Explore sustainable European futures

WP8 - Integration of the Lifestyle & Climate modules

D8.3

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Short Description

This deliverable describes the linkages of the Lifestyles and Climate modules in the general architecture of the EUCalc model. The connections are detailed both in terms of inputs and outputs between the Lifestyle and Climate modules with the other modules, and also in terms of outputs to the Transition Pathway Explorer (TPE), the user-friendly web-interface via which the EUCalc can be used. Furthermore, this deliverable also details the main calculation trees in the Lifestyle and Climate module. The input data is also made available. Although this deliverable is self-contained in terms on understanding the functioning of the Climate and Lifestyles modules, more detailed descriptions are available in the EUCalculator site http://www.european-calculator.eu/documentation/

Quality check

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This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

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List of abbreviations

BMI – Body Mass Index

BMR – Basal Metabolic Rate

EU LFS – European Labour Force Survey

GHG – Green House Gases

ISIMIP – Inter-Sectoral Impact Model Intercomparison Project

PAL – Physical Actively Levels

Pkm – Passenger kilometres

RCP – Representative Concentration Pathway

RoW – Rest of the World

WHO – World Health Organization

1 Executive Summary

This deliverable makes a detailed accounting of the integration of the Lifestyle and Climate modules in the EUCalculator modelling framework. The connections to the other modules - in terms of inputs sent and outputs received - are listed and the calculation taking place within both modules described. Examples of the integration of the Lifestyle and Climate modules with other modules are shown via the current version of the Transition Pathways Explorer (TPE), the user-friendly web-interface via which the EUCalculator model can be used. For both modules focus of this deliverable the ambition levels for each of the levers considered are described. Finally, in the spirit of the calculators before us, the current version of the data inputs files is made available.

2 Introduction

The Lifestyle and Climate module are placed quite upfront in the modelling chain, see Figure 1. The Lifestyle module sets, directly or indirectly, much of the demand for resources, energy and GHG emissions in the EU calculator model. This is done by requesting the activity modules (e.g., Agriculture, Building, Energy, etc in Figure 1) the fulfilment of a determined level of demand for products and resources. For example, the Lifestyle module computes the total travel demand of a country attending to differences in travel patterns across age and gender groups. It then sends this information to the transport module which in turn determines the necessary number of cars, trains, planes etc. needed to satisfy that demand.

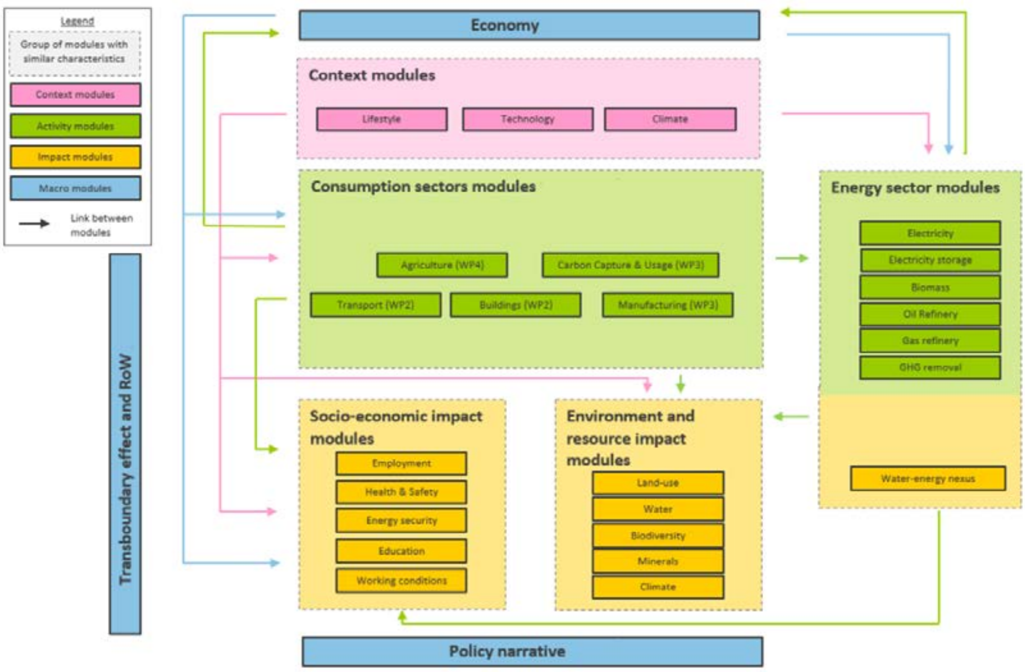

Figure 1- Overview of the EUCalculator model architecture.

The Climate module provides the EUCalculator model with the initial global climate time series based on differential levels of mitigation ambition undertaken by the rest of the World (RoW). This information allows those modules whose EU emissions are dependent on local temperature (e.g., buildings or electricity) to factor in the effects of global climate change when calculating their energy and GHG emissions.

This approach eliminates feedback loops, which could have become infinite if a direct emissions approach was taken. Unlike the Lifestyle module, whose outputs all flow into activity modules, the Climate module also provides outputs using information from the activity modules as inputs, namely: consolidated emissions from activities, and climate-related impacts entailed in temperature and precipitation change, e.g., persons affected by flooding globally.

2.1 Integration of the modules

The Lifestyle and Climate modules are currently fully integrated into the EUCalculator model and provide/recieve outputs/inputs to/from other modules. The outcomes of these interactions can be observed in the current version of the TPE, Transition Pathways Explorer; the user-friendly web-interface via which the EUCalculator model can be used. Some results of the integration are shown below. It is important to highlight that at the moment of writing the EUCalculator model is undergoing calibration and therefore the number shown in this deliverable are preliminary only.

Figure 1 shows the outputs of the Transport module to the TPE using the inputs of passenger distance provided by the Lifestyle module. In the particular case results show the passenger distance resulting from the Lifestyle choice of a level 1 ambition, that is, that passenger distance in EU28+Switzerland evolves in time following the past observed trends (which indicate an increase in travel per person per year).

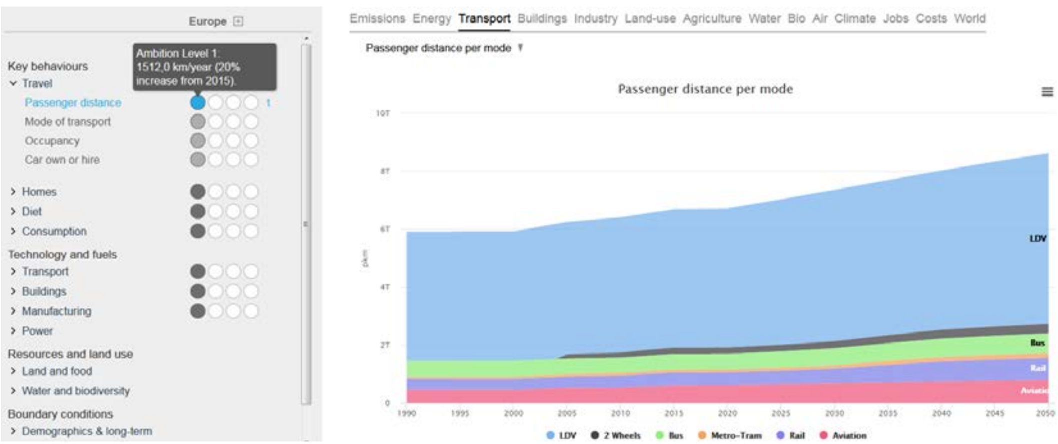

Figure 2 – Evolution of passenger distance per mode in EU28+Switzerland in the Transport module implied by level 1 passenger distance trajectory provided by the Lifestyle module.

Similarly, Figure 3 shows the evolution of the amount of livestock - an output of the Agriculture model - entailed in the dietary trajectories of the population provided by the Lifestyle module (showing maximum level of ambition in dietary shifts).

It is important to notice that in some cases the inputs of the Lifestyle module influence outputs of another module in an indirect way. For example, the amount of steel and aluminium demand arriving at the Manufacturing module is determined by the number of vehicles determined in the Transport module that in turn is a function of the passenger travel demand provided by the Lifestyle module.

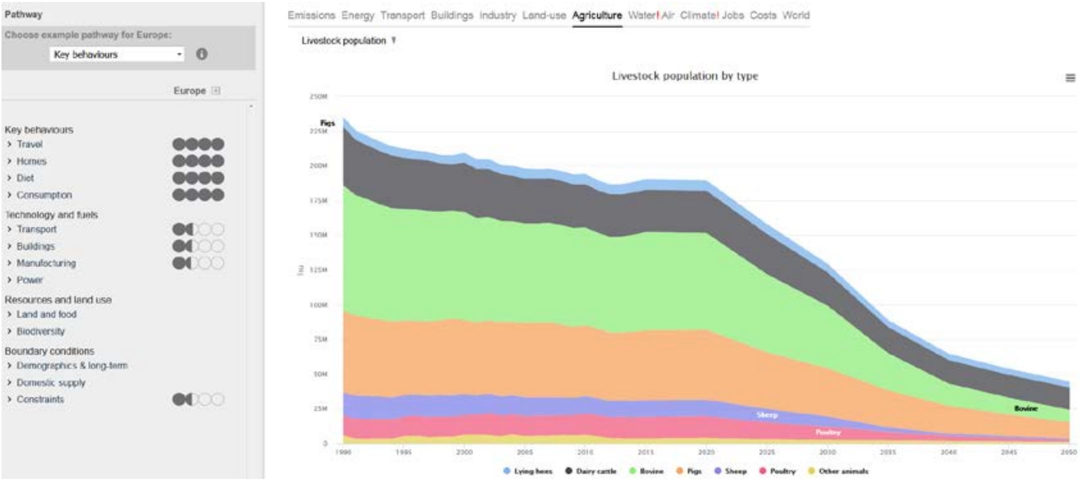

Figure 3 – Livestock evolution in EU28+Switzerland from the Agriculture module implied in the level 4 dietary trajectories provided by the Lifestyle module.

An example of outputs generated by the climate and emissions module and presented in TPE is shown in Figure 4. The top panel depicts the global temperature evolution implied by setting the RoW GHG emission reduction ambitions to level 1, while the bottom panel depicts the evolution implied when setting the lever to level 3. As expected, the global temperature change by the end of the century decreases with increasing effort to reduce GHG emissions.

Figure 4 – Global temperature evolution implied in the RoW GHG emissions reductions Top: Level 1; Bottom: Level 3.

The effects of changing the level of the RoW GHG emission reduction ambitions on other variables than the global temperature are generally less pronounced but still clearly visible. For example, in the case of water availability, reducing GHG emissions and thus the global temperature results in a decrease in water scarcity for many European regions (Figure 5).

Like in the Lifestyle module, the inputs of the Climate module indirectly influence outputs of another module. For instance, a fraction of the energy demand arriving at the energy modules is determined by the amount of heating/cooling needed by the Buildings module, which itself is a function of the temperature provided by the Climate module.

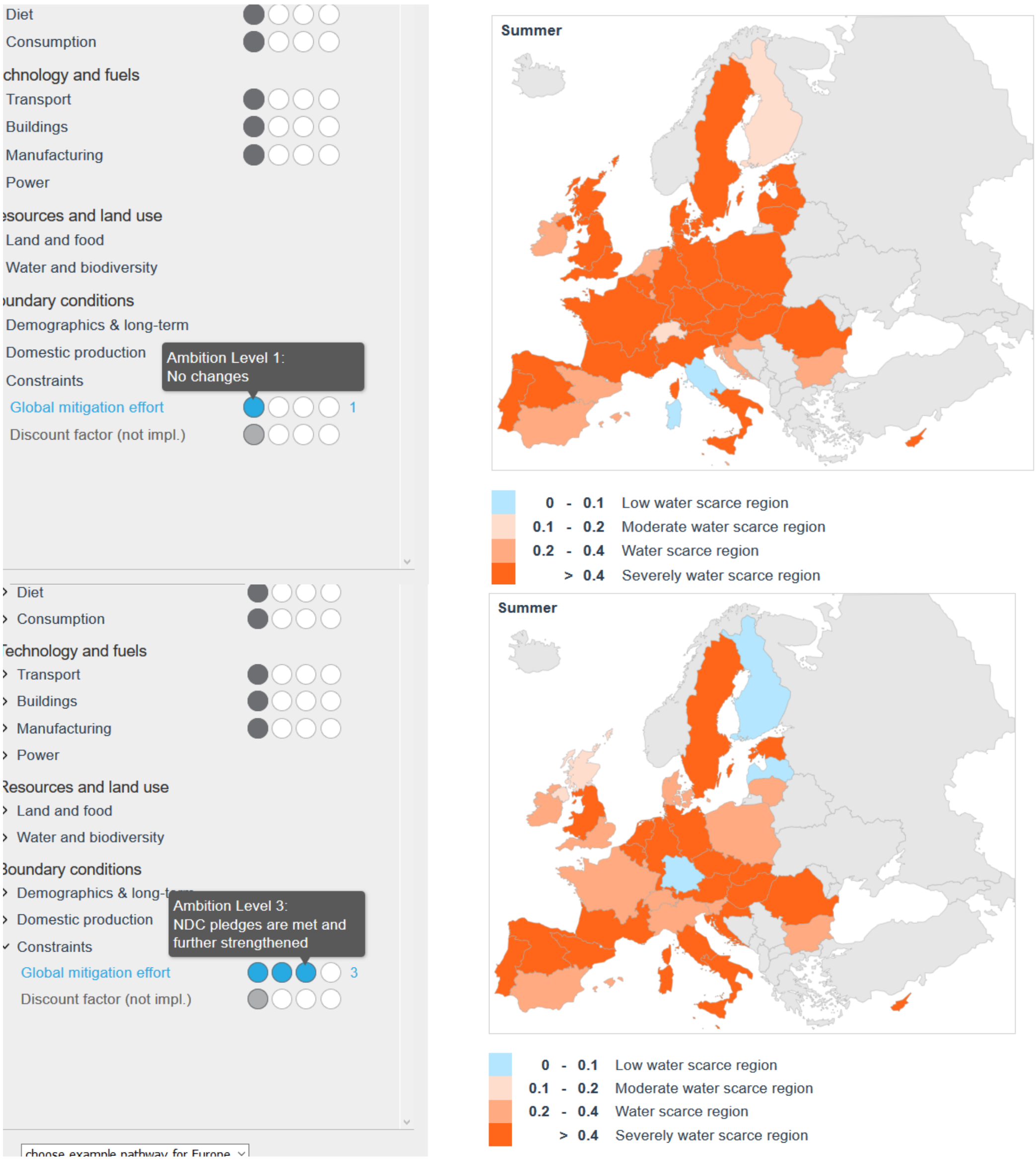

Figure 5 – Water scarcity implied in RoW emissions reductions.
Top: Level 1; Bottom: Level 3.

3 Climate Module

3.1 Overall logic

The disparity between actions taken within the EU and what happens in the RoW has created potential difficulties for EUCalculator. It has been unclear how to properly set the emission assumptions and temperature thresholds within EUCalculator when considering how the RoW behaves and which policy decisions they make. Ultimately, even a completely decarbonised EU can only affect the global temperature by a small amount, unless others follow its lead. This module (lever settings) allows the user to make assumptions about how the RoW behaves and how the resulting climate impact, in turn, feeds back on the European decarbonisation efforts in the other modules. By making the decision about the RoW behaviour upfront, the user can better see the relevant emission savings by decarbonising their own sector. For example, if the RoW is on a Business as Usual pathway (4.5°C warming) then buildings will require more cooling, and there may be constraints on power generation if they cannot cool the power station. Thus, overall fewer emissions can be saved in these sectors as more emissions would need to be generated to achieve the same results.

Setting the RoW ambitions up-front also breaks the feedback loop between GHG emissions and resulting climate conditions in EUCalculator. Reducing GHG emissions has a direct effect on global temperatures which in turn affect emissions and emissions reduction potentials. The framework of EUCalculator does not allow direct modelling of such a loop and it needs to be broken (see Matton et al, 2018, Deliverable 8.2, section 4.2.2). Using climatic conditions based on RoW ambitions to drive the model removes the dependency between GHG emissions and temperature and allows the model to run. The calculation logic adopted here is straightforward but requires other modules to either have spreadsheets for emissions at 1.5, 2, 3.2 and 4.5°C above pre-industrial or to develop a damage function that equates levels of warming with emissions in their modules.

The climate and emissions module also collects the various emissions from the other modules and turns those into CO_2- warming-equivalent emissions and then to a global temperature response.

3.2 Scope definition

The climate and emissions module enables an assessment of how the EU is affected by how the rest of the world decarbonises. As mentioned above, the RoW will have a major impact on GHG emissions and thus global temperatures and changes in climatic conditions. These changes have a direct effect on multiple sectors and thus directly affect the EU's ambitions to reduce GHG emissions.

- Energy demand for heating and cooling of buildings depends on near surface temperature, wind speed and near surface downwelling radiation.
- Capacity factors of wind turbines and sun collectors for energy production are affected by temperature.
- Water availability is mainly driven by precipitation.
- Agricultural food production (crops) depends on temperature, precipitation and CO_2 concentration levels.

In addition, the module enables a coherent conversion of GHG emissions into a warming-equivalent quantity of CO_2 emissions and the projection of European and global emissions until 2100. The module uses the projected emissions to estimate the resulting global temperature change and thus allows assessing the impact of rising temperatures for a variety of sectors beyond 2050. By estimating the global temperature response, it is further possible to project potential physical impacts (e.g. flooding) at the end of the 21st century

3.3 Interactions with other modules

Specific modules (energy, buildings, water, agriculture) worked with UEA to feed appropriate lever settings equating to which years equal a given level of warming from this module to their modules. In the case of buildings, the basic climate data was provided to them to pre-calculate the emissions related to heating and cooling based on climate variables.

3.3.1 Inputs for the climate and emissions module

The climate module receives GHG emissions from GHG emission producing sectors.

Table 1- List of inputs to emissions module

Module	Variable
2.1 Buildings	bld_emissions-CH4[Mt] bld_emissions-N2O[Mt] bld_emissions-CO2[Mt]
2.2 Transport	tra_emissions-CH4[Mt] tra_emissions-N2O[Mt] tra_emissions-CO2[Mt]
2.3 District Heating	dhg_emissions-CH4[Mt] dhg_emissions-N2O[Mt] dhg_emissions-CO2[Mt]
3.1a Industry	ind_emissions-CH4[Mt] ind_emissions-N2O[Mt] ind_emissions-CO2[Mt]

3.1b Industry Ammonia	amm_emissions-CH4_ammonia[Mt] amm_emissions-N2O_ammonia[Mt] amm_emissions-CO2_ammonia[Mt]
4.1 Land-use	lus_land_emissions-CO2_total[Mt]
4.3 Agriculture	agr_emissions-CH4[Mt] agr_emissions-N2O[Mt]
4.5 Biodiversity	bdy_emissions-CH4[Mt] bdy_emissions-N2O[Mt] bdy_emissions-CO2[Mt]
5.1 Electricity	elc_emissions-CO2[Mt]
5.2 Oil Refinery	fos_emissions-CO2[Mt]

3.3.2 Outputs from the climate and emissions module

3.3.2.1 Buildings

The interface between the climate and the buildings modules currently consists of the RoW ambition level, which is directly tied to global temperature. The buildings module uses this information to select the appropriate levels of wind-speed, near-surface temperature and surface downwelling longwave radiation from the ISIMIP database (see 8.1 Databases for climate module).

3.3.2.2 Agriculture

The agriculture module enables the assessment of climate-smart cropping systems for which it needs to estimate crop yields. Crop production is directly affected by precipitation, temperature and CO_2. The climate and emissions module thus provides the agriculture module with a crop production change factor based on the selected RoW ambition level. The change factors were derived from pathways created by FAO (2018). These pathways are based on RCP scenarios and the resulting change factors can thus be directly linked to the RoW ambitions level.

3.3.2.3 Water

The water module estimates water stress as a warning sign for water scarcity as a ratio between water availability and water consumption. Water availability is mainly driven by precipitation which itself is driven by climatic conditions. The climate and emissions module thus provides the amount of water available based on which RoW ambition level is selected. These availability values were derived from a spatially explicit water model creating projections for water resources based on RCP 4.5 and RCP 8.5 climate scenarios (Bisselink et al., 2018). The RoW ambition lever was then matched to appropriate time points in those models runs.

Table 2 - Description of data used to describe future water availability based on RoW ambition lever

RoW ambition level	Description of water resources data used
1	Annual output for period 2016-2050 from model runs based on RCP 8.5
2	Annual output for period 2016-2050 from model runs based on RCP 4.5
3	Annual output for period 2016-2048 from model runs based on RCP 4.5. Recourse levels in years 2049-2050 are kept at level available in 2048.
4	Annual output for period 2016-2030 from model runs based on RCP 4.5. Resource levels in years 2031-2050 are kept at level available in 2030.

3.3.2.4 Electricity

The interfaces between the climate and electricity modules work similarly to the interface between climate and buildings (WP2). The climate module provides the RoW ambition level which allows the selection of temperature-dependent capacity factors.

3.3.2.5 Transition Pathway Explorer

The Transition Pathway explorer displays the output associated with selected lever settings. In case of the climate and emissions module TPE displays the estimated global temperature response and global physical impacts in 2100. The module also provides TPE with cumulative GHG emissions which are used by the TPE interface to represent and adjust the budget to stay below the temperature target.

Table 3 - List of outputs from climate and emissions module to other modules

Module	Variable	
2.1 Buildings	ClimateLeverLevel[num]	
4.3 Agriculture	clm_tmp-annual_cop_yield[%]	
4.4 Water	ClimateLeverLevel[num]	
5.1 Electricity	ClimateLeverLevel[num]	
0.2 Pathway Explorer	bdy_emissions-CO2e[Mt] amm_emissions-CO2e[Mt] fos_emissions-CO2e[Mt] elc_emissions-CO2e_...[Mt] agr_emissions-CO2e_...[Mt] lus_emissions-CO2e_...[Mt]	clt_cstlflooding-mean[people] clt_cstlflooding-min[people] clt_vertebrates-max[%] clt_vertebrates-mean[%] clt_vertebrates-min[%] clt_plants-max[%]

	ind_emissions-CO2e_...[Mt]	clt_plants-mean[%]
	tra_emissions-CO2e_...[Mt]	clt_plants-min[%]
	bld_emissions-CO2e_...[Mt]	clt_mammals-max[%]
	dhg_emissions-CO2e_...[Mt]	clt_mammals-mean[%]
	clt_emissions-CO2e[Mt]	clt_mammals-min[%]
	clt_global-temp[degC]	clt_birds-max[%]
	clt_drought-max[people]	clt_birds-mean[%]
	clt_drought-mean[people]	clt_birds-min[%]
	clt_drought-min[people]	clt_invertebrates-max[%]
	clt_flvflooding-max[people]	clt_invertebrates-mean[%]
	clt_flvflooding-mean[people]	clt_invertebrates-min[%]
	clt_flvflooding-min[people]	clt_cum-emissions-CO2e[Mt]
	clt_cstlflooding-max[people]	

3.4 Detailed calculations

3.4.1 Climate

Based on the RoW temperature lever setting, the climate module loads all necessary data from the database and passes the appropriate data on to other modules.

3.4.2 Emissions

3.4.2.1 EU cumulative emissions

Building, industry, transport, land-use and energy modules generate GHG emissions (Table 2). Emissions are summed into EU totals for each of CO_2, CH_4, N_2O. SO2 hasn't been modelled explicitly when calculating the temperature response in EUCalculator on the basis there is a rough offset between negative aerosol radiative forcing and positive other GHG radiative forcing, so temperature response is well modelled to a first approximation by only CO_2, CH_4 and N_2O emissions. The ability to include SO_2 emissions in the climate module calculation in the future has been designed into the code. These annual time series between the years 1990 and 2016 are calibrated to match the EuroStat emissions inventories for each gas over this period. The 2016 scaling factor is used for all future times. This accounts for missing emissions from the sector output of EUCalculator.

To find the global temperature response, the module combines the separate gases into a physically realistic CO_2-warming-equivalent quantity. By warming-equivalence we mean the CO_2 emissions profile which produces the same warming response as the separate gas emissions. Long-lived gases (lifetime > 100 years; CO_2, N_2O), are converted to their CO_2-warming-equivalent using the

GWP metric with a 100-year horizon (GWP_{100}), while short-lived gases (lifetime < 100 yrs; CH_4, SO_2) are converted using an updated GWP* metric (Allen et al. 2018, Cain et al. 2019). Short-lived and long-lived gases are treated differently because the GWP_{100} metric does not adequately represent the relationship between the emissions of short-lived pollutants and their corresponding temperature response (Cain et al. 2019).

For SO_2, the module uses GWP* following Allen et al. (2018) (Eq. 1), while it uses GWP* following Cain et al. (2019) for CH_4 (Eq. 2).

$$E_{SO2,CO2e*}=\frac{\Delta E_{SO2}}{\Delta t}\times GWP_{H,SO2}\times H \quad (1)$$

$$E_{CH4,CO2e*}=0.75\times\left[\frac{\Delta E_{CH4}}{\Delta t}\times GWP_{H,CH4}\times H\right]+0.25\times\left[E_{CH4}\times GWP_{H,CH4}\right] \quad (2)$$

Here E_x is the emissions of gas x, $\Delta E_x \Delta t$ is the 20 year averaged emissions rate of gas x, $GWP_{H,x}$ is the GWP value for gas x over time horizon H.

3.4.2.2 Emissions after 2050

EUCalculator is not set to directly calculate the emissions after 2050 but a sensible assessment of EU mitigation efforts requires an estimation of GHG emissions for the second part of the century as well. The emissions module thus projects the average GHG gradients between 2035 and 2050 forward to 2100. This projection is limited to a minimum CO_2-warming-equivalent emissions quantity of -1GtCO_2/yr. The limitation is added because for particularly ambitious mitigation efforts the 2035-2050 gradient in emissions could otherwise result substantial and unfeasible levels of negative emissions by 2100. To restrict the negative emissions over the second half of the 21st century in these ambitious scenarios to feasible rates, consistent with global emissions projections, a minimum CO_2-warming-equivalent emissions quantity is set. This value is taken as the EU percentage share of average 2100 annual CO_2 emissions in the IIASA database of 1.5°C-compatible scenarios used in the IPCC SR15 report (where the EU percentage share is found in the same way as for the RoW/EU emissions splitting discussed in section 3.4.2.3).

3.4.2.3 RoW emissions

Calculating the temperature response requires total GHG emissions both for the EU and the RoW. By setting the RoW GHG emission reduction ambitions, the user automatically sets an estimate of the global temperature in 2100 (see section 3.2.1) and its associated GHG emissions. The module thus has to estimate the fraction of emissions originating from the EU and thus of the RoW.

In order to obtain this fraction, the module uses the ratio of GHG emissions between EU and RoW in 2012 as its baseline and assumes this ratio to remain constant until the end of the century. Once the fraction for the RoW is known, the CO_2-warming-equivalent emissions for the RoW are obtained as outlined in section 2.4.2.1. Of course, this is an approximation which will not necessarily hold over all time. However, in order to create a first order estimate of the EUs contribution to future climate change the climate module assumes RoW emissions are a constant fraction of future total global emissions (which represents an upper bound on the calculation).

3.4.2.4 Temperature response

The emission module uses equations originating from the FaIR simple climate module updated based on Millar et al. (2017) and Smith et al. (2018). GHG emissions are split into 4 carbon pools which decay into the biosphere, land, upper ocean and lower ocean respectively, from which the total atmospheric carbon concentration can be found. Subsequently, the module calculates the associated radiative forcing assuming a logarithmic relationship (Eq. 3) between concentration changes and forcing. Here C(t) is the CO_2 concentration at time t, C_0 is the preindustrial CO_2 concentration, F_{2x} is the forcing response to a doubling of CO_2 concentrations, and F_{ext} is any other externally applied climate forcing. The overall temperature response is then found using a two-box model (Millar et al., 2017) with the calculated radiative forcing as input.

$$F(t) = F_{2x} ln\left(\frac{C(t)}{C_0}\right)/ln\,(2) + F_{ext} \quad (3)$$

3.4.3 Physical impacts at the end of the century

To provide the user with an outlook to the consequences of a chosen combination of lever settings, the climate emissions module uses damage functions to quantify the physical impacts associated with the resulting global temperature change at the end of the 21st century. In the most recent version, the model estimates the global number of people at risk from severe droughts, fluvial flooding and coastal flooding as well as the global percentage of species losing more than half of their climatic range. The damage functions are based on projections of people at risk from Warren, Andrews et al. (2018), and projections for impact on species derived from a global assessment performed by the Wallace Initiative (Warren, Price et al., 2018). These functions were created by fitting linear or second-degree curves to available impact data associated with global temperature changes between 1.5°C and 4.5°C.

A selection of possible impacts on biodiversity in 2100 is depicted in Figure 6. With growing global temperature, increasing numbers of species are projected to lose more than half of their climatic range. The same relationship applies for impacts to the human system (Figure 7and Figure 8). However, while growing global temperatures increase the risk in all three sectors, far more people are projected to be at risk from drought than from flooding. The model will not present projections for the full range of possible temperatures but select only those associated with the estimated global temperature response.

EUCalculator deliberately uses damage functions to estimate climate change impacts for the end of the century. Running separate and spatially explicit impact models for each sector is computational intensive and not feasible to perform in real time. An emulation of spatially explicit impact models using damage functions based on these models' outputs was thus considered to be a good alternative. By projecting impacts for 2100 rather than 2050, EUCalculator allows for a better display of mitigation benefits. Although the model displays positive effects immediately after mitigation starts, it will take time until the full benefits become truly visible because some mitigation efforts have a delayed effect. A timescale of 30 years until 2050 was thus considered too short and a longer period until the end of the century was adopted instead.

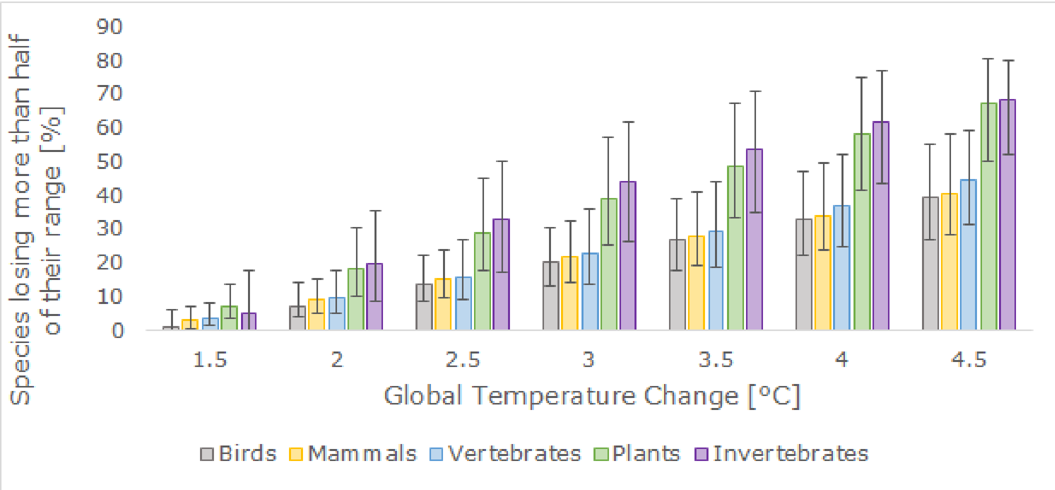

Figure 6 - Projected proportion of species losing more than half of their climatically determined range by 2100. Presented are the mean projections across 21 alternative climate model patterns with error bars representing the 10th and 90th percentile (data from Warren, Andrews et al., 2018).

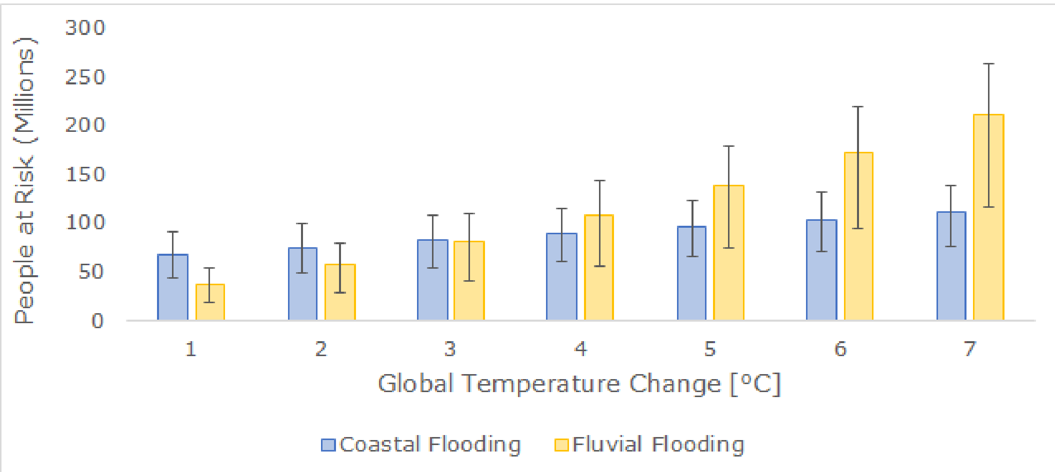

Figure 7 - Projected number of people at risk from coastal flooding and fluvial flooding in 2100. Presented are mean projections across 5 (3 in case of fluvial flooding) alternative climate model patterns with error bars representing the minimum and maximum values (data from Warren, Andrews et al., 2018).

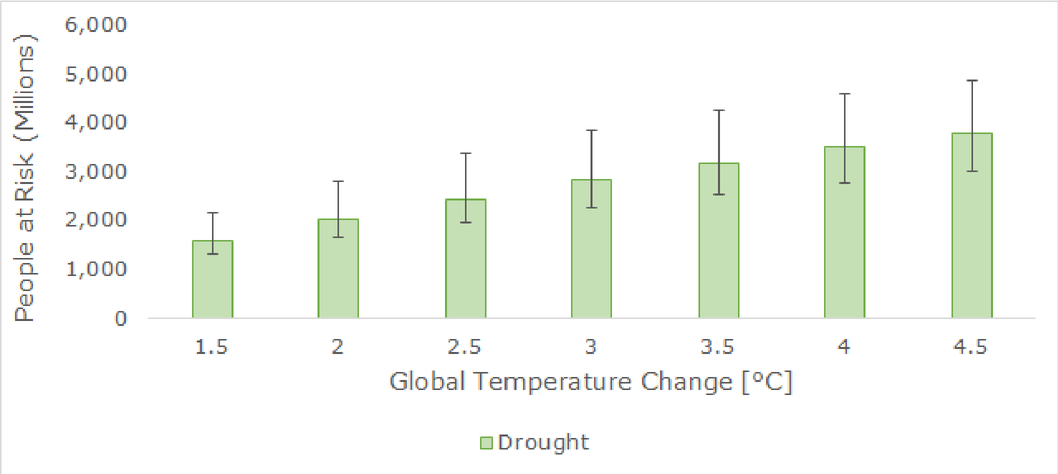

Figure 8 - Projected number of people at risk from drought in 2100. Presented are mean projections across 5 alternative climate model patterns with error bars representing the minimum and maximum values (data from Warren, Andrews et al., 2018).

The results of global physical according to different level of warming shown in the TPE (see Figure 9). The red line indicates the global temperature anomaly resulting from the combined emissions of the countries scope of the EUCalculator and those from the rest of the world.

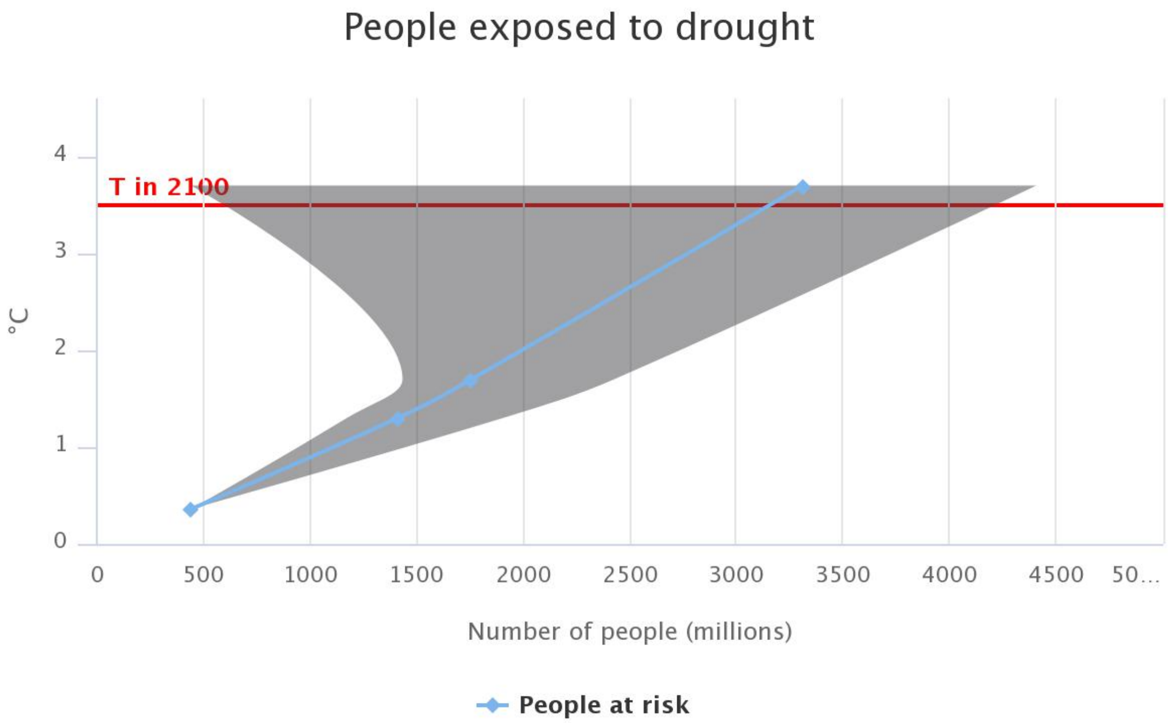

Figure 9 - Example of physical impacts visualized in the TPE

3.5 Levers and ambition levels

The output of the climate and emission modules is driven by the levels of ambition to reduce GHG emissions. By specifying the ambitions of the RoW (countries not included in the EUCalculator framework) and by setting a trajectory for ambitions after 2050, the user can actively change the boundary conditions of a simulation run. To allow exploration of multiple pathways, a choice of 4 levels is provided for either lever, with GHG emission reduction potential increasing by level (see Table 4).

Table 4 – Lever levels used in the climate modules

Lever	Level	Definition
RoW GHG emission reduction ambitions	1	Make no real changes to emissions and fail to follow published emission reduction ambitions. This also takes into account the possibility that some emission reductions are achieved, but climate sensitivity is such that these ambitions make no real difference to the amount of warming in 2100. While this may not seem to be much of an ambition it follows from the increasing levels of CO_2 in the atmosphere and lack of sustained reductions in rates of increase.
	2	Each country meets their NDC[1] pledges within the timeframe specified and goes no farther. This is estimated to lead a climate changes associated with 2.7°C – 3.5°C of warming, and we are proposing to use 3.2°C as the resulting global mean temperature in terms of data fed through to other modules.
	3	Each country meets and further strengthens their NDC targets so as to achieve an overall level of warming of 2°C. While this does not meet the targets of the Paris Accords, it does meet previous ambition levels and is a significant improvement on Level 3 in terms of sectoral impacts.
	4	Highest ambition, equalling meeting a goal of a warming no greater than 1.5°C – the ultimate goal of the Paris Accords (well below 2°C). This does not include the possibility of a significant overshoot in temperature that then is reduced through negative emissions.
Emissions after 2050	1	Make no efforts to further decrease emissions after 2050 and keep them constant at the rate achieved in 2050.
	2	Continued but reduced effort to further decrease emissions after 2050 at 33% of the trend between 2035 and 2050.
	3	Continued but reduced effort to further decrease emissions after 2050 at 66% of the trend between 2035 and 2050
	4	Continued effort to further decrease emissions after 2050 continuing the trend between 2035 and 2050

[1] https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs

4 Lifestyle Module

4.1 Overall logic

Research shows how lifestyle choices and patterns can have significant implications on energy consumption and hence the need to account for the consumer perspective in modelling future energy consumption patterns. A sustainable lifestyle - in the context of the EUCalc - has been defined as "*a cluster of habits and patterns of behaviour embedded in a society and facilitated by institutions, norms and infrastructures that frame individual choice, in order to minimize the use of natural resources and generation of wastes*" (see summary of lessons in Moreau et al., 2017, Del.1.6 - Exploring lifestyle changes in Europe). Accordingly, in the EUCalc a lifestyle is best equated to a combination of future trajectories of activities, products and services at the individual level that have important implications in the amount of resources energy and emissions at the country-level.

The Lifestyle module is based on a bottom-up approach for determining the overall country-level demand for activity, products and services in the EUCalc. The model considers historical data from 1990 to 2015 and computes projections until 2050 based on four ambition levels of lifestyle change towards sustainability (ranging from current trends to transformational change). The measure of sustainability used (consistent across the modules in the EUCalc) is emissions of CO_2. The four levels of ambition see Table 5, have been determined by stakeholder consultation and quantitative analysis of lifestyle drivers (e.g., income, demography) and their causal relationship with the outputs with material and service demand. The ambition levels 1-4 are expressing the range between a minimal (1) and maximum (4) ambition levels in terms of GHG emissions related to lifestyle choices.

Table 5 - Definition of ambition levers in the lifestyle module

Level	Definition
1	**Past trends of lifestyle change:** This level reflects a Europe in which the lifestyle evolves until 2050 follows the 1990-2014 trends. This does not always translate into an increase demand for energy or resources. For example, some countries have been reducing certain types of meat consumption throughout time, while others have seen stagnation is road transport demand. Nevertheless, at an aggregated European scale, this level results in higher emission and resource consumption.
2	**Ambitious change:** This level is more ambitious than a projection of historical trends but falling short from a generalized shift towards the adoption of sustainable lifestyles.
3	**Very ambitious change:** This level is considered as very ambitious but realistic scenario, given the evolution of lifestyles change observed in some geographical areas. In this level, rather than being a niche, sustainable lifestyle practices are the norm

	across all European countries.
4	**Transformational change:** This level is considered as transformational and requires major societal changes. This level is considered a transformational change in European lifestyles that goes beyond the best examples observed today and is only possible by means of a breakthrough on the lifestyle choices made by individuals.

The overall, simplified, calculation logic of the Lifestyle module is presented in Figure 9. The four levels of ambition (Figure 9 left) inform of the per-capita level of a certain dimension of lifestyles (e.g., per capita calorie consumption or passenger distance). These are then scaled by the demography development (Figure 9 centre) of a country (which can be also defined by the user) and then integrated as country demand for a product or service (e.g., calories of poultry meat, travel demand in cities). In some cases the scaling can be done irrespectively of the age and gender differentiation of a country, for example the adoption of mobile phones has become ubiquitous across age classes. In other cases it is important to account for the age and gender stratification of the population (as in the case of demand for food) or the location (rural/urban) of the population within a country (as is the case of transport).

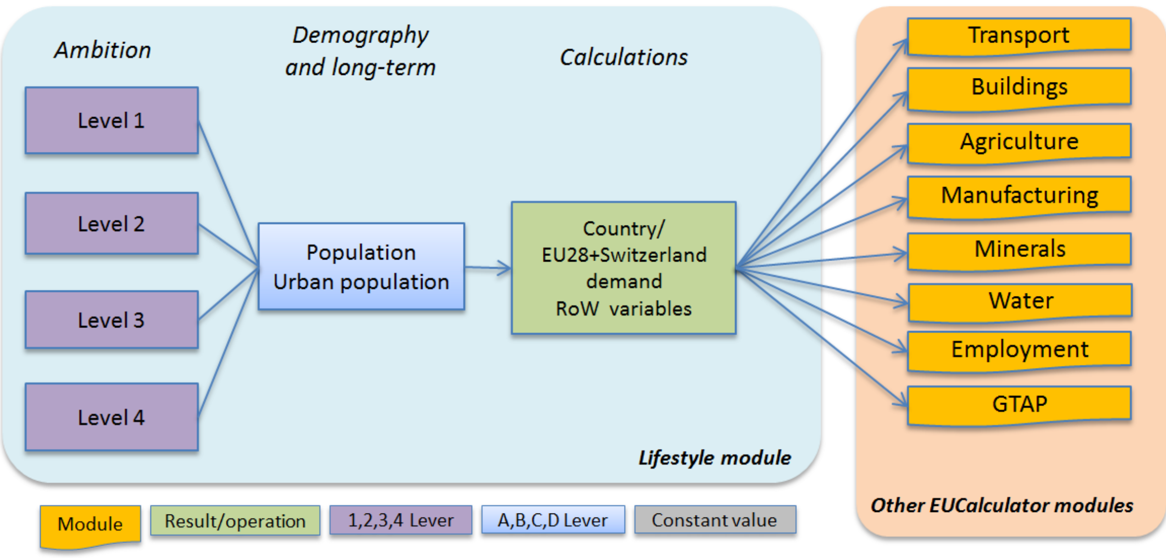

Figure 10 - Simplified calculation logic of the Lifestyle module and its connections to other modules of the EUCalc.

Because the level sustainability of population and "urbanity" developments cannot always be easily framed in terms of CO_2 savings, the projections in these variables are reported as A, B, C and D in the EUCalc. Both for the cases of total population and share of urban population, level A represent a case in which a generalized increase takes place until 2050. Concurrently, level D depicts a scenario where the total amount of population decreases. In regard to urban shares of population, level D delivers a small increase in the urban share of the population wile in level A more habitants move into cities.

The outputs of the module are then used as inputs in the subsequent modules of the EUCalc through a variety of interfaces. In Table 6 the main outputs of the Lifestyle module are listed. The energy demand and the emissions associated with these outputs of the lifestyle module are addressed by the indicated modules (e.g. Transport determines the energy entailed in the travelling demand; Buildings determines the electricity requirements of appliance use; Agriculture determines the resource use such as land and fossil fuels to supply the calorie demand; Manufacturing determines the material use for paper and plastic production).

Table 6 - Main outputs of the Lifestyle module to the other modules of the EUCalc

Outputs to	Output
Transport	• Total EU28 + Switzerland population; • Total passenger distance travelled;
Buildings	• Residential floor area; • Residential floor area cooled; • Comfort temperature; • Number of appliances; • Hours of appliances use; • Appliance retirement timing;
Agriculture	• Total calorie requirements; • Calorie composition of diets; • Calories of food wasted at the consumer level;
Manufacturing	• Graphics and sanitary paper demand; • Paper, plastic, glass and aluminium packaging;
Minerals	• Population in the RoW;
Water	• Total EU28 + Switzerland population;
Employment	• Active EU28 + Switzerland population; • Different aggregations of calorie demand; • Paper and plastic packaging; • Sanitary and graphics paper; • Total use of appliances;
GTAP	• Floor intensity per capita; • Passenger travel per capita; • Different aggregations of calorie demand; • Paper and plastic packaging; • Sanitary and graphics paper; • Aluminium and glass packaging; • Number of appliances;

4.2 Scope definition

The Lifestyle module enables the assessment of the fraction of material, energy demand and consequential GHG emissions that can be avoided by a shift from the current consumption trends to a generalized adoption of sustainable lifestyles. The module has identified four main sectors (Transport, Buildings, Agriculture and Manufacturing) in which a change in Lifestyle can bring about significant changes in the amount of materials, energy and GHG emission as the European level. Within these sectors, a shift towards sustainable Lifestyles can be reflected at the product/resource or service demand. In Table 7 a detailed breakdown of the lifestyle dimensions outputting from the Lifestyle module are listed.

Table 7 - Scope definition of the Lifestyle module and main outputs.

<table>
<tr><th>Product demand and use</th><th>Service demand</th></tr>
<tr><td>Number of washing machines [#] and use [h]
Number of dishwashers [#] and use [h]
Number of dryers [#] and use [h]
Number of fridges [#] and use [h]
Number of freezers [#] and use [h]
Number of TV's [#] and use [h]
Number of computers [#] and use [h]
Number of phones [#]
Plastic packaging [t]
Paper packaging [t]
Glass packaging [t]
Aluminium packaging [t]
Paper printing and graphic [t]
Paper sanitary and household [t]
Appliance retirement timing [%]</td><td>Comfort temperature [ºC]</td></tr>
<tr><th>Space demand</th><th>Transport demand</th></tr>
<tr><td>Residential floor space [m2]
Residential floor space cooled [m2]
Number of households [#]</td><td>Urban travel [km]
Non-urban travel [km]
Non-shiftable travel [km]</td></tr>
<tr><th>Calorie demand</th><th>Food waste</th></tr>
<tr><td>Calories from wine [kcal]
Calories from beer [kcal]
Calories from fermented beverages [kcal]
Calories from alcoholic beverages [kcal]
Calories from cereals [kcal]
Calories from rice [kcal]
Calories from oil crops [kcal]
Calories from pulses [kcal]
Calories from starch [kcal]
Calories from coffee [kcal]
Calories from stimulants [kcal]
Calories from sugars [kcal]
Calories from sweeteners [kcal]
Calories from vegetable oils [kcal]
Calories from vegetables [kcal]
Calories from pelagic fish [kcal]
Calories from demersal fish [kcal]
Calories from sea food [kcal]
Calories from other aquatic animals [kcal]
Calories from eggs [kcal]
Calories from milk [kcal]</td><td>Calories from wine [kcal]
Calories from beer [kcal]
Calories from fermented beverages [kcal]
Calories from alcoholic beverages [kcal]
Calories from cereals [kcal]
Calories from rice [kcal]
Calories from oil crops [kcal]
Calories from pulses [kcal]
Calories from starch [kcal]
Calories from coffee [kcal]
Calories from stimulants [kcal]
Calories from sugars [kcal]
Calories from sweeteners [kcal]
Calories from vegetable oils [kcal]
Calories from vegetables [kcal]
Calories from pelagic fish [kcal]
Calories from demersal fish [kcal]
Calories from sea food [kcal]
Calories from other aquatic animals [kcal]
Calories from eggs [kcal]
Calories from milk [kcal]</td></tr>
</table>

Calories from offals [kcal] Calories from bovine [kcal] Calories from sheep [kcal] Calories from pigs [kcal] Calories from poultry [kcal] Calories from other animals [kcal]	Calories from offal [kcal] Calories from bovine [kcal] Calories from sheep [kcal] Calories from pigs [kcal] Calories from poultry [kcal] Calories from other animals [kcal]

4.3 Inputs and outputs of the module

The Lifestyle module sits the start of the modelling chain and hence it does not receive any inputs from the other modules (see Figure 1 and Section 2). The Lifestyle module sets the overall country-level demand for products, resources and services (see Table 7) that is subsequently passed to other modules in which energy and GHG emission are derived.

4.4 Interactions with other modules

The main interactions of the Lifestyle module are with the Transport, Buildings, Agriculture and Manufacturing. Other interactions with electricity, employment minerals modules are also established. Finally, the Lifestyle module also provides data to GTAP for the integration of transboundary effects in the EUCalc.

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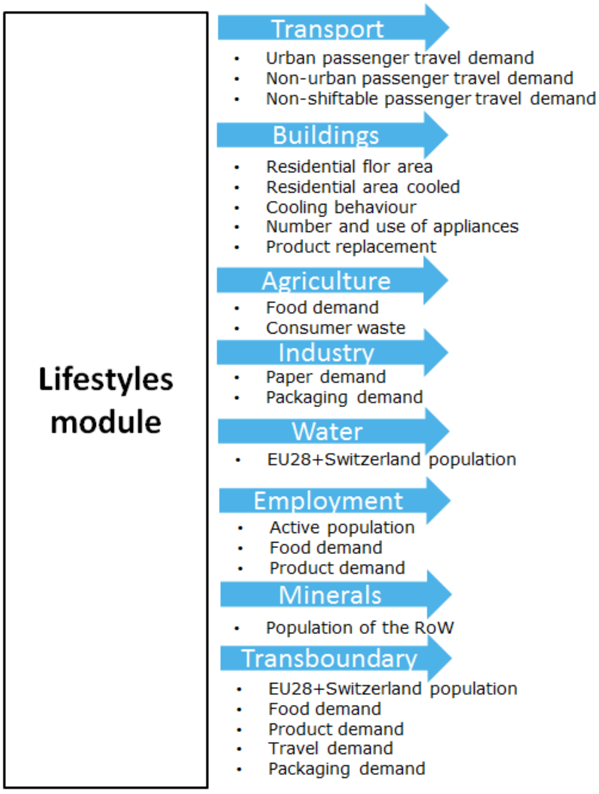

Figure 11 – Main interactions of the Lifestyle module with the other modules composing the EUCalc

4.4.1 Outputs to other modules

4.4.1.1 Buildings

The lifestyle module provides the buildings module with the demand, at the country level, of the total residential floor space based on the individual preferences for the amount of floor space per person. Related to the total floor space, the module also computes the amount of the residential area that is allocated to cooling. In addition, the Lifestyle module also computes number and usage (in terms of hour used) of electrical appliances in buildings. Finally, the Lifestyle module also provides the Building sector with changes in the Appliance retirement timing and the cooling behaviour of the population. The listing of the outputs considered is given below together with the details of units.

- Residential floor space [m2]
- Residential floor space cooled [m2]
- Appliance retirement timing [%]
- Number of washing machines [#] and use [h]
- Number of dishwashers [#] and use [h]
- Number of dryers [#] and use [h]
- Number of fridges [#] and use [h]
- Number of freezers [#] and use [h]
- Number of TV's [#] and use [h]
- Number of phones [#] and use [h]
- Number of computers [#] and use [h]
- Residential cooling set-point [ºC]

4.4.1.2 Transport

The Lifestyle module provides the transport module with the country-level passenger transport demand for a total of three classes. The first two classes are the passenger transport demand taking place within the urban regions and the passenger travel demand taking place in non-urban regions. These classes are those that due to their typical distance (<1000km) are possible to shift from one mode of transportation to another. The third class of passenger transport demand provided is the non-shiftable demand. This demand is equated to that of travel distances above 1000km.

- Urban travel [km]
- Non-urban travel [km]
- Non-shiftable travel [km]

4.4.1.3 Agriculture

To the Agriculture module the Lifestyle module delivers total calorie requirements at the country level for a total of 26 food groups listed below. In addition, to each food group, the corresponding number of calories wasted as food waste is also supplied. Together, calories required plus the amount of calories wasted composes the total food demand of a country. Is it important to note that the fraction of food waste determined in the Lifestyle module refers only to the food waste taking place at the household level and not that the amount of agricultural waste taking place at the farm level. The latter is evaluated in the Agricultural module.

- Calories from wine [kcal]
- Calories from beer [kcal]
- Calories from fermented beverages [kcal]
- Calories from alcoholic beverages [kcal]
- Calories from cereals [kcal]
- Calories from oil crops [kcal]
- Calories from pulses [kcal]
- Calories from starch [kcal]
- Calories from coffee [kcal]
- Calories from stimulants [kcal]
- Calories from sugars [kcal]
- Calories from sweeteners [kcal]
- Calories from vegetable oils [kcal]
- Calories from vegetables [kcal]
- Calories from pelagic fish [kcal]
- Calories from demersal fish [kcal]
- Calories from sea food [kcal]
- Calories from other aquatic animals [kcal]
- Calories from eggs [kcal]
- Calories from milk [kcal]
- Calories from offals [kcal]
- Calories from bovine [kcal]
- Calories from sheep [kcal]
- Calories from pigs [kcal]
- Calories from poultry [kcal]
- Calories from other animals [kcal]

4.4.1.4 Manufacturing

The Lifestyle module provides directly the Manufacturing module with the country aggregated demand for paper demand, both graphics and sanitary; and with the amount of packaging demand. Packaging demand is provided along four types of materials, these are: plastic, paper, glass and aluminium.

- Plastic packaging [t]
- Paper packaging [t]
- Glass packaging [t]
- Aluminum packaging [t]
- Paper printing and graphic [t]
- Paper sanitary and household [t]

It is important to note that the interaction described above is a direct one in the sense that the outputs of the Lifestyle module are direct inputs to the Manufacturing module. In the EUCalc model many indirect interaction take place between he Lifestyles and the Manufacturing module mediated by for example the Transport and Buildings modules. A typical interaction is for example that the Lifestyle module supplies Buildings with the amount of residential floor area needed from which the model computes the additional floor area to be constructed. In turn, the need for construction materials such as cement and steel are requested from the Buildings model to Manufacturing. Indirectly the Lifestyles and Manufacturing are also linked via the outputs provided to Buildings. Similar rationale can be done for the Transport module in respect to cars or trains needed to supply the passenger travel demand.

4.4.1.5 Employment

The Lifestyle module provides the Employment module with the time development of the active population defined as the number of habitants in one country aged between 15 and 65. In addition, it also provides particular aggregations of the calories and waste delivered to the Agriculture module. The aggregations are done so that the outputs of the Lifestyles model better match the input-output model used in the Employment module to compute jobs and skills change.

- Active population in EU+Switzerland [#]
- Paper printing and graphic [t]
- Total calories of beverages [kcal]
- Total calories of vegetables fruits and crops [kcal]
- Total calories of animals (non-fish) [kcal]
- Total calories of fish [kcal]

4.4.1.6 Water

The Lifestyle provides the Minerals module with trajectories of population of the EU28+Switzerland.

- Population in EU+Switzerland [#]

4.4.1.7 Minerals

The Lifestyle provides the Minerals module with trajectories of population of the EU28+Switzerland and also with upper- and lower-bound trajectories of population in the RoW (Rest of the World), defined as Global population – (Population of EU28 + Population of Switzerland).

- Population in EU+Switzerland [#]
- RoW upper-bound population [#]
- RoW lower-bound population [#]

4.4.1.8 Transboundary (GTAP)

The Lifestyle module also provides inputs to the GTAP model. The latter makes the link of the activities taking place within the EU28+Switzerland with the global economy in the RoW. For a more detailed accounting how the GTAP model is linked to the outputs of the EUCalc please refer to deliverable 7.2, Documentation of GTAP-EUCalc inferface and design of GTAP scenarios. The Lifestyle module provides GTAP with the following datasets:

- Plastic packaging [t]
- Paper packaging [t]
- Glass packaging [t]
- Aluminum packaging [t]
- Paper printing and graphic [t]
- Paper sanitary [t]
- Number of washing machines [#]
- Number of dishwashers [#]
- Number of dryers [#]
- Number of fridges [#]
- Number of freezers [#]
- Number of TV's [#]

- Number of phones [#]
- Number of computers [#]
- Population in EU+Switzerland [#]
- Residential floor space per person [m2/cap]
- Same calorie groups as in the Agriculture module

4.5 Detailed calculation trees

The Lifestyle module broadly operates according to the schematics presented in Figure 9 but depending on the output considered there are intermediate steps from determining the ambition level to providing the aggregated country output to the other modules of the EUCalc. The following sections details the calculation taking place within the Lifestyles module.

4.5.1 Population

A total of five modules demand population trajectories for the EU28+Switzerland, or for the RoW. Population numbers in their several aggregations (e.g., total, urban, active) are determined as shown in Figure 11. The simplest aggregation is the total population for EU28+Switzerland which consists of the sum of all age and gender classes considered in the Lifestyle module. For the Employment module, the age classes above 20 years and below 65 are summed up in order to provide information of active population.

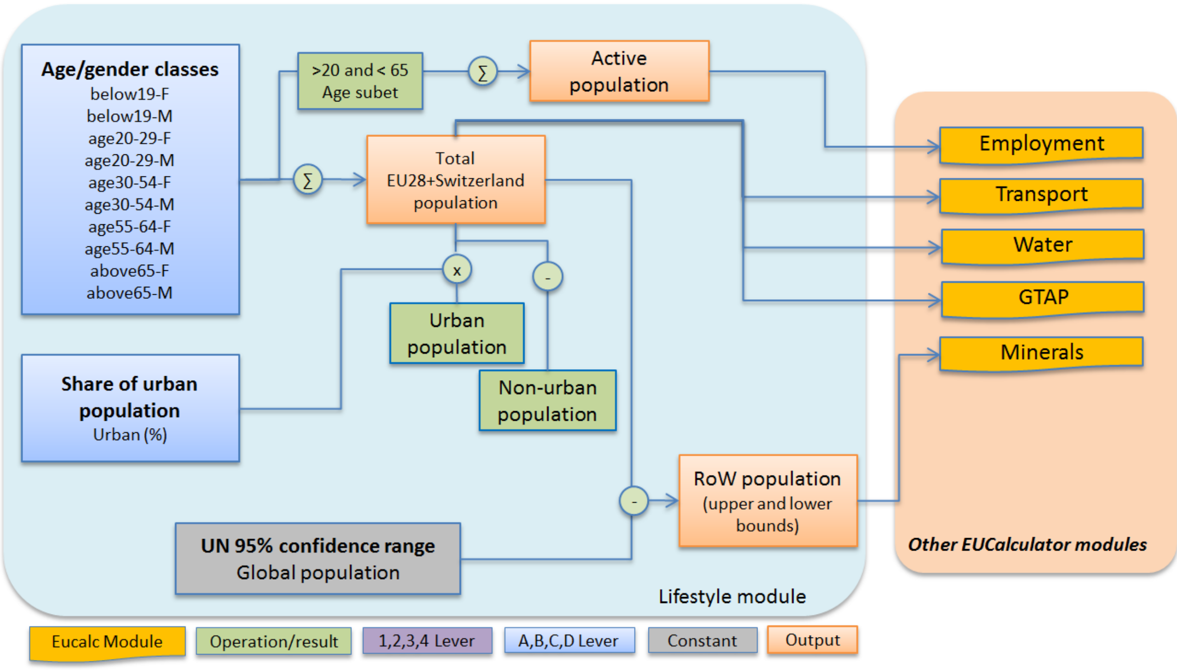

Figure 12 - Calculation tree determining total, active, urban and non-urban population

The minerals module requests upper and lower bound of population trajectories for the RoW. In this case, the total EU28+Switzerland population entailed in each level selection is subtracted to the 95% range of global population trajectories provided by the UN (2015), between 2015 and 2050. The resulting difference is the representation of the RoW population and passed on to the minerals module.

4.5.1.1 Gender considerations

Gender is an important aspect to factor in when evaluating the potential for decarbonisation across society. There are several carbon-intensive domains like transport, diets and consumption in which contrasting behaviours between women and men has been noted. Ultimately, these differences in behaviour influence both the amount of GHG emissions and the mitigation potential of behavioural change.

For example, Swedish research shows that if travel behaviour of women was the norm, climate goals for the transport sector could be met (Kronsell 2016). Challenging prevailing gender norms therefore does not only foster gender equality but also sustainability, thus offering a low-cost readily available approach for CO2 reduction. Regarding diets, different sources report that meat – a key drivers in GHG emissions - is consumed in higher quantities by men (Clonan et al. 2016, Wyness et al 2011, Linseisen et al. 2002). Reasons for this can include a lower economic status of women, women being more concerned with animal welfare (Clonan et al. 2015), and women trying to live a healthier lifestyle (Samoggia et al. 2016), all due to socialization processes. Women in Sweden tend to buy "basic essentials in the form of less expensive but recurring consumer goods for the whole family, such as food, clothing and household articles, while [men] are more likely to buy expensive capital goods and own things like homes, cars and home electronics." (Johnsson-Latham 2007:38). According to OECD findings, setting women's behaviour and consumption patterns as the norm would lead to an overall smaller impact on the environment and promote sustainable patterns that would be beneficial for economy and society (OECD 2008).

4.5.2 Appliances ownership and use

Total number of appliances is requested by the Buildings module and has an input to GTAP. The number of appliances is determined by multiplying the lever setting the number of appliances in each household by the number of households, see Figure 12. In turn the number of households for each country is determined by multiplying the total number of inhabitants by the fixed, 2015, country-specific value of habitants per household taken from the EU LFS[2].

[2] Version 1 released in July 2019 with data up to 2017 available at https://doi.org/10.2907/LFS1983-2018V.1

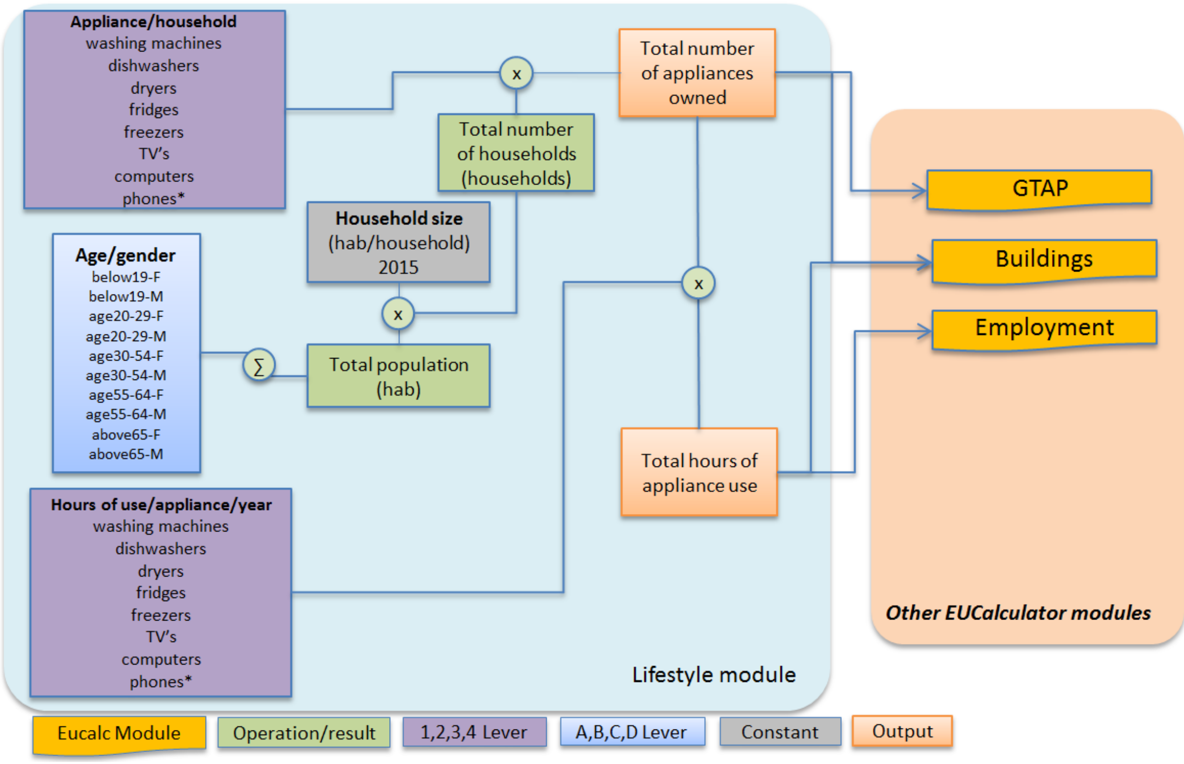

Figure 13 - Calculation tree determining the country-demand of appliances in the Lifestyle module.

For the particular case of phones*, the lever ambition are not expressed in terms of the appliance per household but per capita. Hence, in the calculation tree of Figure 12, phones per capita are multiplied directly by the total population.

For the case of determining the total use of appliances (in hours per year) the procedure is similar. The 1,2,3,4 lever informs on the amount of hours per year that the appliance is used. This information is then multiplied by the total number of appliances as described previously. The total number of appliances owned and use total hours of appliance are passed on to the Buildings module. To GTAP only the total number of appliances is provided and to the Employment module the total hours of appliance use, see Figure 12.

4.5.3 Floor use intensity and area cooled

The total m^2 of residential floor are and residential cooled floor is determined as shown in Figure 13. Total population numbers are multiplied with the lever setting the amount of residential floor area per capita. The total floor area is the integration over a country of the population times the per-capita specification of residential floor space. This results in the country-demand of residential floor area, an output that is the passed to the Buildings module and GTAP. In addition to the total demand for residential floor area, the Lifestyles module provides the Buildings module with estimates of residential floor area subjected to cooling. For this purposes, the demand of residential floor area determined previously is multiplied by the lever setting the % of total residential floor are to be cooled.

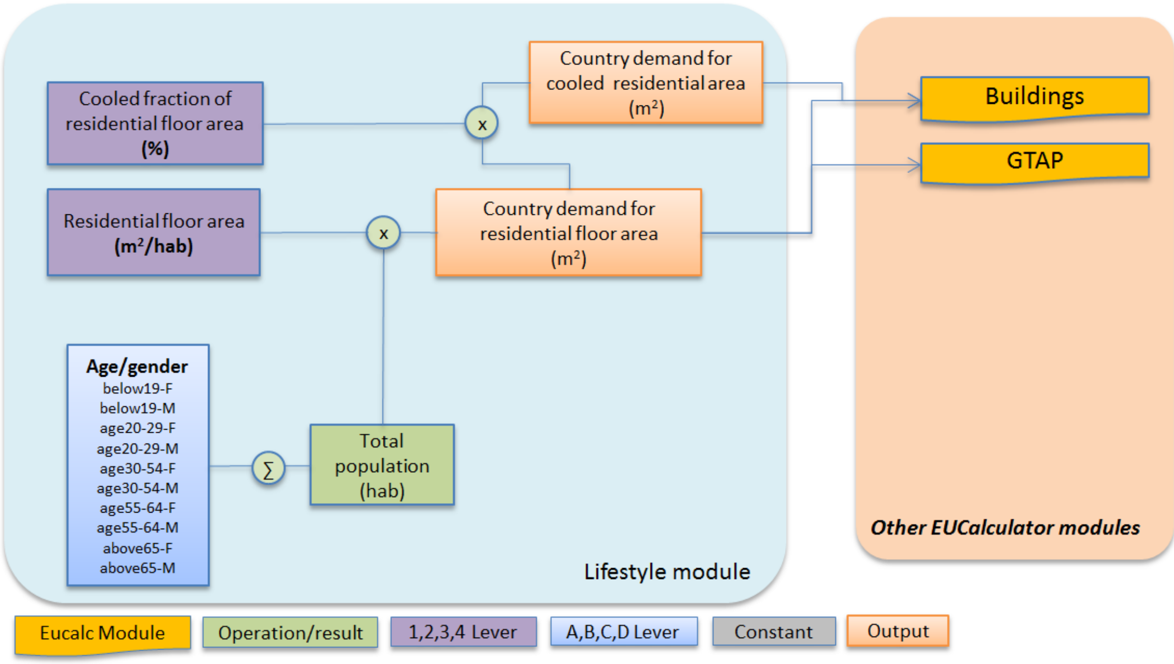

Figure 14 - Calculation tree determining the total demand of residential floor area and area cooled in the lifestyle module.

4.5.4 Passenger travel distance

The total, urban, non-urban and non-shiftable travel demand (in Pkm) of a country is determined following the calculation logic in Figure 14. The lever specifying the amount of travel demand by age class and gender is multiplied by the respective population class in order to obtain yearly distance travelled. The total distance is then multiplied by the fraction taking place outside the urban area. This is done by imputing the lever specification of the fraction of urban population in the “Urban %” term of the function shown in Figure 14. The terms *a* and *b* are constant and country specific and are obtained by running a linear fit between the fraction of total Pkm taking place outside the urban areas with the historical shares of urban population. The result of the function is the share of total Pkm taking place outside the urban space. This share is multiplied by the total PKm determined previously. In this manner total non-urban travel distance is determined. Following, the non-urban travel distance is subtracted to the total; see remaining travel distance in Figure 14.

Finally, the remain travel distance is split into non-shiftable and urban travel by using the average 2010-2014 fractions of Pkm distance above 1000km in the total urban travel taken from the Statistical Pocketbook 2016. All the outputs highlighted in Figure 14 are passed on to the Transport module. GTAP takes information on the per capita passenger travel distance directly for the lever setting.

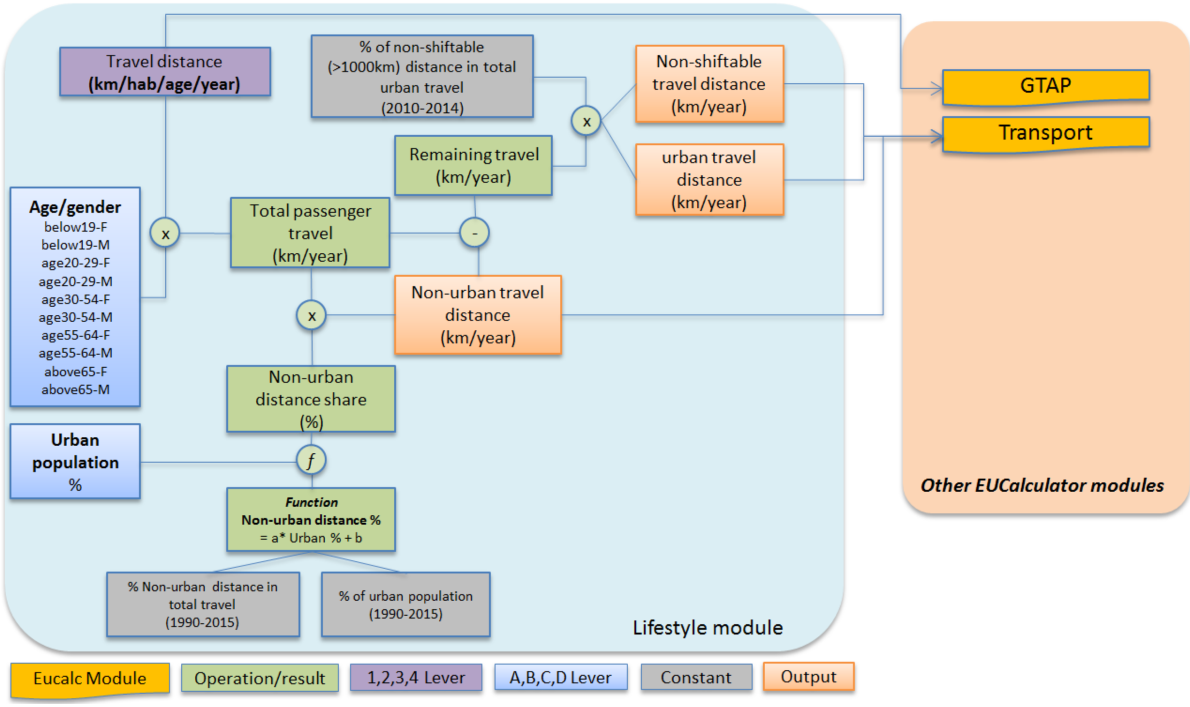

Figure 15 - Calculation tree determining the three-way passenger travel demand in the Lifestyle module.

4.5.5 Food requirements and food waste

The total calorie consumption and food waste at the consumer level is determined following the calculation logic in Figure 15. The calories of food waste at consumer level are directly determined by multiplication of the per-capita calories of food wasted set by the corresponding lever with the user-defined population scenario. As for the calorie demand the calculation is sectioned into two parts. First the total amount of calories required to sustain the biophysical need of the population is determined by multiplication of the population numbers in the different age and gender classes with the corresponding per-capita calories needed (which vary according to different ambition levels).

In parallel, the total amount of calories for the food groups reported on the dietary guidelines of WHO (2003) and WCRF (2007) are used are used, for a complete list of food groups and the respective modelling strategy see Table 21 in the Annex. The calories for these groups are determined according to different ambitions, see “calories of WHO food groups” in Figure 15. By subtracting these calories to the total calories previously calculated we obtain the “Remaining calories required” to fulfil the biophysical need of the population. These are then distributed across the rest of the food groups considered by multiplying the total amount of calories available by the share of the remaining food groups in the total calories for the year 2013 (see “% of RoFG”). For example: if one has 2500 calories required and 500 of them are to fulfil the diet composition of the WHO food groups, then 2000 are still available to be distributed across the other food groups. Although the distribution is done using fix 2013 fractions extracted from the FAO food balance sheets [3], the absolute values are variable in time conditional to the lever combinations.

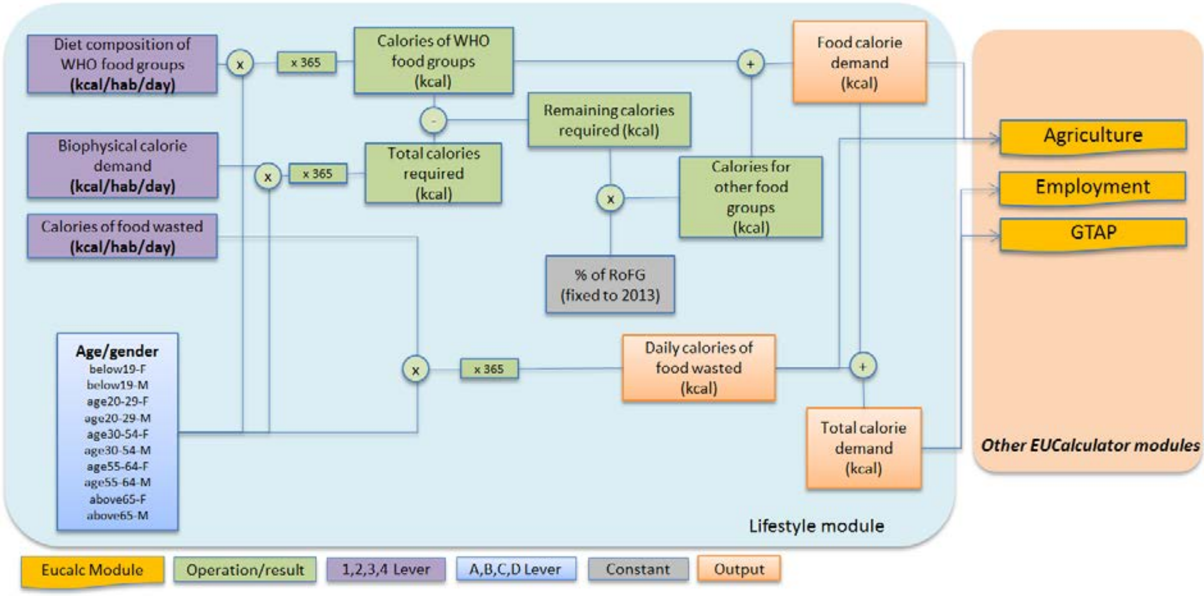

Figure 16 - Calculation tree determining total food demand and waste in the Lifestyle module.

4.5.6 Paper and packaging demand

The calculations of outputs regarding paper and packaging demand are straightforward. Ambition level settings in terms of tons of paper and packaging per capita are multiplied by the total population. The result is total demand of paper and packaging consisting of paper, plastic, glass and aluminium materials, to the Manufacturing and Employment modules and also to GTAP.

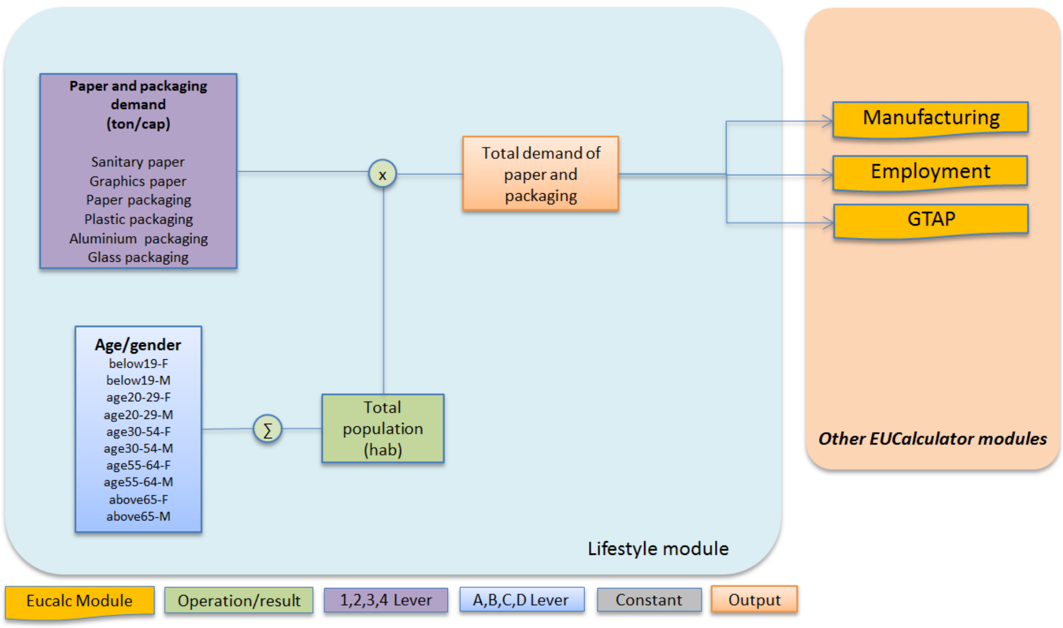

Figure 17 - Calculation tree determining total paper and packaging in the Lifestyle module

[3] http://www.fao.org/faostat/en/#data/FBS

4.6 Levers and ambitions levels

This section summarizes levers and respective ambition levels (mentioned extensively in Section 4.5) defined in the Lifestyles module for the EU28+Switzerland.

4.6.1 Population

The Lifestyle module makes use of the projection[4] of population by age, sex and year ranging from 2015 up to 2050 made available by the Eurostat (Eurostat 2017). The Eurostat projections were find to capture the possibility space of development of future population numbers entailed in the scenarios previously described.

Level A is linked to the High Migration scenario variant in the Eurostat projections. Following this scenarios, European population and Switzerland rises to circa 553 Million by 2050 (see Table 8). This is in line with the maximum in UN (2013) projections but considerably lower than the SSP5. We justify this choice because in order for the SSP5 to be a close representation of the near future, the population of Europe would have to grow at 3.6 million per year in order to the projections by mid-century. Furthermore, this growth would have to be fuelled by migration and internal fertility in order to be consistent with the assumptions. Even at the high of the migration surge observed in Europe in the year 2015, asylum applicants mounted up to 1.3 and million respectively[5]. Even assuming that a 2015 year could repeat itself until 2020, migration numbers would not suffice to get close to SSP5 numbers. In addition, a stagnating average fertility has been observed across EU28 countries since 2008 at circa 1.6 children per woman[6]. With an increase of about 1.1 Million per year referenced to 2015, the A level is very much aligned with the past trends of decadal population growth of 1.3 million/year between 1994 and 2014.

Level B is aligned with the baseline population projection in Eurostat and with those the 2015 Ageing Report (2015) and the SSP2. This represents a scenario of moderate population growth in which by 2050 EU28+Swizerland population tops at 536 million. This level is below the past trends of decadal population growth, see above. Level D is aligned with the low fertility variant of the Eurostat projections. Under this scenario the European population falls to 502 Million by 2050, a 3 % drop from 2015 levels. Level C is set as the average between the Level B and D representing therefore an intermediate scenario between the baseline and that of low fertility.

Table 8 - Ambition level for the population lever

EU + Switzerland	A	B	C	D
Population [Millions]	542	533	516	499

[4] https://ec.europa.eu/eurostat/cache/metadata/en/proj_esms.htm
[5] http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=migr_asyappctzaandlang=en
[6] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Fertility_indicators,_EU-28,_2001%E2%80%932015_YB17.png

Disaggregation by country

There is no disaggregation necessary. The Eurostat projections are available at the country level and for the 10 age/gender classes considered in the EUCal model.

According to the Eurostat (Eurostat 2015), urban areas - defined as cities, towns and suburbs - provide a home to 72% of the EU-28's population Unlike for the case of population, long-term urbanization projections on a country scale are harder to come by for Europe, not to mention consistently for all EU member states. That said, we investigate urbanization estimates from two consistent global studies we could source, the projection entailed in the SSP database and the UN urbanization prospects (UN 2015). To date, the urbanization projections in the SSPs constitute the only consistent set of global urbanization projections at the country level that extend over the whole 21st century. None of the scenarios evaluated anticipates a decline in urbanization across either in Europe, in the case of UN (2015), nor at member state level, as is the case in Riahi et al., (2017).

Considering the literature above it is very unlikely that the urban share of population in the EU28+Switzerland will decline. The future evolution seems therefore to be a question of fast versus slow increase. In order to reflect the full spectrum of ranges found in the literature the level A for this lever is linked to the strong urbanization scenario of SSP1 in which the urban share of European population grows to 83%. This level is the highest of those investigated. Level B is linked to the SSP2 scenario delivering an average fraction of population living in urban areas of 80%, an annual growth of about 0.35% a year. This is also aligned with the choice done for the lever population. Level D is linked to the SSP3 scenario by which the fraction of urban population in Europe reaches 76% at the end of the simulation period. Level C is constructed as an intermediate level between B and D and results in an urban share of population by 2050 of 78%. The % of urban population in SSP databases are country-specific and these were used as inputs to the model.

Table 9 - Ambition levels for the share of urban population lever

EU + Switzerland	A	B	C	D
Urban population [%]	83%	80%	78%	76%

Disaggregation by country

There is no disaggregation necessary. The SSP projections are available at the country level.

4.6.2 Appliances, residential floor area and comfort temperatures

4.6.2.1 Appliances ownership

In Europe there is a lack of published data based on the study of appliance penetration or ownership comparing different countries trends and assessing different appliances families (Cabeza et al., 2017). This is still and hindering reality allowing for a more in depth understanding of the drivers behind household appliance ownership patterns. For the purpose of the EUCalc we make use of the ODISSEE-MURE database for extracting the number of washing machines, dishwashers, dryers, fridges, freezers and TV's. For computers and TV's and mobile phones data sources please see the metadata files provided via the link in section, data access.

Table 10 - Ambition levels for the number of appliances per household

Name / Unit	1	2	3	4
Number of washing machines per household [#]	1	0.9	0.85	0.8
Number of dishwashers per household [#]	0.7	0.65	0.55	0.5
Number of dryers per household [#]	0.45	0.43	0.42	0.4
Number of fridges per household [#]	1.1	1.05	1.02	1
Number of freezers per household [#]	0.8	0.7	0.6	0.5
Number of TV's per household [#]	1.4	1.3	1.2	1.1
Number of computers per household [#]	2.5	2.1	1.7	1.3
Number of phones per person [#]	1.5	1.2	1.1	1

For level 1, we assume countries converge to levels of appliance ownership typical found in European countries with high income levels, typical beyond 40k € per year in 2014. For example, for the adoption of fridge's this would imply a convergence to 1.1, similar to the penetration found in Germany in the year 2015. For computers, a 2 value per household is assumed, a typical value found in affluent countries such as Switzerland. For dishwashers, countries are set to converge to vales of 0.7, a value typically found in EU countries with incomes beyond 40k.

For level 4 countries converge in general to appliance ownership of countries with middle incomes, typical between 20 and 30k in the year 2014. This is a level of income that largely eliminates the monetary barrier of individuals buying an appliance. For the case of dishwashers, countries converge to 0.5 per household (the same of Italy at an income level of approximately 25k in 2014); computers to 1.3 (the same of Spain at an income level of approximately 22k in 2014); TV's to 1.1 (similar to the level of Slovenia at an income level of approximately 20k in 2014). For the case of washing machines, a convergence to 0.8 is assumed reflecting the levels found in Switzerland. Although Switzerland is classified as an affluent country, we take this level of washing machine penetration to show what is possible to achieve lower levels of appliance penetration via device sharing. Levels 2 to 3 are calculated as intermediate levels.

Disaggregation by country

In terms of disaggregation rational it is assumed that as countries grow more affluent the barriers to the acquisition of home appliances is reduced although not eliminated. If the country starts from a low penetration level for a given appliance, literature says that it should converge rather rapidly to middle/high levels of income. Accordingly, regarding appliance ownership it is assumed that countries converge to the average European value by 2050. In the EUCalc model the average size of households is kept constant throughout the time frame of analysis (at the country-level) and there is no considerations made about the gender composition of households. That said, the absolute number of households changes in time driven by changes in the total amount of population.

4.6.2.2 Appliances use

In the lack of concrete scenarios regarding the use of appliances, the Lifestyle module borrows from the reference targets of healthy screen time found in World Health Organization, 2019. For the other appliances the future scenarios are constructed to take into account the best current geographic practices in regard to appliance use.

Table 11 - Ambition levels for the use of appliances per household

Name / Unit	1	2	3	4
Use of washing machine per household [h/day]	0.45	0.4	0.36	0.3
Use of dishwasher per household [h/day]	1	0.93	0.87	0.7
Use of dryer per household [h/day]	0.45	0.4	0.36	0.3
Use of fridge per household [h/day]	24	24	24	24
Use of freezer per household [h/day]	24	24	24	24
Use TV per household [h/day]	2	1.5	1.2	1
Use of computer per household [h/day]	4.3	3.2	2.2	1
Use of phone per person [h/day]	24	24	24	24

Level 4 for the use of computer and TV in households is equated to 2h of use per day combined (or 1h each). The World Health Organization (2019) recommendation suggests a maximum of total screen time of 1h for children less than 5 years of age. We extend this value to 1h of TV and computer each in order to encompass the entire population. Level 1 assumes a drop of 20% in viewing time for TV following past trends by 2050 and a rise in time spent in front of a computer by 50%, also reflecting the empirical trend in Bucksch et al., 2016. Levels 2 and 3 are constructed as intermediate scenarios.

For dishwashers, driers and washing machines level 3 is equated to the operation time found in Scandinavian countries and taken from the Pan-European

Consumer Survey PECS (2014) and level 4 a reduction of further 20%. Level 1 is assumed that countries increase in 10% their appliance use from the levels observed current. Level 2 is set as an intermediate scenario between level 1 and 3. Fridges and freezers maintain a 24h operation across lever settings.

Disaggregation by country

Countries converge to the European level set by the lever by 2050.

4.6.2.3 Appliance retirement timing

Traditionally, much more attention has been placed on the amount of energy used by product than the amount of energy it took to produce it. But not all appliances are created equal. White appliances, including refrigerators, clothes washers, and dishwashers, require a significant amount of energy to produce but their overall (full life cycle) energy expenditure takes place during operation. Manufacturing accounts for about 4 to 12% of the total lifetime energy use (Gonzalez et al., 2012). Building on a data-rich case of was of waste flows in Electrical and Electronic Equipment (EEE) of the Netherlands, Huisman et al., (2012) concluded that basically all appliances investigated shown decreasing residence times of equipment putted in the marked in 2000 versus that introduced in 2010.

A similar conclusion regarding the increasing frequency of product replacement was reached by Prakash et al., 2016 (in German). The study acknowledges that there are material, functional, psychological and economic obsolescence considerations driving the replacement of products but that in general useful service life of most of the analysed product groups has decreased over the last years. In particular that an increasing shares of appliances are replaced or disposed of before they reach an average first useful service life or age of 5 years (Prakash et al., 2016).

Table 12 - Ambition levels for the appliance retirement timing lever

Name / Unit	1	2	3	4
Replacement of washing machines [%]	96	100	105	110
Replacement of dishwashers per household [%]	93	100	105	110
Replacement of dryers per household [%]	93	100	105	110
Replacement of fridges per household [%]	96	100	105	110
Replacement of freezers per household [%]	96	100	105	110
Replacement of TV's per household [%]	83	100	115	130
Replacement of computers per household [%]	90	100	115	130
Replacement of phones per person [%]	90	100	115	130

In ambition level 1 the replacement of appliances follows the evidence of shorter residence times suggested in and Prakash et al., (2016) and Huisman et al., (2012). This means that for example for fridges and freezers a decrease in residence time of 4% is assumed which in turn is equated to the lifetime of the appliance in the technology matrix to be reduced to 96% of its technical lifetime. For TV's and IT the decrease in technical lifetime is equated to 83 and 90% respectively. Regarding level 4, a reduction of purchase frequency of new appliances by 30% proposed in Moran et al., (2018) is achieved for IT, and TV's. This reduction was the most ambition level we found in the literature.

For the other appliances level 4 ambition is reduced to 10% in order to avoid rebound effects of potentially old appliances with low energy standards in service. In level 2 it is assumed that households or individuals only replace their appliances once these reach their technical lifetime. Level 3 is an intermediate level between 2 and 4.

Disaggregation by country

There is no disaggregation rational applied in this lever. The current and future state of the technical lifetime of appliances is determined in the Buildings and Technology matrix modules. The lever proposed informs on extending or shortening the technical lifetime of the appliance. It is assumed that this is not conditional to a particular country in the same measure that the availability of technologies in countries is not constrained in the technology matrix. Countries converge to the European level set by the lever by 2050.

4.6.2.4 Residential floor area

Combining total floor area of dwellings from the ODYSSEE MURE database[7] and country population for EU28 Member states between the years 2000 and 2014 we observed that residential floor area per capita has increased from 36.1 to 45.5 m^2 between the years 2000 and 2014, a per annum increase of 0.4 m^2.

Güneralp et al., (2017) uses empirical multiple linear regression models to predict residential area using a panel dataset for 32 regions in 1990 and 2000. Explanatory variables used are GDP per capita and urban population density. Using the fitted parameter values of the regression model, three scenarios of low, medium and high residential floor area per capita are determined by 2050 for each region urban population density change rate and GDP/cap from the forecasts exercises (Clarke et al., 2007, UNPD 2013). When measured as percentage change between 2015 and 2050, the results of the exercise deliver a generalized increase in floor area ranging between 10 to 15% for Central and Eastern Europe and between 13 and 20% for Western Europe.

[7] http://www.odyssee-mure.eu/

Table 13 - Ambition levels for the intensity floor use lever

Name / Unit	1	2	3	4
Floor intensity (m2/cap)	55	50	43	37

Given that the scenario in Güneralp et al., (2017) reflects the current observed trends and dependencies of floor area with income and urbanization dynamics, the projections are taken as reference to establish ambition level 1. Accordingly, floor area in Europe under this level of ambition is set to increase by 20%, which would imply a 2050 floor space per capita of 54.4 m^2.

Level 4 should represent a transformational change towards sustainability in terms of residential floor space per capita. In a European context previous literature pointed that a target value of 20m^2 would, see Mont et al., (2014). This level has been proposed as indicative of a sustainable lifestyle and taken also in Del 4.1[8] of the SPREAD[9] Sustainable Lifestyles 2050 (a 7th Framework project.) Romania, with a 2014 floor space of 18m^2/person, is the European country closest to the 20m^2 per capita proposed in the literature. For example, in Korea, an affluent country with living standards on par with rich European countries, the minimum standard for living space is 12 m^2 for one person (Rao and Min 2018). Showing that in some geographic contexts a very low floor-space per person is possible, even when the country is affluent.

We assume that such radical transformation would not be feasible in Europe in the sense that would imply to more than half the current per capita average of floor space. Accordingly, we align level 4 to Rao and Min (2018) suggest the value of 37 m^2/cap (that of China's average home size in urban areas) as the benchmark for decent living in affluent countries. In the same study, the floor area value is justified to be compatible with the current demographic trends in Europe towards small families. Levels 2 and 3 are intermediate levels between level 4 and level 1.

Disaggregation methodology rational

Countries maintain their relative distance to the European mean as in the year 2014 throughout projections time frame. Countries that are currently below the average are allowed to converge faster than the average for levels 1, 2 and 3. For level 4 all countries reduce the residential floor use but a higher burden is put on rich countries while others (e.g., former socialistic countries) undergo on very small reductions.

[8] www.sustainable-lifestyles.eu/fileadmin/images/content/D4.1_FourFutureScenarios.pdf

[9] https://www.sustainable-lifestyles.eu/

4.6.2.5 Residential cooled floor area

In 2015, the amount of cooled area as share of a country's total residential area varies between values of more than 50% in Malta and Cyprus to less than 0.5% in countries such as Finland or Germany (Source: Space Cooling Technology in Europe, Technology Data and Demand Modelling. Deliverable 3.2: Cooling technology datasheets in the EU28, of the Heat Roadmaps (2016) project available online). The variation reflects the main driving variable for cooled floor area is climatic although it is also noted that income levels to play a role.

Given the inertia of the climate system, a certain degree of warming is unavoidable until 2050 even in the case of stringent mitigation efforts. Accordingly, no scenario in which the share of cooled are is reduced or even maintained constant is considered. This is justified by two evidences. The first is that countries are expected to continue becoming more affluent and hence the financial burden of acquiring new cooling systems is progressively lowered. Secondly the fraction of elderly population in Europe, who are disproportionately affected by heat impacts (Hajat et al., 2007), is expected to increase pretty much independently of the demographic scenario considered. When combined, these robust trends are expected to drive the increase of cooled surface area in Europe.

Table 14 - Ambition for the fraction of residential floor space cooled

Name / Unit	1	2	3	4
Share of residential area cooled (%)	22	18	13	8

Ambition Level 1 is equated to the shares of cooled area developed in Heat Roadmap Europe 2016. Level 4 of ambition reflects a scenario in which the rise in which the rise of cooled area follows the average developments of population aging in accommodate the growing fraction of vulnerable population. In average the population share the elderly in the total population of the EU-28 is projected to increase from 19.2 % at the start of 2016 to 29.1 % by 2080. This implies that the share of the elderly is projected to rise by about 10%[10]. In order to reflect the fact that the projections of the EUCalc only run until 2050, level 4 bounds the increase of cooled area to 8% of the total residential. Levels 2 and 3 are constructed as intermediate scenarios.

Disaggregation by country

The disaggregation follows the differences between countries implied in the projections of % of cooled area for residential buildings proposed in Heat Roadmaps (2016).

[10] https://bit.ly/2EImGWB

4.6.2.6 Cooling temperature

The inclusion of this lever introduces the cooling behavior aspect in the Lifestyle module complementing the levers on floor intensity and growing shares of cooled area. Hoyt *et al.*, (2005) explored a simulation model of air-conditioning systems and reviewed case studies that suggst energy savings of 7-15% per each degree of increase or decrease temperature. Furthermore, the inclusion of this lever will allow the user to investigate the relative energy implications between this lever and those controlling the floor use intensity and the share of residential area subjected to cooling.

Table 15 – Ambition levels for the cooling temperature lever

Name / Unit	1	2	3	4
Comfort temperature	21.5	22	22.5	23

Level 4 is assumed to be that in which dwellers set their room temperatures to that equivalent to the conform temperature determined in Ballester et al., 2011 at the country level. The estimates of comfort temperature in Ballester et al., 2011 are determined empirically using mortality data at NUTS2 level between 1998 and 2003, and refer to the temperature at which the cases of excess mortality due to heat are at the lowest. At the European level the comfort temperature was set at about 23ºC of maximum daily temperature. Levels 3 to 1 are set in half-degree reductions from the most ambitious level. This reflects incremental scenarios in which the inhabitants of dwellings cool their rooms further than the comfort temperature.

Disaggregation by country

The different scenarios of European change are translated directly to the country comfort temperature level by subtracting the assumed European change to the country's current comfort temperatures. For example if the comfort temperature is 20 degrees (level4), level 3 would be 19.5 degrees.

4.6.3 Passenger transport demand

Passenger travel distance in EU28+Switzerland (given in pkm/year/person), has increased from about 8328 in 1990 to about 12466 in the year 2015; an annual growth nearly 25 (own calculations based on pkm data from the Statistical Pocketbook, 2016 and population data from Eurostat). Importantly, the rise of air passenger transport is pushing total volumes of passenger km's travelled. In the EU28, air passenger transport increased by 37% between 2000 and 2014, a 2% year on year increase (Statistical Pocketbook, 2016). Furthermore, air traffic is projected to grow in the long-term, driven by global GDP growth and pkm are forecast to grow over the period 2016 - 2035 at a rate of 4.5 to 4.8% per year (DGMOVE, 2017).

Table 16 - Ambition levels for the passenger transport lever

Name / Unit	1	2	3	4
Passenger travel distance (pkm/cap/year)	15120	14424	13714	11521

Using data of time spent on travel time for leisure, work/study and access to services from Eurostat (2003), and total per capita passenger transport (pkm/person/year) from the Statistical Pocketbook (2016), the level of passenger travel demand are determined according to the equation below. It is worth to notice that the calculations of passenger travel demand are done for of five age classes for males and females separately. The age classes are: males/females below 19 years old, male/females between 20 and 29, male/females between 30 and 54, male/females between 55 and 65 and male/females above 65. These age classes are the same for calculation of calorie requirements (Section 4.6.4)

$$\begin{aligned} &\textit{Passenger travel demand (km per year)} \\ &\quad = \textit{travel time for leisure (h per day)} + \textit{travel time for work or study (h per day)} \\ &\quad + \textit{travel time for access to service(h per day)} * \textit{average daily speed(km per hour)} \\ &\quad * 365(\textit{days}) \end{aligned}$$

In Level 1 travel time for leisure is set to converge by 2050 to levels of 0.7 hours/day, a level slightly higher than that of current affluent EU countries see Figure 17 in Annex). The time spent for work/study and for access to services remains constant to year 2000 values (approximately 0.3 and 0.2 h/day). Average travel speeds remain constant for all the levers settings to 2014 values. Under this assumption average passenger travel distance in EU28+Switzerland reaches circa 15120 pkm per person per year, a 21.3% increase from 2015 levels.

For level 3, current travel time dedicated for leisure is equal to that of level 1 and by 2050 travel spent on travelling to work/study drops by 25% from current values. This reflects the situation in the Czech Republic where 15% of the working population (the driving force behind travel for work) is involved in telework at least “a quarter of the time” or more (International Labour Office, 2016). Time spent for shopping and access to services is reduced by 20%, reflecting the reductions of time spend traveling for shopping in England (Francke & Visser 2015). As results, by 2050, average passenger travel distance in EU28+Switzerland reaches 13714 pkm per person, a 10% increase from 2015 levels.

In Level 4 the travel time for leisure activities leisure is equal to that of level 1. Time spent on travelling to work/study is reduced by 50% reflecting the opportunities of full teleworking potential and a doubling of the situation of level

3. Time spent for shopping and services is reduced by 40%, a doubling of the situation in level 3. In addition, travel for leisure drops in 2050 to 80% of the value typically found in rich countries today. This would represent a shift in preferences for people to commute smaller distances for the purposes of leisure. As result, by 2050, average passenger travel distance EU28+Switzerland reaches 11521 pkm per person, a 7.1 % decrease from 2015. Level 2 is set as an intermediate level between level 1 and 3.

Disaggregation by country

In level 1 country evolve in accordance with their historical individual growth in travel time allocated to leisure. In levels 2 to 4 countries converge from their current position to the distance implied by the assumed reductions of travel time.

4.6.4 Calorie requirements

Global demand for agricultural crops is increasing, and may continue to do so for decades, propelled by a 2.3 billion person increase in global population and greater per capita incomes anticipated through mid-century (Tilman et al., 2011). Income growth and human development, particularly in low- and middle-income countries, is suggested to accelerate dietary transitions towards high and very high caloric intake (Pradhan et al., 2013). This prospect will put more pressure in already strained agricultural systems and potentially lead to an increase of emissions in the agricultural sector.

Table 17 - Ambition levels for the calorie requirements lever

Name / Unit	1	2	3	4
Calorie requirements (kcal/cap/day)	2837	2757	2657	2606

Our estimates of calorie requirements are based on the methodology put forward in (Hiç et al., 2016). Calorie requirements are a function of demography, BMR (Basal Metabolic Rate) and Physical Activity Level (PAL), see equation below. Constant *C,* and slope, *S,* depend on age and sex groups. The country-specific information for these variables has been taken from (Hiç et al., 2016). Demography is included in order to account for the fact that calorie requirements between younger and older population are rather distinct, being higher in younger age classes for males and lower for female age classes above 65[11]. The energy requirements are separately calculated for four age groups, infants, children, and adolescents, adults, elders, and pregnant and lactating women.

$$\begin{aligned} &Calorie\ requirements\ (kca\ per\ person\ per\ day) \\ &\qquad = BMR(\ C(age, sex) + S\ (age, sex) * BW\ (age, sex)) * PAL \end{aligned}$$

[11] http://www.fao.org/3/a-y5686e.pdf

Level 1 of calorie requirements in the EUCalc is determined by extending the country-specific linear trends of BMI (Body Mass Index) in time observed between 1990 and 2013 extracted from NCD-RisC 2016. From the future BMI a new BMR is derived assuming that the BW component in the equation above increases in the same proportion and the BMI trend. Values of PAL are kept constant and equal to those reported in Hiç et al., 2017. Calorie requirements for Levels 3 and 4 are assumed to be those resulting from a decline in BMI so that overweight levels of a country are, respectively, a quarter of that observed in 2015 and half of that observed in 2015. Level 2 is set as an intermediate level between level 3 and 1.

Disaggregation by country

For level 1 the BW (see previous equation) of countries evolves in the same rate as the country-specific linear trends of BMI between 1990 and 2013 extracted from NCD-RisC 2016. Similarly, reductions in calorie requirements are simulated for each country as a reduction of country-specific BW necessary to reduce overweight levels (e.g., to a quarter and half).

4.6.5 Diets

Recent investigations confirm that the total share of animal based calories is estimated to rise strongly for income for low-income groups but that for high income groups strong and slight negative time-trends are possible (Bodirsky et al., 2015). These shifts in consumption towards more animal-base products are expected to lead to an increase of GHG emissions. Hence, dietary shifts have been proposed as an effective way of reducing associated greenhouse emissions in the agricultural sector (Springmann et al., 2018).

Ambition level 1 is assumed to be the continuation of the past (2000-2013) trend of calories change for each food group until the year 2050. It is important to mention that in some cases the reduction of particular food groups (say bovine meat) might be enough to fulfil the dietary guidelines of levels 3 and even 4. If that is the case then the dietary requirements for the meat-related food groups in question are further lowered to 60% of the dietary recommendation. This assumption goes beyond the level proposed in WHO but is still in line with the most ambitious level of dietary change in Springmann et al., 2018. In case the historical trend determined under level 1 delivers already the best dietary requirements for vegetables and fruits the same calorie values are kept at level 1 for all levels. In case the historical trend determined under level 1 delivers already the best dietary requirements for sugar and sweeteners, the same calorie values are kept at level 1 for all levels.

Table 18 - Ambition levels for the diet lever

Name / Unit	1	2	3	4
Calories per food group (kcal/cap/day)				
Bovine Meat	41	31	21	14
Demersal Fish	12	8	3	2
Freshwater Fish	7	4	2	1
Fruits - Excluding Wine	79	157	234	351
Meat, Other	5	4	3	2
Mutton and Goat Meat	7	6	4	3
Offals	11	9	7	7
Pelagic Fish	23	14	5	3
Pigmeat	150	114	79	52
Poultry Meat	85	54	24	15
Sea food	5	3	1	1
Sugar	301	248	195	118
Sweeteners	46	38	30	18
Vegetables	54	112	171	256
Beer Beverages, Alcoholic Beverages, Fermented Cereals - Excluding Beer Rice Coffee and products Eggs Fats, Animals, Raw Milk Oilcrops Pulses Starchy Roots Stimulants Vegetable Oils Wine	A function of the difference between calorie requirements and the sum of the calories from the groups above implied in the lever selection.			

For level 3 it is assumed that counties converse to fulfil the minimum dietary requirements of World Health Organization 2003 and WCRF 2017. This means that countries converge to a diet in which all meat does not go over 90g/day (of which only up to 71g/day is read meat); where sugars and sweeteners are kept below 10% of calorie consumption and where fruits and vegetables consumption is of at least 400g/day. Level 4 assumes a general improvement of all the above calories so that countries full fill the best dietary standards in the cited documents. This implies red meat to be kept at no more than 42g/day; sugars s and sweeteners at below 5% of calorie intake; and fruits and vegetables consumption to be over 600g/day. Fractions of calories for the remaining of the food groups considered (26 in total, see section 4.4.1.3) are kept constant to their relative values of 2013. The absolute calorie values for the remaining food groups are calculated as detailed in section 4.5.5.

Disaggregation by country

In level 1 the countries evolve independently according to their past dietary trend. For level 3 and 4 countries converge to per capita food group consumption that best mimics the health guidelines in WHO and to the Flexitarian diet in Springmann et al., 2018. For level 2 countries converge to the mid-point between level 1 and 3.

4.6.6 Food waste

For 2012, food waste at the EU-28 estimated at 88 million tonnes (Stenmarck et al., 2017). This equates to 173 kilograms of food waste per person in the EU-28. The total amounts of food produced in EU for 2011 were around 865 kg / person, this would mean that in total we are wasting 20 % of the total food produced. Recent estimates for 2017 puts the number at 89.2 million tonnes of food each year. Germany (10.3 million tonnes), the Netherlands (9.4 million), France (9 million) and Poland (8.9 million) make up the top five most profligate countries. Malta is the least wasteful country, with the relatively little excess of 25,000 tonnes per year[12].

Table 19 - Ambition levels of food calories wasted at consumer level

Name / Unit	1	2	3	4
Calorie wasted (kcal/cap/day)	522	390	260	130

The average fraction of fractions of food waste in Europe per food group are taken from Gustafsson et al., 2013 and assumed unchanged for each country. This means for example that consumer-wasted fraction of cereal calories (around 25% of Europe's cereal consumption) is the same in every country considered. The absolute value of waste varies from country to country given the different dietary compositions and population.

For level 1 food waste per capita, at the consumer level, remains constant at an average food waste for EU28+Switzerland of 522kcals. For level 3 it is assumed that by 2050 countries achieve food waste reductions at the consumer level of about 50%, thus complying with the SDG target 12.3 (originally set by 2030). This translates to an average food waste for EU28+Switzerland of 260 kcal. For level 4 countries achieve food waste reductions at the consumer level of about 75% by 2050, thus overcoming the SDG target 12.3 by 2030. This translates to

12 https://www.independent.co.uk/news/world/europe/how-much-food-does-the-eu-waste-a6778351.html

an average food waste for EU28+Switzerland of 130 kcal. Level 2 is set as an intermediate level between level 1 and level 3.

Disaggregation by country

Countries converge to the individual food waste targets which take into account the current consumption levels of each country.

4.6.7 Paper and packaging demand

For level 1 the change in paper printing and graphics arrive in 2050 to the negative trend proposed in Hänninen et al., (2014) for 2030 - 26% reduction. For level 2 we extend the Hänninen et al., (2014) trend to 36% by 2050. Regarding level 4, we add the reductions in level 2 those identified in Calloway and Michel, (2003) and Moberg et al., (2010) - that is 10% each – to arrive at an ambition level of 56% reductions by 2050. Level 3 is set an intermediate level between 2 and 4. An indicative 2% growth trend (over 5 years) in tissue paper[13] is used to set level 1 for paper sanitary and household by 2050 at an increase of 17%. For level 2 the growth is set at 1%, reflecting the possibility of Eastern European countries curbing their growth faster that Wester European countries did in the past. In level 4 we assume a complete stagnation of sanitary paper use, which would be extremely ambitious. Level 3 is set as an intermediate level.

Table 20 - Ambition levels of changes in paper and packaging demand

Name / Unit	1	2	3	4
Plastic packaging change [%]	125	112	100	90
Glass packaging change [%]	150	155	165	170
Aluminium packaging change [%]	125	112	100	90
Paper printing and graphic change [%]	26	36	46	56
Paper sanitary and household change [%]	117	108	104	100

For plastic packaging level 1 reflects the growth scenario in Lebreton and Andrady (2019) under which disposable plastic, and hence also packaging demand in Europe, increases by 25%. In its communication of 2018, A European Strategy for Plastics in a Circular Economy, the European Commission declares that is aims to increase plastic recycling and for all plastic packaging to be reusable or recyclable by 2030. The EU also wants 55% of all plastic to be recycled by 2030 and to reduce the use of bags per person from 90 a year to 40

[13] *Demand scenarios for fiber-based products available online at: https://mck.co/2z21cvo*

by 2026. The effectiveness of this strategy in curtailing the demand for plastic packaging is still unclear at the time of writing and it was decided that for level 1, the link between wealth and plastic waste generation remains unchanged in the future and hence there is an increase in plastic packaging under level 1.

Level 4 is set at the technical feasibility of reducing household plastic consumption by 10% in Moran et al., (2018). Level 3 is equated to stagnation of today's levels of packaging and level 2 and intermediate level between 1 and 3. These levels are also assumed for the case of aluminium packaging.

Glass packaging is rising as seen beforehand in this section and its growth is level 1 is set at a yearly rate of 1.6% as implied in the 2012-2017 growth rate reported in FAVE 2019. This would yield a rise in about 50% in 2050. For level 4 a growth of 70% is assumed in order to compensate the drops in plastic and aluminium packaging. Levels 2 to 3 are constructed as intermediate scenarios.

Disaggregation by country

Countries reduce their demand in paper in packaging according to the European % reduction target assumed in the ambition levels.

4.7 Data access

In the spirit of the calculators before us, we make available the current data inputs for the Lifestyles module. These can be accessed via the link and password provided below. The naming of each input file and well as the metadata provided follow the EUCalc standards detailed in the project's Data Management, Deliverable 11.2, accessible via this link.

Link to the input datasets: https://cloud.pik-potsdam.de/index.php/s/s2MpLr9Hqbjrxki

Password: lfs_euc_09

5 Conclusions

This deliverable describes how the Lifestyle and Climate modules are integrated within the EUCalc framework. Located at the start of the modelling pipeline, the models provide a wide selection of inputs to other modules and thus indirectly or directly shape the demand of energy, resources and GHG emissions within EUCalc. Located at the end of the pipeline, the emissions section of the Climate modules estimates a global temperature response and potential impacts, e.g. drought risk, at the end of the 21st century. Regarding the Lifestyles module, this deliverable details the main calculations and outputs provided to the other modules of the EUCalc framework, as well as the assumptions entailed in the ambition lever definitions. Finally, the current input files of the Lifestyles module are also provided.

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6 Annex

Table 21 - Food groups considered in the EUCalc and modelling strategy used

Food group considered in the EU Calculator	Modelling strategy
Bovine Meat Demersal Fish Freshwater Fish Fruits - Excluding Wine Meat, Other Mutton and Goat Meat Offals Pelagic Fish Pigmeat Poultry Meat Sea food Sugar Sweeteners Vegetables	Affected by the WHO and WCRF dietary guidelines
Beer Beverages, Alcoholic Beverages, Fermented Cereals - Excluding Beer Rice Coffee and products Eggs Fats, Animals, Raw Milk Oilcrops Pulses Starchy Roots Stimulants Vegetable Oils Wine	Balanced depending on the total calories and the sum of the calories on the food groups affected by the dietary guidelines of WHO and WCRF

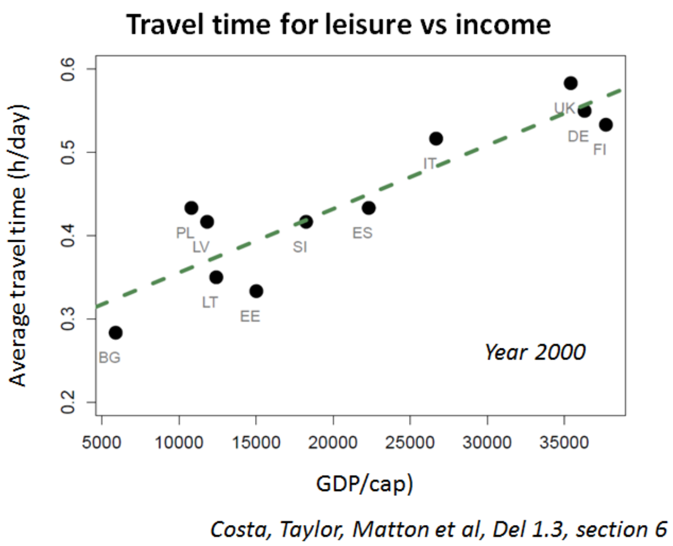

Figure 18 - Leisure travel time vs income for European countries.