we assume that a new campaign with water savings, with a strong focus on health reasons for bathing and showering less, can further reduce water use. Assuming that 80% of the hot water is used for bathing and ⅔ of the population can reduce bathing or showering to half, the potential is 27% reduction in hot water use. Given experience with a maximum of 1.7% water savings per year, we assume that the maximum saving until 2030 is 17%.
Further work is needed to determine with more precision the fraction of the people that are able and willing to change habits, for instance via living labs with this focus. However, we use the 17% saving in 2030 and to calculate the savings the average hot water consumption for the country is needed.

When we propose both this measure and the above measure with labels, the two measures combined will give less than the sum of the two measures as they have a relatively large influence on the same consumption. This is elaborated in section 3.1.6.

3.1.6 Heat Sufficiency in Households

The total reduction in heat demand originating from the four sufficiency measures described in section 3.1.2-3.1.5 are to be combined to total heat reduction.

For water savings showerheads and taps (20% reduction) and shorter/fewer baths (17% reduction), the combined savings will be less than the sum: The water saving showerheads

[9] 37% of total water consumption in households are used for bath and hygiene and 10% is used for dishwashing and cleaning, which are the categories involving hot water use. Source: DANVA. https://vandetsvej.dk/faglig-viden/vandforbrug/grundviden/vandforbrug-hjemmet

[10] Annual consumptions are read from graph on page 4 in DANVA annual report “Vand i tal 2020”, see https://www.danva.dk/media/7003/2020_vand-i-tal_web.pdf

and taps, consumption will be reduced to 80% and then the shorter/fewer baths will reduce 17% of the 80%, i.e. a reduction to 66% of previous demand. Thus the total reduction will be 34% of the hot water demand, which will save 34% of 5.65 TWh equal to 1.92 TWh .

Reduction in heat demand in Denmark in 2030 compared to IDAs Klimasvar.

Reduced indoor temperature	0.61 TWh	2.2 PJ	(from 3.1.2)
Reduced living space	0.28 TWh	1.0 PJ	(from 3.1.3)
Water savings	1.92 TWh	6.9 PJ	(combining 3.1.4 and 3.1.5)
Total reduction in head demand	2.81 TWh	10.1 PJ	

3.1.7 Electricity Sufficiency in Households

It is possible to live a modern life with much less electricity use than the average Danish family. In this section, we will limit the proposals to moderate changes in lifestyle – such as using fewer appliances or using them in a shorter time – that we expect can be implemented on a larger scale to save electricity.

Electricity is used for a lot of purposes in households. In work package 2 report “Systematisation of experiences with energy sufficiency initiatives” section 5.4 Electricity Savings in Households an analysis is made of the Danish use of electricity for different purposes and the estimated electricity savings for an average household.

Empirical Experiences

The average Danish electricity demand is 1770 kWh/person including heating. The average demand is approximately 1500 kWh/person without heating[11].

An analysis is made based on possible reductions in some of the electricity uses in typical Danish households. Every second year, an extensive statistic is made of the electricity demand for household appliances with information about the stock of appliances and usage [12]. The sufficiency changes proposed are chosen based on compatibility with typical Danish lifestyles, but they are not tested for general acceptance, except for a few.

The average electricity use of these appliances is given in table 3.2 together with possible sufficiency actions. All uses with no action proposed are not specified. A more detailed table of consumption can be found in WP2 section 5.4 Electricity Savings in Households as well as more explanations about the assumptions behind the sufficiency actions proposed.

The resulting savings, with sufficiency actions in 10 different types of electricity consumption, gives average electricity savings of 20% of the household demand for appliances and lighting.

[11] Energy Statistics 2019. The Danish Energy Agency. https://ens.dk/en/our-services/statistics-data-key-figures-and-energy-maps/annual-and-monthly-statistics
[12] ElmodelBolig: Nyhedsrapport 2018 and Bestandens elforbrug 2018. https://statistic.electric-demand.dk/.

Household electricity demand	Consump-tion 2019	Action	Saving	Consump-tion with sufficiency
Per HH 2019, kWh/year	3234		20%	2590
Cooking	278	Optimise	20%	222
Fridge, combined fridge/freezer	281	Half HH with two fridges	16%	236
Washing machine	176	Wash less	37%	111
Dryer	228	Dry outside every second time, dry less	68%	73
Lighting	260	Turn off when not in use	30%	182
TV, DVD a.o.	442	Turn of when not in use, see more TV together	20%	354
Stereos, game consoles	105	Turn of when not in use	30%	74
PC, printer, a.o.	269	Turn of when not in use	20%	215
Network (router, modem, TV boxes)	105	Turn off at night and during work hours	35%	68
Standby - TV, PC, Stereo, Washing m, Dishwasher, Dryer	70	Turn totally of when not in use	50%	35

Other – including all uses with no proposed action	1020	No action	0%	1020

Table 3.2 Electricity consumption in Danish households excl. Heating (2019), electricity savings from various sufficiency measures and electricity consumption in 2030 after sufficiency measures.

Impact from proposed sufficiency measure

To convert the Danish effect to other countries, it is necessary to look at electricity use in the country, and determine if they are similar to Denmark.

The input data needed for exogenous energy modelling is the reduction in electricity demand.

In Denmark sufficiency measures will reduce the electricity demand by 20% in 2030.

The electricity demand for appliances and lighting in Danish households in 2018 was 10.30 TWh. In the IDAs Klimasvar, energy efficiency in household electricity use of 10% 2020 – 2030 is included, which results in 9.27 TWh electricity demand in 2030. This can be achieved with energy efficiency, in particular with implementation of EU ecodesign regulations, combined with replacement of older, more consuming equipment with new equipment that is following modern energy efficiency requirements.

The 20% reduction is 0.2 * 9.27 = 1.85 TWh (6.7 PJ)

The reduction in electricity demand from sufficiency measures will be 1.85 TWh.
See chapter 4 regarding how to integrate this in Energy Plan input data.

3.2 Mobility

3.2.1 Initiatives proposed in "Omstilling til Bæredygtig Mobilitet" (Transition to Sustainable Mobility)

In the fall of 2020, three societies within IDA (IDA Rail, IDA Green Technology, IDA Transport and Urban Planning) worked on a plan for transition to sustainable mobility in Denmark, to reduce emissions with transport measures to move transport from cars to bicycles and public transport and reduce transport in general. A series of policy measures are proposed to realise the change. Descriptions of the policies can be found in the work package 2 report "Systematisation of experiences with energy sufficiency initiatives" report section 6.1.

IDAs Klimasvar also proposed some sufficiency measures that will reduce car use compared to business as usual with change to bicycles and public transport.

Both plans also include partial changes to electric cars.

Empirical Experiences - Studies

The combined effects of the proposals in the plan for transition to sustainable mobility have been calculated for the different travel distances for the target year 2030 with the largest reductions in car transport for the shortest travelling distances. The main findings are that the measures can reduce car travel and its emissions by 43% in 2030 compared with a business as usual development with continued growth in car transport of 2% per year 2020 – 2030. In addition, the plan includes a change of 50% of personal cars to electric cars, giving a total emissions reduction of 70% in domestic transport.

The policy measures in IDAs Klimasvar are estimated to reduce car use by 4% in 2030. We estimate that of this, 3.5% is driven by some of the same measures that are included in the plan for transition to sustainable mobility.

As for the other sectors, we will combine the action proposals (in this case, the plan for transition to sustainable mobility) with IDAs Klimasvar. In this combination, all measures in IDAs Klimasvar will be implemented, except the proposal in IDAs Klimasvar to reduce taxation, which will give cheaper cars. This proposal will in itself increase car use. In IDAs Klimasvar, it is combined with road-pricing, which can be part of a set of policy measures for a small reduction in car use, as the 4% reduction in IDAs Klimasvar. The reduced taxation is not compatible with the plan for transition to sustainable mobility as it will make it impossible to reach the large reduction of car use with the proposed measures.

The only traffic reducing measure that is only included in the IDAs Klimasvar is urban zones, where car driving is limited to electric cars only. We will include it in the scenario and we estimate that this measure in itself will reduce car use by 0.5%. The result of combining measures in IDAs Klimasvar and the plan for transition to sustainable mobility will then be a 43.5% reduction of car use.

IDAs Klimasvar includes a 23% reduction of transport fuel for other uses than personal cars and around 1 PJ of electric smart charging for other transport uses than personal cars. We will include that in the scenario.

IDAs Klimasvar includes 10.2 PJ (2.82 TWh) electrofuels in diesel, which we also include in the scenario. We use the assumption that the electrofuel is mixed into diesel, in which case it will be 3.3 PJ for personal cars and 6.9 PJ for other domestic transport.

The electricity use for transport in the scenario is estimated as the electricity needed for personal cars plus the demand in IDAs Klimasvar for electricity in other transport. The efficiency of electric cars is estimated to be a factor 4 better than for fuel driven cars.

Impact from proposed sufficiency measures

In the plan for transition to sustainable transport is included a shift of 50% to electric cars while in IDAs Klimasvar is included 39% electric cars (1.3 million electric cars out of a total of 3.3 million cars). To be able to compare the effects of the sufficiency action in the plan for transition to sustainable mobility with IDAs Klimasvar, we will include a scenario with the large reduction in car use, but with only 39% electric cars. With this scenario, it is possible to see the effects of the sufficiency actions without the extra technical change to electric cars.

We will compare four transport scenarios for 2030:

- Business as usual (BAU) for transport in 2030, using BAU 2030 scenario in IDAs Klimasvar
- IDAs Klimasvar
- All sufficiency actions to reduce car use 43.5%, but same fraction of electric personal cars as in IDAs Klimasvar (39%)
- All sufficiency actions to reduce personal car use 43.5% and same fraction of electric cars as in the plan for transition to sustainable mobility (50%)

In all scenarios, the transport scenario is combined with IDAs Klimasvar and the proposed sufficiency action in this report for the other sectors.

In the input data for a scenario made with an exogenous model as EnergyPLAN, the reduction of car use will reduce transport fuel demands while the change to electric transport will replace fuel demand with a smaller electricity demand.The results from these calculations are shown in the table below for the four Danish 2030 transport scenarios. They will be input for the energy scenarios.

Energy use for domestic transport excl. air (PJ)						
	Fuel, personal cars	Fuel, other transport	Fossil fuel, total	Electrofuels + biofuels	Hydrogen	Electricity
2019 Statistics	108.0	63	163.0	9.5*	0	1.7
BAU 2030	106.4	63.4	169.8	0*	0	7.5
IDAs Klimasvar 2030	62.3	49.2	101.3	10.2	0	19.9
IDAs Klimasvar + additional sufficiency 2030	36.7	49.2	75.6	10.2	0	15.7
IDAs Klimasvar + additional sufficiency + 50% electric cars 2030	30.0	49.2	69.0	10.2	0	17.3

Table 3.3 Energy use for Danish domestic transport excl. aviation and military. For 2019 from Danish Energy Agency, energy statistics, figures2020, sheet “Transport”, BAU for 2030 in

*IDAs Klimasvar, the reduction scenario for 2030 in IDAs Klimasvar and the effect of the proposed sufficiency actions, combined with respectively 39% and 50% change to electric personal cars. (*Until 2020 EU required a renewable energy fraction in transport energy, as seen in the statistics for 2019, while at the time of development of the BAU2030 scenario, there was no requirement for 2030).*

See chapter 4 regarding how to integrate this in Energy Plan input data.

4.0 Development of energy model: EnergyPLAN

EnergyPLAN is a complete energy sector model, covering all energy forms and all types of energy consumption. It is an exogenous model regarding energy demands and regarding investment decisions and it only handles a specific year that is defined by the user. It is easy to use, but for multi-annual analysis, it is necessary for each year to generate inputs and run the model.

EnergyPLAN models the energy system of a country or a region with hourly variations of electricity, gas, and heat demands within an energy system for one year. It models an energy system with one electricity dispatch centre, with interconnections to other electricity systems and with connections between electricity, heat, and gas networks as well as energy storages (electricity, heat, gas). It can optimise the operation of the energy system over the year to provide the demand needed every hour of the year, using technical or economic optimisation for optimal use of energy storages, energy imports, and flexible demands. The demand-side inputs for EnergyPLAN are final energy demands (electricity, heat, fuels). The energy units can be set to GWh and TWh.

EnergyPLAN has as additional demand-side inputs:

- The demand profiles for heating (district heating and gas), and electricity, with variations hour-by-hour over the year
- Specification of flexible electricity demand (how much electricity consumption can be moved: one day, one week, 4 weeks).

Generally, EnergyPLAN does not distinguish between end-use efficiency and sufficiency. These are to be combined in the determination of the input parameters of final energy demands. Typically the energy service demand including sufficiency is multiplied with the energy efficiency factor (specific energy demand), but it can be modified with for instance rebound-effects.

Thus, to use EnergyPLAN, it is necessary to estimate the final energy demands for the years covered by the scenario. EnergyPLAN is a tool to develop a scenario for a single year, a target year or a base year. Thus, the inputs needed are the final energy use for the target and/or base years. The target years are typically the end year of a scenario as well as some milestone (intermediate target) years. As an example, 2050 can be the end year while 2030 and 2040 can be milestone years. For each target and base year, the final energy demand can be calculated with estimation of energy service levels and energy efficiencies.

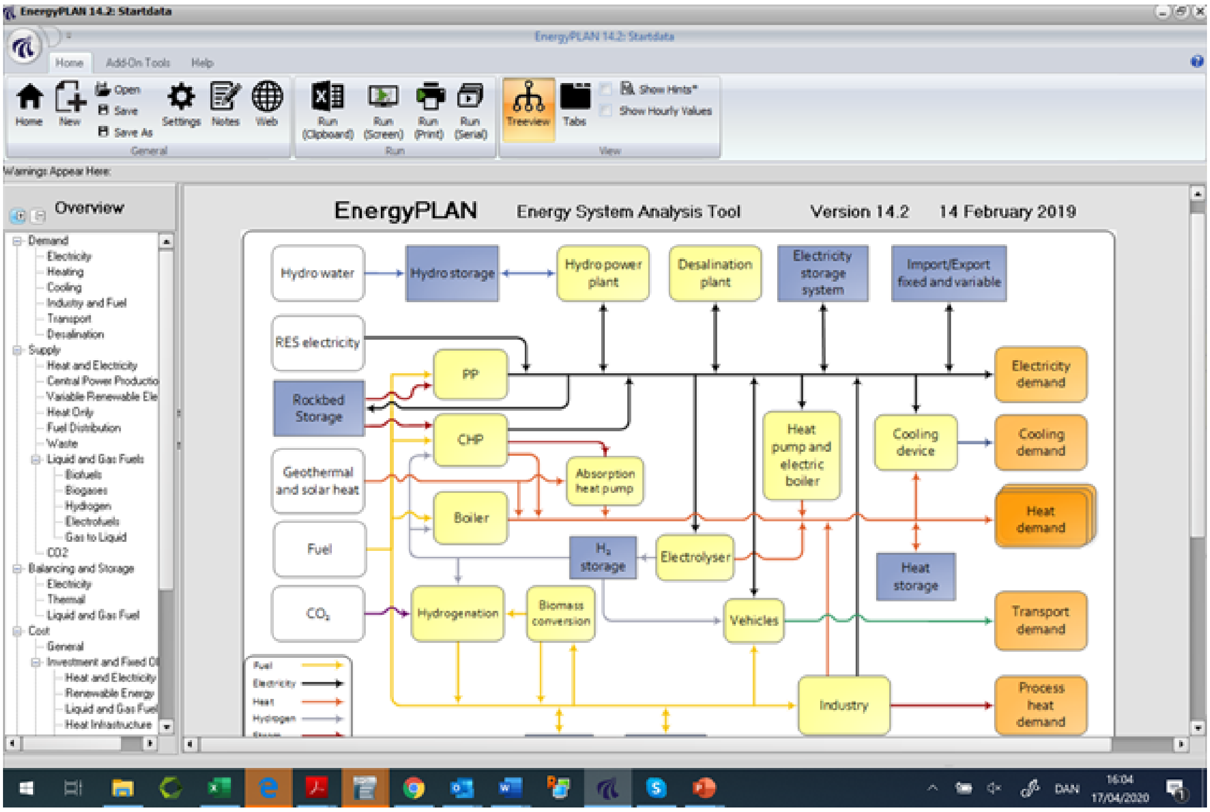

Figure 4.1 The main energy flows in EnergyPLAN

Figure 4.1 is an illustration of the Energy Plan energy flows. The flows go to the 5 main types of demand: electricity, space heating, space and district cooling, transport, as well as process heat and fuel demands (covering the productive sectors of manufacturing, agriculture etc.). The four first energy demands are directly influenced by energy sufficiency while the process energy is only indirectly influenced by sufficiency via the purchase and consumption of products. The energy flows for each of the five end uses are divided in a number of different flows, depending on the structure of demand. For electricity, a flexibility of demand to relocate in time, can also be specified.

4.1 Heat Demands in EnergyPLAN

4.1.1 Input of Heat Demands in EnergyPLAN

In EnergyPLAN, heat is treated as a final demand that can be met via individual heating (boilers, heat pumps, local cogeneration of heat and electricity, electric heating) as well as via district heating. The heat input sheets in EnergyPLAN cover input of low temperature heat demands for space and water heating and district heating for productive uses that require low-temperature heating (typically below 100ºC). EnergyPLAN has another input sheet for fuels for high-temperature heating.

- For individual boilers, the input is fuel demands and boiler efficiency (annual averages).
- For micro-CHP, heat pumps and electric heating, the input is heat demand and efficiency (annual average). For heat pumps the efficiency is the seasonal coefficient of performance (SCOP) while for electric heating the efficiency is assumed to be 100%[13].
- For district heating the input is heat produced at the heating stations, while final heat demand is calculated by the model with inputs of efficiencies of heat supply networks.

For each type of individual heating, the fuel or electricity demand can be reduced with local solar heating, covering all or a fraction of the houses using each type of individual heating.

For district heating, only central solar heating in the district heating networks can be directly specified, but it is possible to subtract solar heat production from demands when specifying heat demands.

Heat demands and fuel demands are input as total annual demands and with distribution of demands over the year (divided in hours). EnergyPLAN uses these inputs to calculate hourly demands for use of electricity, gas, and district heating. It is possible to have different hourly distributions for individual heating and for district heating.

Heat demands from district heating include all demands in dwellings and service sectors (space heating and hot water) as well as district heating used in other sectors (industry, agriculture). The input data includes the combined demand profile for district heating covering all demands for district heating (space heating, hot water, productive uses, losses) as well as the total demands.

4.1.2 Sufficiency in Space Heat Demand

Heat demands can be determined as energy service demand for heating times specific heat demand. For space heating the energy service demand can be described as the heated area times the temperature difference between outdoor and indoor. The specific heat demand is the specific heat loss minus use of free energy in the building. Thus, the heat demand, Q, can be described as:

$Q = A * \Delta t * q_{specific}, - Q_{bld}$ where

A is the heated area

Δt is the temperature difference between indoor and outdoor

$q_{specific}$ is the specific heat loss by the building per m^2 of heated space and per ºC of temperature difference

[13] That end-use efficiency of electric heating has 100% efficiency is a standard definition, assuming that there are no losses in end-use, even though in practice there can be losses due to overheating.

Q_{bld} is the useful free heat sources, from people, equipment and sunlight

The formula is for a specific time of the day and year, and for a building space that is heated uniformly. To describe the annual heat consumption of a building, the heat consumption of each time period with heat demand (for instance with hourly heat demands) and of each space, should be summarised.

The above formula can be further refined, for instance by dividing heat losses in ventilation losses and losses of the building envelope. This is not necessary for this analysis.

In the formula, sufficiency can influence the heated area as well as the temperature difference that the heating should provide. This will not only influence the heat demand, it will also change the hourly distributions. In table 4.1 is an overview of how sufficiency of heating can be taken into account in EnergyPLAN scenarios.

Heating type	**Smaller area***	**Smaller fraction of area heated at a given time**	**Lower indoor temperature**
Individual, boiler	Lower demand	Lower demand, lower boiler efficiency with re-heating peaks	Lower demand, lower or higher efficiency
Individual, CHP	Lower demand	Lower demand, change in CHP coverage, efficiencies	Lower demand, higher coverage from CHP unit (less additional heat source need), higher efficiency with lower temperatures
Individual, heat pump	Lower demand	Lower demand, change in heat pump coverage, lower efficiency with re-heating peaks	Lower demand, higher coverage from heat pump unit (less additional heat source need), higher efficiency with lower temperatures
Individual, electric	Lower demand	Lower demand	Lower demand
District heating	Lower demand	Lower demand, higher relative system losses	Lower demand, higher or same relative system losses**

Table 4.1 Overview of how sufficiency of heating can be taken into account in EnergyPLAN scenarios. (It is assumed that boilers, CHP, heat pumps and district heating networks are adapted to the lower heated area, simply by the construction of fewer and/or smaller houses. ** If all houses reduce indoor temperature, district heating temperatures can also be reduced and there will generally be the same reduction of heat losses in the district heating system as in houses. If only some houses reduce indoor temperatures, the district heating system*

cannot reduce temperature and absolute system losses will remain the same, thus relative system losses will go up. If a district heating system is already optimised for low temperature and the system temperature is needed by the hot water production, the temperature and the system losses cannot be reduced either.)

4.1.3 Sufficiency in Water Heating

Demand for heating of water is also part of the heat demand input in EnergyPLAN and should be added to the other heat demands to calculate heat input data.

Heating of water can be determined as the volume of hot water used times the temperature difference between hot water and cold water times the specific heat demand for heating water. The water heat demand, Q_{HW},can be expressed as:

$Q_{HW} = V * \Delta t * k * \eta$, where:

V is the volume of water used

Δt is the temperature difference between hot and cold water

k is the specific heat capacity of water, 4.18 kJ/kgK

η is the efficiency of the hot water supply

The total heat demand is the sum of the heat demand for the different hot water uses: bathing, hand-washing, cleaning, dish-washing, clothes-washing.

Sufficiency measures can influence the volume of water needed for the different uses.

It is also possible to reduce heat demand with lower hot water temperature, for instance for certain purposes. This can also be characterised as sufficiency.

For EnergyPLAN, the water saving measures will reduce heat demand, and it will change the profile of the heat demand with less demand during daytime, when hot water is used, but equal reduction throughout the year, as water demand is not dependent on seasons.

For hot water use, the influence of less demand for the different types of heating can be seen in table 4.2.

Heating type	**Less hot water use**
Individual, boiler	Lower demand, lower or higher efficiency

Individual, CHP	Lower demand, higher coverage, higher efficiency
Individual, heat pump	Lower demand, higher coverage and less higher temperature demand, higher efficiency*
Individual, electric	Lower demand
District heating	Lower demand, higher or same relative system losses

Table 4.2. The influence of less hot water demand on the different types of heating. (Heat pumps normally provide space heating with a lower temperature than hot water and as the heat pump efficiency is lower with higher temperature, the overall efficiency is increased if the fraction of hot water is reduced).*

4.1.4 Examples

In section 3.1 a number of sufficiency proposals are included for space heating and hot water and calculations are made for Denmark.

The reduction in heat demand is to be divided between fuel, electricity and district heating. We will in this example show how it will change the input data for EnergyPLAN, starting from a scenario for IDAs Klimasvar 2030. In IDAs Klimasvar for 2030, only biomass fuel is used and all electricity is for heat pumps, assuming no remaining direct electric heating. This simplifies the implementation.

We will assume that the sufficiency actions are distributed equally between boiler, heat pumps and district heating relative to the consumption from each source.

Total reduction in head demand with actions proposed in 3.1: 2.81 TWh

The total heat demand in 2030 is 48.16 TWh before sufficiency measures in IDAs Klimasvar 2030. After sufficiency measures the total heat demand will then be 2.81 TWh less, equal to 45.35 TWh.

For fuel boilers and heat pumps, no change in energy efficiency is expected with the lower load.

For district heating, in the EnergyPLAN input data, the losses in pipes are relative to consumption. As most of the savings in this example is from hot water (see section 3.1), the savings cannot be converted to reduced temperatures in district heat and thus will not lead to reduced losses in the pipes in the short term. After the reductions in hot water is implemented, new district heating pipes could be thinner with lower losses for the systems, where hot water demand is the main design parameter (systems with heat exchangers instead of hot water tanks in the houses); but this will not have effects until 2030.

Heating, TWh	**IDAs Klimasvar**	**IDAs Klimasvar + sufficiency**	**Input data, Energy Plan**
Biomass boilers, fuel	1.91	1.80	YES
Biomass boilers, net heat	1.72	1.62	
Heat pumps, net heat	15.45	14.55	YES
District heating, group 2, net heat	10.95	10.31	
District heating, group 3, net heat	20.04	18.87	
Net heat total	**48.16**	**45.35**	
Network loss, group 2	21.5%	22.5%	YES
Network loss, group 2	3.0	3.0	
District heat demand at central. group 2	13.95	13.31	YES
Network loss, group 3	21.5%	22.5%	YES
Network loss, group 3	5.49	5.49	
District heat demand at central. group 3	25.53	24.36	YES

Table 4.3 Input data for EnergyPLAN for heat demand with and without sufficiency measures proposed in section 3.1.

4.2 Space and District Cooling in EnergyPLAN

4.2.1 Input of Space and District Cooling in EnergyPLAN

Energy Plan has inputs for cooling divided in individual cooling, which is effectively air conditioning, and district cooling. District cooling can serve all cooling demands, but it is primarily used by institutions and companies with large cooling demands and that are placed in cities, where cooling demands are high within a small geographical area.

In EnergyPLAN is, as an input, a general hourly distribution of cooling throughout a year.

For individual cooling there are two input parameters:

- electricity demand for cooling,
- coefficient of performance (COP) of air-conditioners.

This is used in the model to calculate hourly electricity demand for cooling and hourly cooling demand.

District cooling has five input parameters:

- COP for production of cooling with district heating (individual inputs possible from three district heating networks)
- COP for production of cooling with electricity
- Cooling demand (divided into cooling supplied by each of three district heating networks and by electricity)
- Supply of natural cooling: input is total natural cooling and its hourly distribution over a year
- Network losses in cooling networks

This is used to calculate hourly cooling demand and demands for district heating and electricity for cooling.

The cooling demands are added up to a total cooling demand that can be used to manually change between the different forms of cooling. To the district cooling demand shall be added the commercial cooling demand connected to the cooling network.

4.2.2 Sufficiency in Space Cooling

The demand for space cooling depends on the buildings, ventilation (natural and mechanical), use of local cooling options as night cooling, reductions of solar heat through windows with shutters, and the temperature requirements of the building users.

Sufficiency of space cooling can combine a number of practices:

- Appropriate sizing of dwellings and other buildings for their use, for instance sizing of dwelling to the needs of inhabitants. This can be realised in a number of ways, in the construction phase as well as with movements of people in existing houses.
- Cooling of needed parts of the buildings only, reduced cooling of unused spaces and during unused hours
- Higher indoor temperatures.

- Use of shutters to reduce solar heating (this can be done with manual movement of shutters, in which case it falls under sufficiency and with automatic systems in which case it does not)
- Use of night ventilation (this can be done with manual opening of windows etc., in which case it falls under sufficiency and with automatic ventilation in which case it does not)

The space cooling Q_c, can be described as:

$Q_c = A * \Delta t * q_{specific}, + Q_{bld} – Q_{c\text{-}natural}$ where

A is the cooled area

Δt is the temperature difference between indoor and outdoor

$q_{specific}$ is the specific heat flux by the building per m^2 of cooled space and per ºC of temperature difference

Q_{bld} is the buildings heat sources, from people, equipment and sunlight

$Q_{c\text{-}natural}$ is the cooling demand covered with natural ventilation, including night ventilation

The formula is for a specific time of the day and year, and for a building space that is cooled uniformly. To describe the cooling consumption of a building, the cooling demand of each time period with heat demand (for instance with hourly) and of each space, should be summarised.

In the formula, sufficiency can influence the cooled area as well as the temperature difference that the heating should provide, the heat from sunlight, and the use of ventilation. This will influence the energy demand for cooling. It will also change the hourly distribution.

For cooling demands in Europe, sufficiency related measures (accepting higher temperatures, use of shutters, night ventilation) can often reduce cooling demands to close to zero.

4.2.3 Examples of Space Cooling Sufficiency

Space cooling is not much used in dwellings in Denmark. Also, we do not have quantified examples for space cooling sufficiency that would be relevant for Denmark.

4.3 Electricity Use in EnergyPLAN

4.3.1 Input of Electricity Use input in EnergyPLAN

In EnergyPLAN electricity demand is treated as total electricity demand, including final electricity demand in the different sectors and electricity network losses. The inputs are:

- “Electricity demand”, which covers all sectors including grid losses, but it does not include electricity for transport (see section 4.4), or production of energy carriers (hydrogen and its derivatives, such as electrofuels). Electricity use in households is included in this demand.
- If there are different demands with different load profiles, it is possible to add a second electricity demand (labelled “Additional electricity demand”).
- If electricity for heating and cooling is included in the totals, EnergyPLAN allows that they are subtracted from the general electricity use, to avoid double counting, if they are included under the heating and/or cooling sectors.

To allow for flexible electricity demands that are not covered in other sectors (heating, cooling, transport, production of hydrogen, etc.), it is possible to include three types of flexible electricity demands:

- Electricity demand that can be flexible within one day (in TWh/year) and maximum demand capacity during use of this demand (in MW). This flexible demand is part of total annual electricity demand
- Electricity demand that can be flexible within one week (in TWh/year), and maximum demand capacity during use (in MW). This flexible demand is part of total annual electricity demand
- Electricity demand that can be flexible within 4 weeks (in TWh/year) and maximum demand capacity during use (in MW). This flexible demand is part of total annual electricity demand

For general and additional electricity demands, the distribution of the two demands over the year must be defined with files describing the hourly distribution of demands over the year.

4.3.2 Sufficiency in Electricity Use

Electricity is used for a multitude of purposes and for most of them it is possible to reduce consumption with energy sufficiency. The most important energy uses and proposed sufficiency actions to reduce them are described in section 3.1.7

Change of use of electricity to periods with large supply and/or small demands can also be included as energy sufficiency in electricity. This could be moving the time of use of washing machines and other energy consuming equipment.

In the service sector, electricity is also increasingly used for information technology and communication (ITC) while other larger uses are light, food preparation in restaurants, and refrigeration in food shops and storages. The demand for online data and for ready made food as well as for restaurants drive energy demands that are driven by people's private lives. They are in many ways similar to the direct demand for electricity and other forms of energy in dwellings, but we have not included them in this study.

In addition to the electricity used in the residential and traditional service sectors, there is an increasing hidden electricity demand in products. This includes energy demands for the production of goods, which is similar to other energy uses.

4.3.3 Examples of Policies for Sufficiency in Electricity Demands

In section 3.1.7 is described proposed sufficiency measures that together will reduce electricity consumption in dwellings, not including electricity for heating, with 20% in Denmark. IDAs Klimasvar includes a 10% reduction in this electricity until 2030, which will result in a consumption in 2030 of 9.27 TWh. With an additional reduction of 20% through sufficiency measures, the electricity demand will be reduced 1.85 TWh. This is to be subtracted from the general electricity demand. With the basis of IDAs Klimasvar, this is:

Electricity demand (general) IDAs Klimasvar	30.22 TWh
Reduction with energy sufficiency in dwellings	1.85 TWh
Electricity demand, IDAs Klimasvar + sufficiency	28.37 TWh

In this example, there are no other changes in input data. We have not included change of the time of use in this example.

4.4 Energy Sufficiency in Transport

4.4.1 Input of Transport Energy Use input in EnergyPLAN

In Energy Plan transport energy demand is divided in demands for 8 types of fuel and energy:

- Jet fuel (divided in fossil fuel, biofuel, electrofuel)
- diesel and DME (divided in fossil fuel, biofuel, electrofuel)
- Petrol and methanol (divided in fossil fuel, biofuel, electrofuel)

- Natural gas from gas network (only fossil), hourly variation of gas demand
- LPG gas (only fossil)
- Hydrogen, only produced by electrolyser from electricity
- Electricity, “dump charge”, hourly variation of demand
- Electricity, “smart charge”, hourly variation of demand, capacity of grid to vehicle in all vehicles, share of parked vehicles connected to grid, share of parked vehicles during peak demand, battery capacity.

In addition is an option for using electricity from parked cars for peak demand (vehicle-to-grid), where additional parameters are electric capacity of battery to grid connection, efficiencies of grid-to-battery and of battery-to-grid electric flows.

In EnergyPLAN, energy demands are for all transport types, including freight transport, trains, ferries, etc. Each fuel type often combines energy for different transport modes (as diesel for cars, trucks, trains, and buses, electricity for electric cars and trains). The energy demand of the different transport modes must be combined to determine the input data.

4.4.2 Sufficiency in Transport

In transport, sufficiency can include a number of practises: Each of the practises contribute directly to energy consumption of transport, which for personal transport can be calculated as:

$E = D_p * P * c_v/O$ where:

E is energy demand of personal transport

D_p is the distance each person makes on average in a year

P is number of persons

c_v is specific consumption of vehicle (for instance in kWh/km)

O is occupancy of vehicles

For more transport modes, the total energy demand is the sum of the different modes.

For energy sufficiency in transport, we include reductions in the distance that each person makes (D_p) and increased occupancy of vehicles (O), Reductions in specific consumption is energy efficiency.

4.4.3 Examples of Transport Sufficiency

The proposed energy sufficiency measures in section 3.2 can be used to develop reductions in the input data for EnergyPLAN. Fossil fuel should be divided in diesel, petrol and gas while electricity should be divided in dump and smart charge.

For division of fossil fuel, we base the scenario on IDAs Klimasvar and use the following assumptions for the transition to sustainable transport:

- Half the gas use is changed to electricity.
- All petrol use is reduced from BAU for 2030 (BAU scenario in IDAs Klimasvar), first with 43,5% from reduced use of cars and then with 39%/50% with the different change to electric cars in the two scenarios. The assumption behind this is that petrol is almost entirely used for private cars.
- Diesel for personal cars is reduced from BAU for 2030, first with 43,5% then with respectively 39% and 50% in the two scenarios.
- Diesel for other transport purposes is as in the IDAs Klimasvar.
- Electricity use is increased with 25% of the reduction in petrol + diesel use.
- Increased electricity use is with smart charging as it is used for private cars.

The results are shown in table 4.4.

Energy demand for domestic transport excl. air (TWh)								
	Fuel, personal cars	Fuel, other transport	Diesel	Petrol	N-gas	Electro-fuels + biofuels	Electricity, dump charge	Electricity, smart charge
BAU 2030	29.5	17.6	30.4	16.6	0.14	0	1.27	0.81
IDAs Klimasvar 2030	17.3	13.7	18.5	9.5	0.14	2.82	2.44	3.1
IDAs Klimasvar + additional sufficiency	10.2	13.7	15.2	5.7	0.09	2.82	2.44	1.9
IDAs Klimasvar + add. suff. + 50% electric cars 2030	8.4	13.7	14.4	4.7	0.07	2.82	2.44	2.4
Input for EnergyPLAN			YES	YES	YES	YES	YES	YES

Table 4.4 Input data for EnergyPLAN for energy demand for transport for different Danish scenarios with and without sufficiency measures. Given the increase in electric vehicles, the

charging and battery capacity for electric vehicles could be increased/decreased similarly to the increase/decrease in smart charge.

5.0 Development of energy model: MESSAGE

This project used the MESSAGE model to model Lithuanian and Latvian energy development scenarios with sufficiency modelled in an exogenous way (see Work package 4 report “Development of revised national sustainable energy scenarios for Denmark, Latvia and Lithuania”) and to test endogenous sufficiency modelling methods. As previously described exogenous modelling steps can be implemented for different energy system models, including MESSAGE, in this part of the report we will concentrate on endogenous modelling that requires more flexibility of a modelling tool.

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental impacts) is a modelling framework for medium- to long-term energy system planning, energy policy analysis, and scenario development. Although there are several varieties of the tool, they share some common features that are also typical for other popular energy modelling tools such as TIMES or OSeMOSYS (for a comprehensive overview of tools and their features see (Connolly, Lund, Mathiesen, & Leahy, 2010; Prina, Manzolini, Moser, Nastasi, & Sparber, 2020; Ringkjøb, Haugan, & Solbrekke, 2018)). The main features of MESSAGE model to be highlighted in the context of sufficiency modelling are:

- It is an energy supply model, representing energy conversion and utilisation processes of the energy system (or its part) and their environmental impacts for an exogenously given demand of final energy (or energy services; this approach can be relaxed by modelling sufficiency and efficiency measures as alternative ways to satisfy exogenous demands);

- It is used to develop long- and medium-term strategies (modelling time scope is limited only by input data uncertainties). The energy system dynamics is modelled by a multi-period approach;

- The optimisation is used to calculate the least-cost energy supply system under defined constraints. The model minimises the total discounted energy system cost, subject to the constraints representing demands, resource scarcity, capacity bounds, etc.

The representation of the energy system in the model created in the MESSAGE tool is based on a network concept. The activities and relationships of the energy system are described as an oriented graph, depicting the energy chain starting from extraction or supply of primary energy, passing through the several energy conversion processes (e.g. electricity generation, transmission, and distribution) to satisfy the demands in the industry, household, transportation, and other economy branches. Using the notation of the oriented graph, the links of the graph represent technologies or transportation and allocation processes of energy, whilst the nodes represent energy forms (like electricity, oil, and gas).

There is no strict pre-defined structure of the oriented graph used in the model. Its design depends on the reference energy system and research questions to be answered by the modelling. The user has a lot of flexibility in designing the model (and its reference energy system) depending on the research questions. Therefore, new methods for sufficiency integration to energy planning models in the MESSAGE environment can be created using ordinary tools of the program.

In this project, the MESSAGE V version from the International Atomic Energy Agency (IAEA) was applied for testing purposes. Still, the sufficiency modelling solutions developed are expected to be suitable for both different MESSAGE varieties and other modelling tools that share the same paradigm. Therefore, in the description of sufficiency modelling in MESSAGE, we focus on modelling principles rather than their implementation in a particular tool.

5.1 General principles of endogenous sufficiency modelling

The main idea behind endogenous sufficiency modelling is that energy sufficiency and efficiency can be understood as alternative resources that can be modelled similarly to energy generation technologies. This is crucial in prioritising policy options and ensuring a level playing field among energy generation options, efficiency, and sufficiency.

In sufficiency modelling, it is important to distinguish positive and normative approaches. The positive approach illustrates possible changes in demand due to different consumption reduction options introduced to the model. They appear to be the optimal solution if they are more attractive than energy consumption for various reasons (change in values, additional support, etc.). The positive approach tries to mimic reality and show what would happen under certain conditions. The normative approach sets targets (e.g., carbon reduction) and looks for the least cost scenario to achieve them. Sufficiency actions are described reflecting their cost (e.g., of lost comfort) and may appear in the solution if they allow overall cost reduction. The normative approach aims to determine what should happen.

The main difference is that the outcomes of the positive approach are expected to happen without additional measures, while the outcomes of the normative approach require extra effort to be implemented (e.g., policies that encourage sufficiency actions). Both approaches are necessary for policy development and can be implemented in energy planning models.

Due to its flexibility in designing the energy system modelled, the MESSAGE tool provides an opportunity to reflect the same energy system in different ways. Figure 5.1 can illustrate this by showing three heat supply modelling examples that may reflect different research questions.

The easiest and least data-requiring modelling way is depicted in the upper-left (a) part of Figure 5.1. In this case, heat demand in the entire system modelled can be satisfied by three supply options: gas heating, biomass heating, and district heating. While gas and biomass heating are modelled more explicitly by providing details on fuel supply, district heating is depicted without any inputs. Thus, this model takes the consumer‘s perspective focused on district heat price and its comparison to locally available heat production options (in this case, gas heating and biomass heating). In this example, the model pays no attention to the possible changes in district heat production facilities that could, in principle, increase the attractiveness of district heating, e.g., by moving from natural gas to biomass in district heat production.

These details are reflected in the upper-right (b) part of Figure 5.1, which shows heat plants and natural gas distribution systems, possibly reflecting that gas supply to retail consumers may be more expensive. More details on the district heat production side in this configuration of the reference energy system allows the modeller to provide more insights on the development of the district heating system and the competitiveness of other heat supply options in the context of district heating system development.

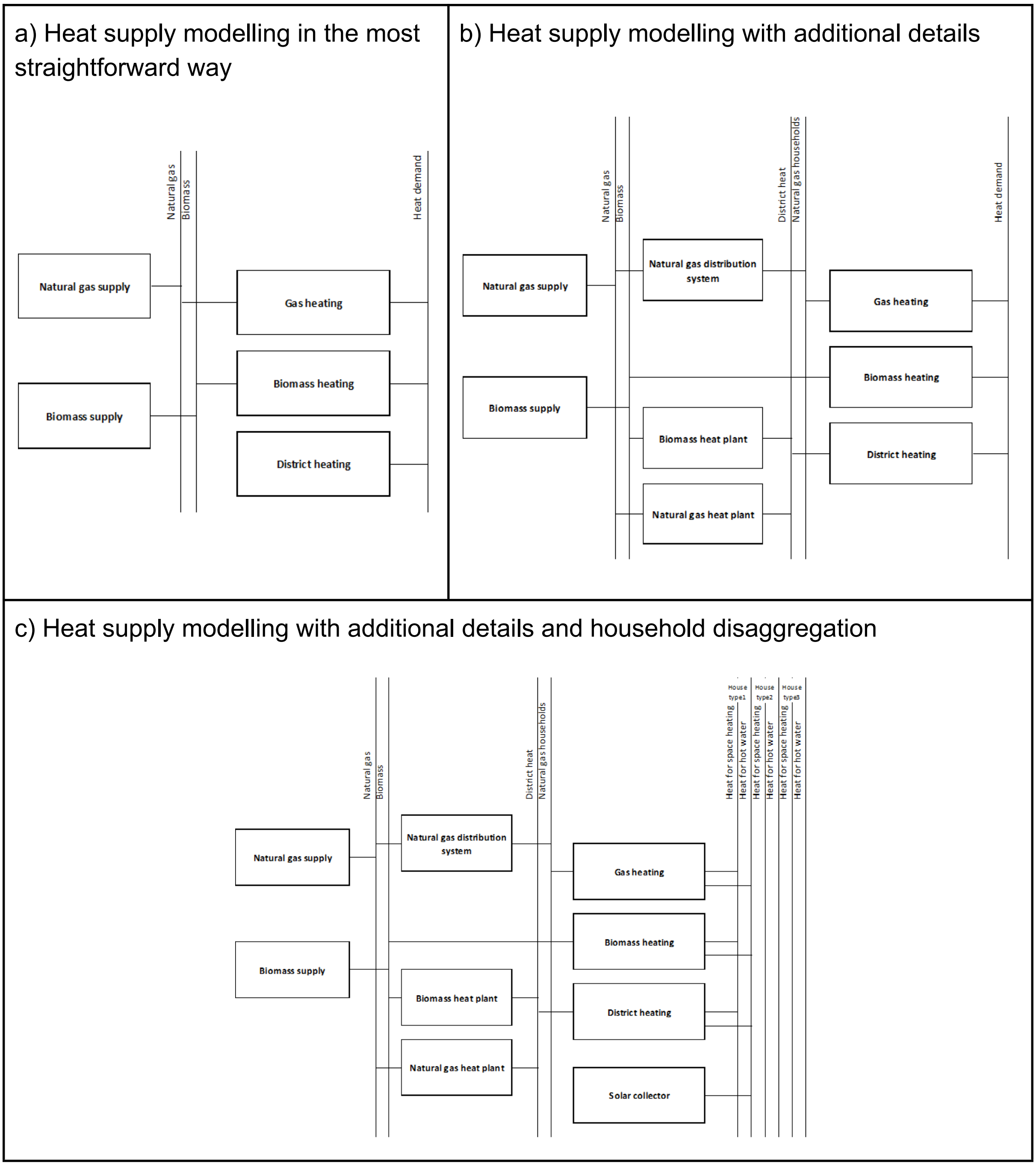

Fig. 5.1. Different ways to describe heat supply options in the model

The lower part of Figure 5.1 shows a further enhanced reference energy system that disaggregates heat consumption by purpose (space heating and hot water preparation) and household types. These disaggregations could be necessary if, for example, a modeller is interested in the possible penetration of solar collectors into the market. It might be well that not all houses are evenly suitable for constructing solar collectors, and household disaggregation can reflect potential differences. On the other hand, the disaggregation of heat consumption by purpose allows better reflection of generation capacities used to satisfy different needs.

The same example of heat supply modelling can also be employed to illustrate sufficiency and efficiency modelling principles. Figure 5.2 shows examples of additional technologies that can be introduced to the model to reflect some sufficiency and efficiency options.

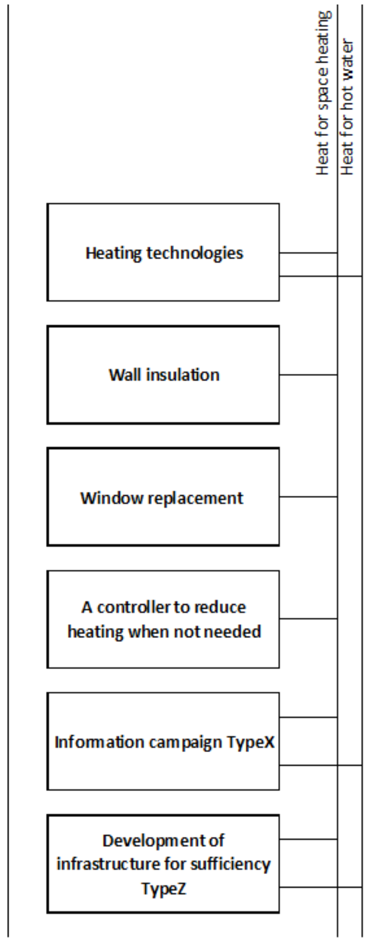

Fig. 5.2. Updating reference energy system to reflect energy sufficiency and efficiency

In Figure 5.2, heating technologies are shown in an aggregated way but can be described with more details, similar to the examples provided in Figure 5.1. Energy efficiency and sufficiency options can be described using similar principles as energy generation technologies (these options are also called 'Technologies' in MESSAGE). For example, the main properties of wall insulation reflected in the model are the investment required and increased thermal resistance that results in reduced heat demands. From the modelling point of view, wall insulation can be imagined as a technology that requires some investment and “generates" heat savings. However, a modeller must be careful in modelling to avoid situations with unrealistic savings (e.g., when savings exceed demands). The same modelling principle can be applied to other efficiency measures such as window replacement.

Additional devices that reduce energy use when not needed are somewhere between efficiency and sufficiency as they also involve behavioural issues. Their modelling may involve not only investment, as is the case with many efficiency measures, but also some operation cost and, importantly, changes in load curves they cause. Both efficiency and sufficiency measures can contribute to solving such energy system issues as peak shaving and/or better integration of renewables due to demand adjustments. Therefore, behavioural actions that not necessarily reduce energy consumption but, for example, shift energy demands towards periods with better availability of renewable energies can also be considered sufficiency actions.

Energy sufficiency is often related to different measures that enable it. There are some voluntary sufficiency examples where energy demand reductions are obtained without additional cost, a more general approach would say that in those cases, the costs were equal to zero. Following this understanding, the modelling of some sufficiency measures can be put to the same framework as modelling of energy generation sources or efficiency. Figure 5.2 exemplifies this by an information campaign that has its costs and provides some results (changes in consumer behaviour that lead to energy demand reductions) and the development of infrastructure that enables more sustainable lifestyles and energy demand reductions.

Theoretically, such examples of integrated modelling look very attractive, but there are many practical challenges for modelling with sufficiency. Correct “technical” representation of sufficiency in the models and avoiding unrealistic assumptions is one and, perhaps, not the most complicated side. Separate sufficiency actions (e.g., reduced washing with no sufficiency or efficiency alternatives modelled) is the most straightforward modelling case, but it usually requires pre-screening of possible alternatives to ensure that important combinations of options are not missed. In reality, combined actions are much more prominent. For example, reduced space might be combined with reduced temperature and increased building energy efficiency. The modelling challenge here is avoiding double-counting to provide a fair comparison of alternatives. The reflection of energy service demands independently from technologies and their efficiency (and sufficiency) considerations contribute to resolving this challenge. For example, heat demand can be reflected by the area to be heated and heating degree days instead of energy units (heat demand of a certain number of megawatt-hours actually refers to a specific efficiency level of a building).

Sufficiency measures driven by economic rationale fall to the same conceptual structure that is employed in energy modelling tools under consideration. Thus, they are the easiest to implement in the models. Still, the fact that economic cost is not the only driving force must be acknowledged in any case. „Soft“ sufficiency measures and behaviour/lifestyle changes are much more difficult to model, and sometimes only exogenous assumptions about their impact on energy service demand can be integrated into an economic model. Additional parameters (e.g., the market penetration rate of sustainable consumption practices) can just partially reflect this issue. Studies on willingness to accept/adopt sufficiency behaviour may help increase comparability of sufficiency in the context of other decarbonisation options. Finally, option ranking approaches may be implemented instead of sufficiency monetisation in some cases. With limited data on the perceived cost, option rankings may be evaluated and reflected in the model by their relative cost. The least acceptable sufficiency actions can be reflected by the very high cost to be selected only in extreme cases (e.g., if there is a strict carbon ceiling and there are no other suitable decarbonisation options).

Another crucial issue with sufficiency that contrasts with traditional energy modelling is the huge diversity of actors and their preferences. Therefore, models need to include a high disaggregation level of energy consumers to reflect their diversity in technical and social and behavioural terms. Different households may have different sufficiency enablers and their reflection may differ as well as the perceived cost of sufficiency and actions needed. High disaggregation, however, comes at the cost of computational complexity. Therefore, there is a need to find a balance that ensures the model’s solvability and accuracy.

Due to different drivers, endogenous modelling of sufficiency can only be a „step forward“ in understanding the possible role of sufficiency rather than a complete modelling solution.

5.2 Sufficiency in the use of household appliances: the case of washing

Sufficiency modelling in household appliances is illustrated in Figure 5.3 by providing an example of washing.

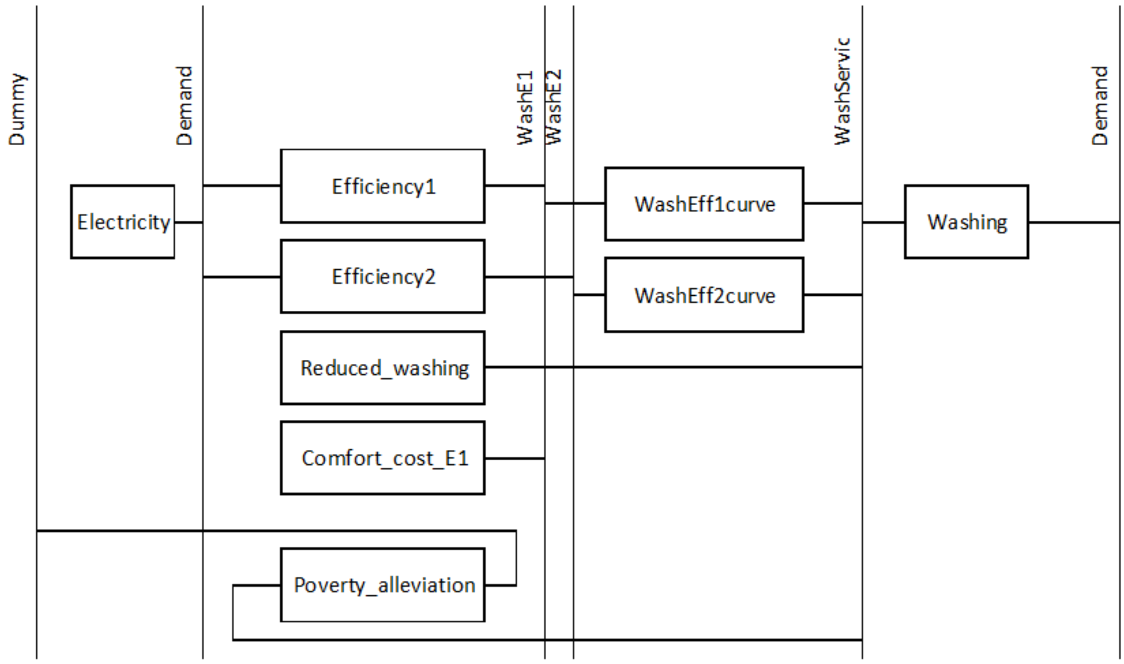

Fig. 5.3. An example of sufficiency modelling in appliances

Here, washing demand can be reflected by the number of washing cycles needed. They can be provided by washing machines with different efficiencies (Efficiency1 and Efficiency2 in Figure 5.3). Obviously, investment in these machines is different. Thus, it might be good that a more efficient solution is taken just after the end of the lifetime of the existing less efficient device. Dummy technologies WashEff1curve and WashEff2curve are used to ensure the correct representation of washing machine replacement in multiple households (if one demand node represents several households, the model tends to use the most efficient solution as much as possible, but in reality the new washing machine would be used just in one household or additional sharing solutions would be needed). Three sufficiency technologies represent different possible aspects of the issue. Reduced_washing represents changing social norms that are not associated with comfort loss. While the washing demand in the model remains unchanged, it is partially satisfied by Reduced_washing technology that has no inputs and does not use electricity. Technology Comfort_cost_E1 represents the case when reduced washing is associated with some inconveniences or loss of comfort that may be estimated by willingness to accept studies. In Figure 5.3, it is assumed only for households with less efficient (Efficiency1) washing machines. Finally, Poverty_alleviation represents another side of sufficiency – increased washing in households that were unable to satisfy what is considered as basic needs.

5.3 Sufficiency in heating

Similar principles are applied for the endogenous modelling of sufficiency in heating. However, the modelling is more complex as more factors have to be taken into account. The example of sufficiency modelling in heating is provided in Figure 5.4.

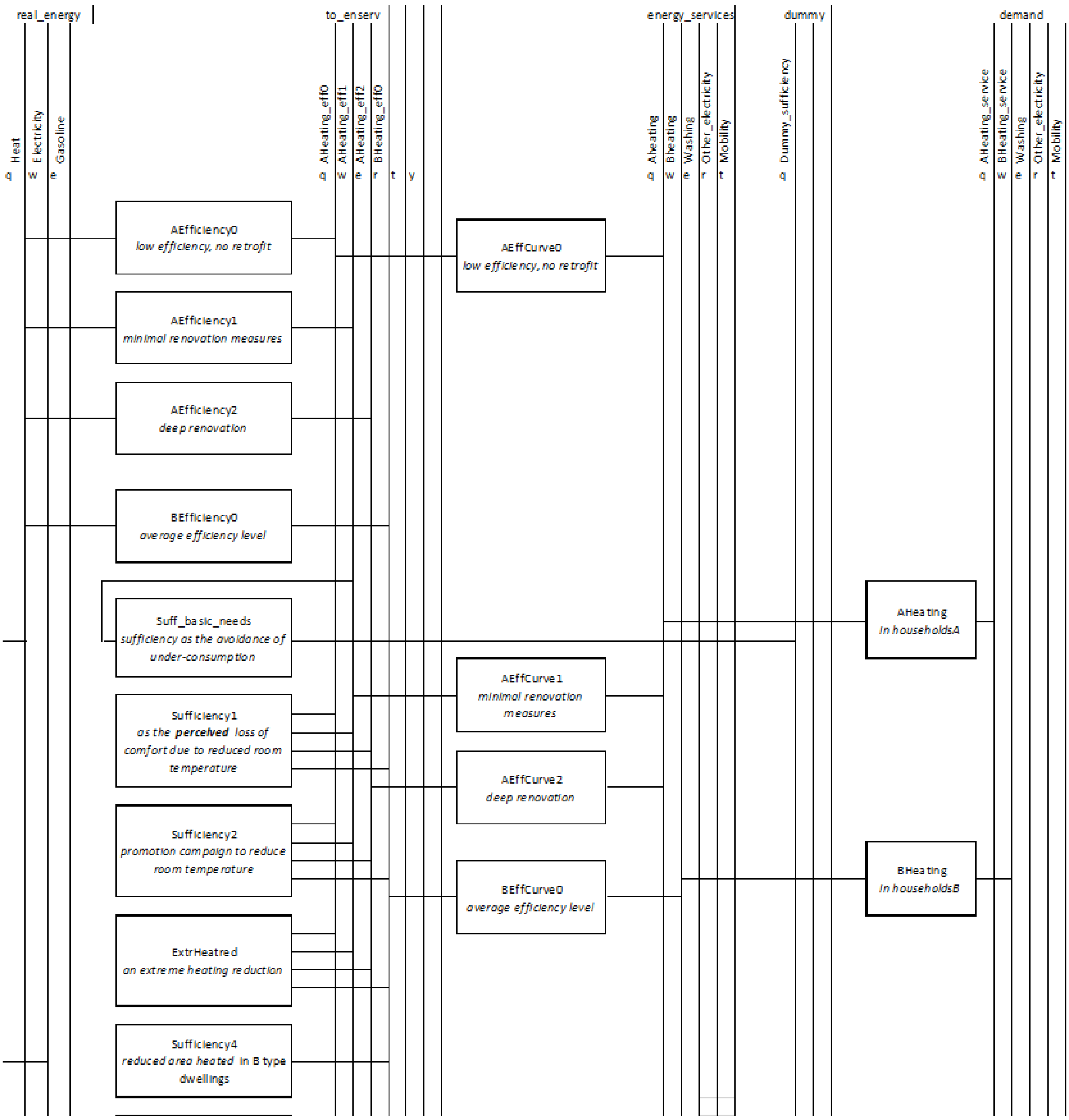

Fig. 5.4. An example of sufficiency modelling in appliances

Different modelling options are possible and their reflection in the model depends on the questions analysed. In this example, two household types A and B are analysed. For households of type A, three efficiency options are introduced from low efficiency to deep renovation. As in case with washing, efficiency curves are used to ensure that efficiency gains are provided to the correct amount of households. Also, different sufficiency options are introduced. Suff_basic_needs is meant for energy poverty alleviation and represents sufficiency as an avoidance of under consumption. This technology uses heat as input and transfers it to the dummy level to ensure that a sufficient amount of heat is produced in the system. Sufficiency1 represents perceived loss of comfort due to reduced room temperature (its cost must be estimated from separate studies). Sufficiency2 represents effects of the promotion campaign similarly as with the example in Figure 5.2. ExtrHeatred represents an extreme heating reduction by using modelling technique that does not require a cost estimation: the modeller may assume any big cost number to ensure that this option will be included to the optimal solution in case of absolute need (e.g., if any other combination of options available is unable to ensure desired decarbonisation level). Finally, Sufficiency4 represents reduced area heated only in B type households.

5.4 Sufficiency in transport and mobility

There are many options for transport modelling in energy planning models. Figure 5.5 provides a very simple representation with mobility demand and different options to satisfy it.

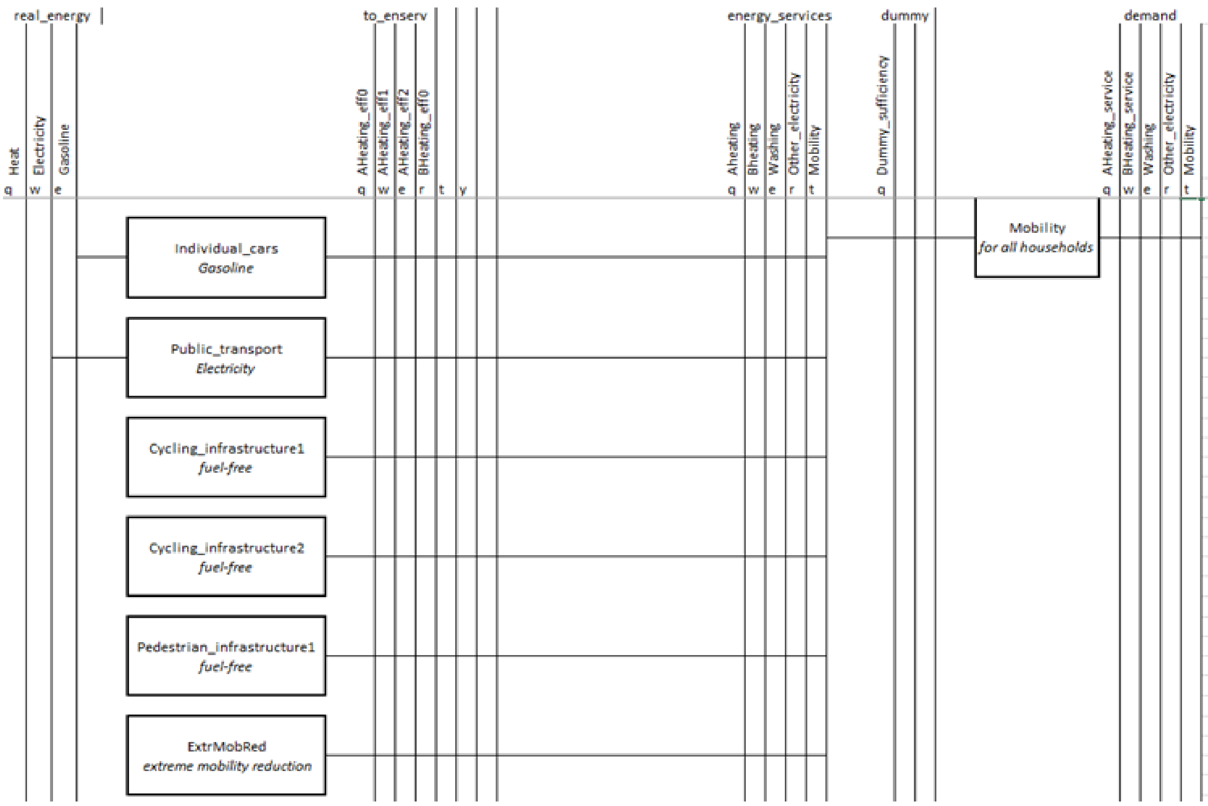

Fig. 5.5. An example of sufficiency modelling in appliances

To represent the dynamics of the sector, more details have to be modelled, but such a framework is useful to highlight the role of energy sufficiency. In this case, it is reflected by technologies that represent sufficiency enablers and contribute to satisfying mobility demands. For example, cycling and pedestrian infrastructures require investments but, as a result, create conditions needed for reduced car use. In the model, this is reflected by technologies that have investment and variable cost but no fuel input and contribute to satisfying mobility demands.

Conclusions from Chapter 5

- Many sufficiency measures can be endogenously modelled in the traditional energy planning models.
- However, new models need to be built with highly disaggregated demand sectors.
- Data on sufficiency remains the main challenge.