WP7 – Transboundary effects module documentation

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EUCALC

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Short Description
This report describes - *The GTAP-EUCalc model development;* - *The construction of the 2050 economic baseline;* - *The integration process of GTAP-EUCalc and the EUCalc 'core' modules;* - *The pathways simulated with GTAP-EUCalc;* - *The transboundary module results shown in the TPE.*

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Statement of originality:

This report contains original unpublished work except where clearly indicated otherwise.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

2W:	Two-wheels
BAU:	Business as usual
BEV:	Battery electric vehicle
Cap:	Capita
CD:	Cobb Douglas
CDE:	Constant difference of elasticities
CES:	Constant elasticity of substitution
CEV:	Catenary electric vehicle
CGE:	Computable General Equilibrium
CSA:	Climate Smart Agriculture
EUCalc:	European Calculator
FCEV:	Fuel cell electric vehicle
GTAP:	Global Trade Analysis Project
GWP:	Global Warming Potential
HDVH:	Heavy-duty vehicles, heavy
HDVL:	Heavy-duty vehicles, light
HDVM:	Heavy-duty vehicles, medium
ICE:	Internal combustion engine
IWW:	Inland waterways transport
Kcal:	Kilocalorie
LDV:	Light duty vehicle
LSU:	LiveStock Unit
MS:	Member State
PHV:	Plug-in Hybrid Electric Vehicle
PKM:	Passenger kilometer
SSP:	Shared Socio-economic Pathway
TFP:	Total Factor Productivity
TKM:	Tonne kilometer
VKM:	Vehicle kilometer
WP:	Work Package

1 Module introduction

The module based on the research performed by the work package on "Transboundary Effects and Trade Flows" (WP7 hereafter), within the EUCalc project, aims at quantifying the transboundary effects of user-selected decarbonization pathways, defined at sectoral levels and obtained from combinations of levers[a] from other EUCalc modules. Trade effects are generated by using a computable general equilibrium (CGE) modeling framework that simulates perturbations to a projected baseline of the world economy in 2050. The simulated transboundary effects will inform EUCalc users of likely future economic dependencies inside the EU28+Switzerland as well as between the EU28+Switzerland and the rest of the world (ROW) due to the decarbonization efforts of EU28+Switzerland.

Transboundary flows refer to the trade of goods and services amongst the EU28+Switzerland States, as well as between the EU28+Switzerland and ROW. As the envisioned decarbonization pathways impose changes in both demand and supply, levels and structures of production and consumption of sectors and countries are also altered. This, in turn, changes the economic dependences concerning the aforementioned States at sectoral levels and leads to modifications in trade patterns. Furthermore, as transboundary flows of goods and services also embody energy consumption and GHG emissions, projecting transboundary flows is an important consideration in evaluating the options and tradeoffs of decarbonization pathways for the EU28+Switzerland and their "GHG emission effectiveness" in a global context.

Modeling the transboundary effects mandates the use of an economic modeling system that takes into consideration not only inter-sectoral linkages, such as the input-output associations connecting raw materials and fossil fuels to final outputs, but also linkages through the competition/allocation of available economic resources such as labor and capital. Additionally, States in EU28+Switzerland and other ROW economies must be connected in the model such that imbalances between demand and supply at sectoral levels for each country can be accounted for via transboundary trade flows. Essentially, this requires the use of a global CGE model focused on trade linkages. In fact, CGE models are a typical tool for empirical analysis of distributional and welfare impacts of different policies (Winters and Hertel, 2005, Anderson and Martin, 2005, Bourne and Philippidis, 2018). More generally, they can be used to measure the result of shocks to an economic system (i.e. computable), encompassing simultaneously all economic activities (consumption, production, employment, taxes, savings, trade etc.) and the linkages among them (i.e. general), in an economy where at a given set of prices all agents are satisfied (i.e. equilibrium) (Burfisher, 2011). To analyze the trade and transboundary effects of EUCalc decarbonization pathways, this module adopts a modified version of the GTAP-E model (Burniaux and Truong, 2002, McDougall and Golub, 2007), nicknamed GTAP-EUCalc.

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[a] Levers represent different GHG abatement ambition levels with respect to behavior, technology or practices patterns in different sectors, which the EUCalc model's user can modify to formulate their own decarbonization pathways and visualize the results of their choices on a web interface.

Research efforts in WP7 can be summarized as follows:

1. Modify the structure of the GTAP-E model for the scope of EUCalc, i.e. to project the world economy to the year 2050, to accommodate the sectoral coverages of other EUCalc WPs, and to design new model structures to facilitate the implementation of the large structural shocks implied by the sectoral lever settings. The new model, nicknamed GTAP-EUCalc, is presented in Deliverable 7.4 (Clora and Yu, 2019a);

2. Construct a baseline projection of the world economy for 2050. The data chosen to project the GTAP-9 database are introduced in Deliverable 7.1 (Yu and Clora, 2018). Refinements to the baseline are described in Deliverable 7.4 (Clora and Yu, 2019a);

3. Design an interface to facilitate the transformation of alternative sectoral EUCalc pathways as inputs into the GTAP-EUCalc model, in order to simulate the transboundary effects. The interface design process and description are addressed in Deliverables 7.2 (Baudry et al., 2018) and 8.6 (Clora and Yu, 2019b);

4. Simulate the alternative EUCalc pathways as model scenarios, to generate the transboundary effects to be included in the EUCalc Transition Pathway Explorer (TPE). A library of pathways simulated in GTAP-EUCalc is presented in this report.

The document is thus structured as follows. Section 2 introduces the GTAP-EUCalc model and database. Section 3 presents the 2050 economic baseline projection exercise. Section 4 summarizes the integration of GTAP-EUCalc and EUCalc, and section 5 presents the interfaces between GTAP-EUCalc and individual EUCalc 'core' modules. Section 6 describes the sets of scenarios simulated in GTAP-EUCalc, and the final section 7 lists and explains the module's outputs.

2 The GTAP-EUCalc model

Trade and transboundary effects of EUCalc decarbonization pathways are simulated and analyzed by adopting a modified version of the GTAP-E model (McDougall and Golub, 2007, Burniaux and Truong, 2002), which is the energy-environmental version of the GTAP model (Hertel et al., 1997). The GTAP-EUCalc model has been developed adapting the GTAP-E version 6-pre2 (McDougall and Golub, 2007) to the scope of the EUCalc.

2.1 The GTAP framework

The GTAP model is among the most widely used CGE models. GTAP's extensive country coverage and its general equilibrium modeling structure on sectoral and trade linkages within and across countries complement the scope of the EUCalc as it allows for simulating the transboundary effects of alternative EUCalc pathways under various lever settings.

The GTAP framework[b] at its core consists of a database and a standard model on which multiple models have been developed. The dataset contains

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[b] For more information, visit www.gtap.org

national/regional input-output tables that are linked through bilateral trade flows, transport, and protection linkages. The GTAP-9 database (Aguiar et al., 2016) characterizes the world economy, with the available benchmark years being 2011, 2007 and 2004. It includes data on consumption, production, trade, energy and CO_2 emissions. The GTAP-9 database includes 140 regions, 57 tradable commodities, and 5 non-tradable primary factors. The values in the GTAP-9 database are all presented in millions of (2004, 2007 and 2011) current USD. Carbon dioxide emissions are displayed by region, commodity, and use. In detail, the current GTAP database differentiates emissions from households and government consumption of domestic and imported products, and emissions from firms' usage of domestic and imported intermediate goods. The values are expressed in mega-tonnes of CO_2 (Mt CO_2).

We also use the GTAP satellite non-CO_2 emissions database, developed by Irfanoglu and van der Mensbrugghe (2015) based on the work of Rose and Lee (2008). It includes non-CO_2 emissions by region and sector, for the three main non-CO_2 gases, i.e. CH_4, N_2O and a cluster encompassing fluorinated gases ('F-gases'). Emissions are generated by four drivers: final private consumption, intermediate consumption, endowment use (capital and land), and output. Unlike the standard GTAP database, no distinction between consumption of imported and domestically produced commodities is specified. Data are provided both in giga-grams (Gg) and MtCO2e. The global warming potentials adopted to convert giga-grams of each non-CO_2 gas into CO2e are shown in table 2.1. Such values are consistent with IPCC (2014).

Table 2.1 - Global warming potentials[c] of GHG gases, for a time horizon of 100 years, used in GTAP-9 satellite non-CO2 emissions database

Gas	GWP
CO2	1
CH4	21
N2O	310
CF4	6500
SF6	23900
HFC-22	11700
HFC-234a	1300

The standard GTAP model (Hertel et al., 1997) – on which the GTAP-E model is built - is a static multi-region/country, multi-sector CGE model, with perfectly competitive markets and constant returns to scale technologies. It includes treatment of private household behavior, government expenditure, international trade and transport activity, and global investments/savings relationship.

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[c] The Global Warming Potential represents how much of a given mass of a gas contributes to global warming, over a given time period, compared to the same mass of carbon dioxide, chosen as a benchmark.

The underlying system of equations in the GTAP model includes two types of equations: accounting (identity) relationships, ensuring that revenues and expenditures of every agent in the economy are equalized, and behavioral equations, specifying the behavior of optimizing agents (i.e. consumers and producers) in the economy when they have to modify their optimal choices in the presence of shocks (Brockmeier, 2001).

Figure 2.1 depicts the core structure of the GTAP model, focusing on the accounting relationships, and allows to visualize the flows and linkages. For a clearer representation, the figure only shows the value flows within the economy; the corresponding factors/inputs/commodity flows in the opposite direction are not displayed.
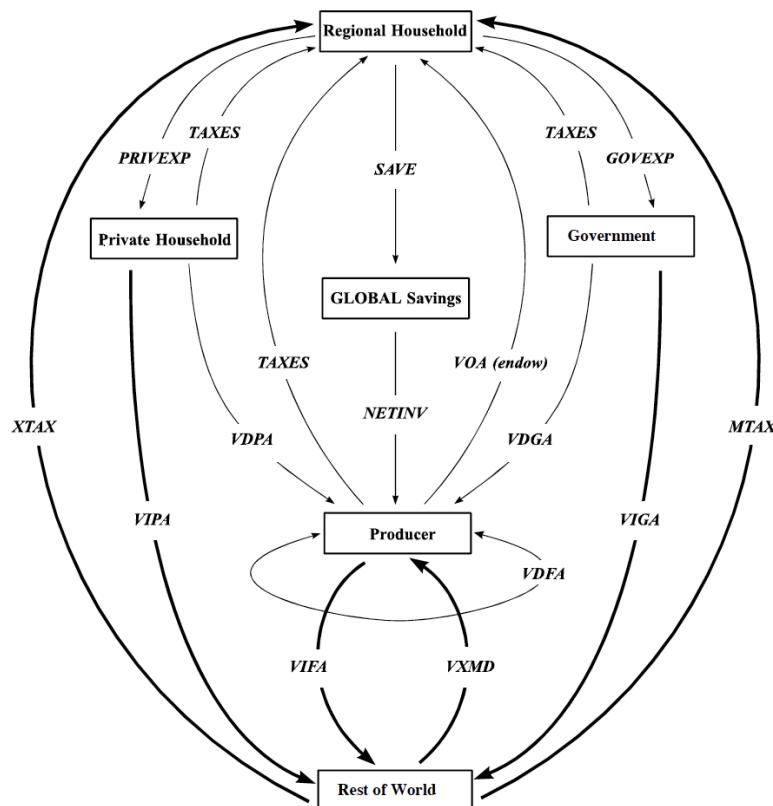
Figure 2.1 - GTAP structure (Brockmeier, 2001)
PRIVEXP: private consumption expenditure in region r; VDPA: domestic purchases, by households, at agents' prices; VIPA: import purchases, by households, at agents' prices; GOVEXP: government consumption expenditure in region r; VDGA: domestic purchases, by government, at agents' prices; VIGA: import purchases, by government, at agents' prices; SAVE: net saving, by region; NETINV: regional net investment; VOA: value of commodity i output in region r at agents' prices; VDFA: domestic purchases, by firms, at agents' prices; VIFA: import purchases, by firms, at agents' prices; VXMD: Non-margin exports, at market prices; TAXES: different kind of taxes or subsidies; MTAX: tax on imports on good i from source r in destination s; XTAX: tax on exports on good i from source r in destination s.

The household associated with each region collects all the income generated in each regional economy, and fully consumes it over government expenditures, private expenditures and savings, according to a Cobb-Douglas (CD) per capita utility function. Domestic government purchases at agent's price are modeled according to a CD sub-utility function, with constant expenditures across all commodities. Savings are entirely consumed on investment. In GTAP, domestic

private consumption is represented by the Constant Difference of Elasticity (CDE) implicit expenditure function. The producers receive payments from selling final consumption goods, intermediate inputs to other producers, and from investment goods to the global saving sector. These revenues are used on expenditures for primary factors of production and for intermediate inputs, given the zero-profit assumption.

Additionally to the closed economy described in the paragraph above, the GTAP model represents also policy interventions, and linkages among the various economies in the world. Taxes are paid by firms, government and private consumers to the regional household, and are captured by a wedge between agent's prices (including the tax) and market prices. For international trade, a two-tier "Armington" structure (Armington, 1969) is specified to allow for imperfect substitutions between imports and domestically produced products, as well as between imports from different sourcing countries. This structure enables the model to track both imports and exports between any given pair of importing and exporting countries (see figure 2.2). Tariffs are paid on imports, by firms, the private agent and the government. Imported and domestic commodities are combined in a composite nest for the private and government households, in a fashion similar to the firms production tree. Household's and firms' import demands differ only in their import shares, since the elasticity of substitution between imported and domestic goods in the composite nest of the utility tree is assumed to be equal across uses.

Zooming in the production structure, an intuitive way to describe it is through a 'production tree', shown in figure 2.2. Each node of the tree symbolizes a composite intermediate commodity or a primary factor, resulting as an aggregate of the commodities and factors included one level below. An appropriate input demand in each node of the production structure results from cost minimization behavior from firms.
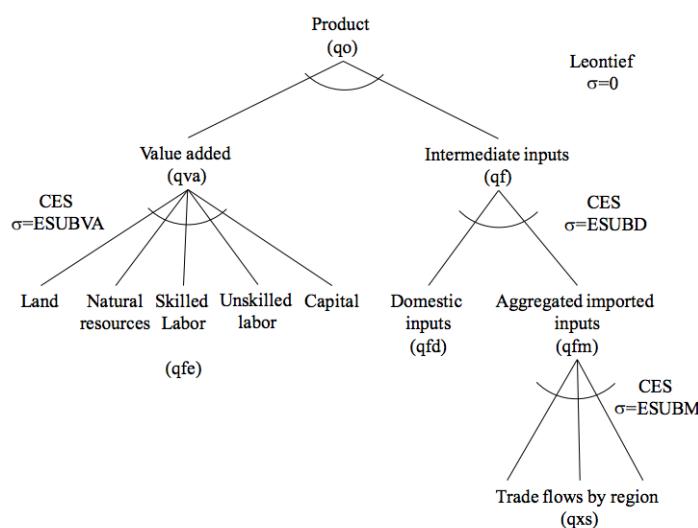
Figure 2.2 - Production structure in the standard GTAP model

Firms purchase intermediate inputs that are either domestically produced or imported. Imported inputs are aggregated by a constant elasticity of substitution (CES) production function. Likewise, a CES production function regulates the grouping of domestic intermediate inputs and combined imported ones. In the other intermediate nest, endowment commodities are aggregated through a CES function, generating the value-added nest. The primary production factors are fully

employed within each region, and cannot migrate between regions. In the final step, the value added nest is combined with intermediate inputs through a Leontief production function, in order to generate output, implying an elasticity of substitution between bundled intermediate inputs and primary factors equal to zero. Given the assumption of constant returns to scale and the Leontief production function in the highest production nest, firms choose their optimal mix of primary factors independently from intermediate inputs' prices. Furthermore, within the value-added nest, the factors are perfectly mobile, earning the same market returns across sectors, and endowments sluggish to adjust, earning differential returns (Hertel et al. 1997).

The GTAP-E model differs from the standard GTAP model mainly because it adds an explicit capital-energy composite input into the production structure (figure 2.3), allowing for a degree of capital-energy substitution (Burniaux and Truong, 2002). In addition, it comprises a different treatment of energy demand, inter-fuel substitution, CO2 accounting, taxation and regional emission trading. In GTAP-E, the final consumption structure is altered too. Government consumption is based on a CD structure, and energy commodities are separated from the others by a CES structure. The household private consumption structure is the same as in the standard GTAP model, and adopts the CDE functional form. However, in the second-level nest, an energy composite using a CES functional form is specified.
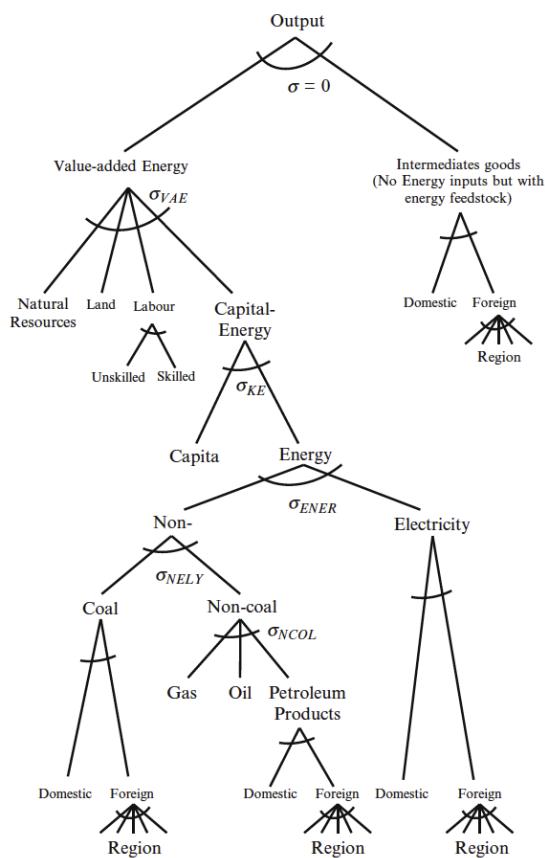
Figure 2.3 - GTAP-E production structure

For the scope of EUCalc, a modified version of the GTAP-E model (McDougall and Golub, 2007, Burniaux and Truong, 2002) has been developed, including several key modifications to the standard GTAP-E model that are documented in the next section.

2.2 Key features of GTAP-EUCalc

The GTAP-EUCalc model differs from its predecessor (GTAP-E) by incorporating an aggregate land supply function, a new private demand system with two embedded within-budget share shifters to target changes consumption shares, a twist parameter in each nest of the CES firms' structure, and additional sets of equations accounting for non-CO2 emissions and overall GHG emissions. In the following paragraphs, the main differences and modifications with respect to GTAP-E are described.

2.2.1 Two alternative private demand systems

Two alternative private demand systems are used. The standard CDE functional form, first proposed by Hanoch (1975), is used for projecting the GTAP-9 database from 2011 to 2050. This system is robust and regular globally[d] with very significant income increases (Yu et al., 2004), and is widely used in CGE models since the work of Hertel et al. (1991). In fact, it allows for differences in both price and income responsiveness of demand in different regions, contingent on the development level and observed consumption patterns in that region. However, such a complex system is not easily reparametrized for purposes of generating the very large demand structural changes implied by many of the assumed lifestyle levers in WP1. In fact, pre-trials of selected demand shocks from the relevant EUCalc modules cannot be solved without changing the underlying consumer preferences behind the CDE demand system. Therefore, to simulate decarbonization pathways in 2050, the CDE is substituted by a CD demand system. In practice, this is done in GTAP-E by setting the expansion parameter equal to 1 and the substitution parameter equal to 0. Under homothetic preferences, income elasticities are unitary and budget shares are constant, regardless of the income levels.

2.2.2 Twist parameters

To simulate lifestyle changes as defined by the EUCalc Lifestyle module, two within-budget share shifters have been introduced in the private demand nests. The first shifter is implemented in the CES energy private consumption nest and allows to modify consumption between coal, oil, gas, oil products and electricity. The second shifter is added to the CD upper consumption nest, allowing for exogenous preference-driven changes across the energy bundle and the non-energy commodities. Thanks to these shifters, designed similarly to Dixon and Rimmer (2002), it is possible to represent EUCalc-derived modifications to the private demand for energy and non-energy commodities based on preference changes with relative ease.

Similarly to the within-budget shifter, a twist-parameter in each nest of the CES production structure allowing for changes in cost shares is added to the model, as

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[d] The "regularity requirements are related to the properties of the expenditure function. An expenditure function is considered regular if its value is non-negative, its first derivatives with respect to prices (compensated demands) are non-negative, and if the matrix of second partial derivatives with respect to prices is negative semi-definite (implied by the concavity property). The non-negativity requirement, coupled with the adding-up property, requires that the budget share of the good should lie in the [0,1] interval. In long run projections, with considerable changes in income/expenditure, this requirement is crucial in ensuring the demand system behaves in accordance with economic theory." (Yu et al., 2004)

proposed by Dixon and Rimmer (2002) and applied, among others, by WTO (2018). This implementation is performed to facilitate the modeling of changes in technologies in many of the EUCalc sectors, according to their lever settings.

2.2.3 Aggregate land supply function

The model also features an isoelastic aggregate supply of land to allow for aggregated land supply responses by country/region. The land price elasticities are econometrically estimated by Philippidis et al. (2017), and shown in table 2.2 below. In the GTAP-EUCalc code, the land supply function is implemented with an approach similar to the one developed by Kløverpris and Baltzer (2008).

Table 2.2 - Aggregate land price elasticity of supply (ELND), estimated at the country level

Country	ELND	Country	ELND	Country	ELND
Austria	0.027	France	0.015	Malta	0.015
Belgium	0.035	United Kingdom	0.015	Netherlands	0.015
Bulgaria	0.015	Greece	0.015	Poland	0.141
Cyprus	0.112	Croatia	0.04	Portugal	0.015
Czech Republic	0.015	Hungary	0.016	Romania	0.041
Germany	0.218	Ireland	0.015	Slovakia	0.015
Denmark	0.015	Italy	0.025	Slovenia	0.015
Spain	0.015	Lithuania	0.009	Sweden	0.015
Estonia	0.065	Luxembourg	0.015	Switzerland	0.015
Finland	0.015	Latvia	0.014		

2.2.4 GHG accounting equations

A set of accounting equations for non-CO_2 emissions and for overall GHG emissions is added. Owing to the different structures of the CO_2 and non-CO_2 GTAP9 databases, some assumptions are necessary. In GTAP-E, carbon emissions are shown by country/region, commodity and use (private demand, government demand, intermediate demand), with a distinction between domestically produced and imported goods. They are assumed to be proportional to uses of fossil fuels. Non-CO_2 emissions, as mentioned above, are generated by private and intermediate consumption, endowment use (capital and land), and outputs. Differently from the CO_2 database, the non-CO_2 database accounts for emissions generated not only by fossil fuel usage, but also by industries' production processes (e.g. fugitives from mining activities, landfilling of solid waste, use of ozone depleting substances substitutes) and by agriculture (e.g. livestock enteric fermentation, manure management, fertilizers use). Additionally, emissions caused by private and intermediate consumption are not differentiated by origin. These differences are addressed in the new set of equations written to incorporate non-CO_2 emissions in GTAP-EUCalc. In fact, we assume a linear relationship between non-CO_2 emissions and their drivers, implicitly distinguishing emissions due to the consumption of imported and domestically produced products. Furthermore, a set of equations to account for total GHG emissions at the sectoral and regional levels is defined. These equations allow us to generate a measure of GHG emitted per commodity produced, which in turn permits to track GHG embedded in bilateral trade flows.

2.3 Country and sectoral aggregations in GTAP-EUCalc

The core data used for model simulations with GTAP-EUCalc is the GTAP database version 9 (Aguiar et al., 2016) encompassing 140 countries/regions and 57 sectors, supplemented with satellite data on CO2 and non-CO2 emission data (Irfanoglu and van der Mensbrugghe, 2015). For the specific purposes of the EUCalc project, the GTAP database has been aggregated to match the sectoral and regional aggregation of the EUCalc modules, taking into account their economic sensibility and the simulations' solvability. The aggregations are presented in table 2.3 and table 2.4.

On the country dimension, two similar (yet different) aggregations are implemented. When projecting the 2050 economic baseline, the EU28 MSs and Switzerland are not aggregated. This first aggregation allows to achieve consistency with the GDP projections and its main drivers gathered in Deliverable 7.1 (Yu and Clora, 2018), and to fully capture the linkages between the EU countries, without hampering the model computability. When simulating the EUCalc pathways, EU28 MSs and Switzerland are aggregated into 17 countries/regions, as shown in table 2.3. The rest of the world, not modeled by EUCalc core modules, is combined into 15 countries/regions in both aggregations, as reported in table 2.3. This aggregation is necessary to reduce the possibility of not being able to solve the model, nevertheless allowing to capture the main regional impacts of decarbonization pathways.

Table 2.3 - GTAP-EUCalc regional aggregation

GTAP-EUCalc region	GTAP region
Austria (aut)	Austria (AUT)
Germany (deu)	Germany (DEU)
Denmark (dnk)	Denmark (DNK)
Spain (esp)	Spain (ESP)
Finland (fin)	Finland (FIN)
France (fra)	France (FRA)
UK (gbr)	UK (GBR)
Ireland (irl)	Ireland (IRL)
Italy (ita)	Italy (ITA)
Netherlands (nld)	Netherlands (NLD)
Poland (pol)	Poland (POL)
Portugal (prt)	Portugal (PRT)
Slovakia (svk)	Slovakia (SVK)
Sweden (swe)	Sweden (SWE)
Belgium and Luxembourg (belux)	Belgium (BEL), Luxembourg (LUX)
Balkans, South and South-East Europe (bk_s_se_eu)	Bulgaria (BGR), Cyprus (CYP), Greece (GRC), Croatia (HRV), Malta (MLT), Romania (ROU), Slovenia (SVN)
Baltics and Central Europe (btc_c_eu)	Czech Republic (CZE), Estonia (EST), Hungary (HUN), Lithuania (LTU), Latvia (LVA), Slovakia (SVK)
Switzerland (che)	Switzerland (CHE)

Rest of Europe (r_eur)	Norway (NOR), Rest of EFTA (XEF), Albania (ALB), Ukraine (UKR), Rest of Eastern Europe (XEE), Rest of Europe (XER)
Russia (rus)	Russia (RUS)
Rest of ex-USSR (fsu)	Kazakhstan (KAZ), Tajikistan (TJK), Azerbaijan (AZE), Belarus (BLR), Georgia (GEO), Kyrgyzstan (KGZ), Rest of Former Soviet Union (XSU), Armenia (ARM)
China (chn)	China (CHN)
India (ind)	India (IND)
High-Income South-East Asia (hi_sea)	Hong Kong (HKG), Japan (JPN), Korea (KOR), Taiwan (TWN), Singapore (SGP)
Rest of South-East Asia and Pacific (r_sea_p)	Rest of Oceania (XOC), Mongolia (MNG), Rest of East Asia (XEA), Brunei Darussalam (BRN), Cambodia (KHM), Indonesia (IDN), Laos (LAO), Malaysia (MYS), Philippines (PHL), Thailand (THA), Viet Nam (VNM), Rest of Southeast Asia (XSE), Bangladesh (BGD), Nepal (NPL), Pakistan (PAK), Sri Lanka (LKA), Rest of South Asia (XSA)
Australia and New Zealand (aus_nz)	Australia (AUS), New Zealand (NZL)
Middle East and North Africa (mena)	Israel (ISR), Bahrain (BHR), Iran (IRN), Kuwait (KWT), Oman (OMN), Qatar (QAT), Saudi Arabia (SAU), United Arab Emirates (ARE), Rest of Western Asia (XWS), Rest of North Africa (XNF), Jordan (JOR), Turkey (TUR), Egypt (EGY), Morocco (MAR), Tunisia (TUN)
Rest of Africa (r_afr)	Benin (BEN), Burkina Faso (BFA), Cameroon (CMR), Côte d'Ivoire (CIV), Ghana (GHA), Guinea (GIN), Nigeria (NGA), Senegal (SEN), Togo (TGO), Rest of Western Africa (XWF), Central Africa (XCF), South-Central Africa (XAC), Ethiopia (ETH), Kenya (KEN), Madagascar (MDG), Malawi (MWI), Mauritius (MUS), Mozambique (MOZ), Rwanda (RWA), Tanzania (TZA), Uganda (UGA), Zambia (ZMB), Zimbabwe (ZWE), Rest of Eastern Africa (XEC), Botswana (BWA), Namibia (NAM), South Africa (ZAF), Rest of South African Customs Union (XSC), Rest of the World (XTW)
USA (usa)	United States (USA)
Canada and rest of North America (cnd_na)	Canada (CAN), Rest of North America (XNA)
Mexico (mex)	Mexico (MEX)
Brazil (bra)	Brazil (BRA)
Rest of Latin America (r_lam)	Argentina (ARG), Chile (CHL), Paraguay (PRY), Peru (PER), Uruguay (URY), Rest of South America (XSM), Costa Rica (CRI), Guatemala (GTM), Honduras (HND), Nicaragua (NIC), Panama (PAN), El Salvador (SLV), Rest of Central America (XCA), Dominican Republic (DOM), Jamaica (JAM), Puerto Rico (PRI), Trinidad and Tobago (TTO), Rest of Caribbean (XCB), Bolivia (BOL), Colombia (COL), Ecuador (ECU), Venezuela (VEN)

On the sectoral dimension, the 57 GTAP sectors are aggregated into 17, in order to represent the EUCalc classifications. Similarly to the regional aggregation, this allows to capture sectoral interactions and heterogeneities while owing to the model complexities.

Table 2.4 - GTAP-EUCalc sectoral aggregation and EUCalc sectoral mapping

GTAP-EUCalc sector	GTAP sector	EUCalc sector
Crops (crops)	Paddy rice (PDR); Wheat (WHT); Cereal grains nec (GRO); Vegetables, fruit, nuts (V_F); Oil seeds (OSD); Sugar cane, sugar beet (C_B); Plant-based fibers (PFB); Crops nec (OCR)	WP1 (lifestyles), WP4 (crops)
Livestock (lvstck)	Bovine cattle, sheep and goats, horses (CTL); Animal products nec (OAP); Raw milk (RMK); Wool, silk-worm cocoons (WOL)	WP4 (livestock)
Rest of extraction (r_ext)	Forestry (FRS); Fishing (FSH); Minerals nec (OMN)	WP4 (Forestry, Land Use and Land Use Change, Agriculture, Minerals)
Animal-based food (f_anm)	Bovine meat products (CMT); Meat products nec (OMT); Dairy products (MIL)	WP1 (lifestyles), WP4 (food production)
Non animal-based food (f_n_anm)	Vegetable oils and fats (VOL); Processed rice (PCR); Sugar (SGR); Food products nec (OFD); Beverages and tobacco products (B_T)	
Gas (gas)	Gas (GAS); Gas manufacture, distribution (GDT)	WP5 (energy)
Coal (coal)	Coal (COA)	
Oil (oil)	Oil (OIL)	
Oil products (oil_pcts)	Petroleum, coal products (P_C)	
Electricity (electricity)	Electricity (ELY)	
Manufacture (mnf)	Mineral products nec (NMM); Ferrous metals (I_S); Metals nec (NFM); Metal products (FMP); Wood products (LUM); Paper products, publishing (PPP); Textiles (TEX); Wearing apparel (WAP); Leather products (LEA); Motor vehicles and parts (MVH); Transport equipment nec (OTN); Electronic equipment (ELE); Machinery and equipment nec (OME); Manufactures nec (OMF)	WP3 (manufacture)
Chemical products (crp)	Chemical, rubber, plastic products (CRP)	
Road and rail transport (otp)	Transport nec (OTP)	WP2 (transportation)
Water transport (wtp)	Water transport (WTP)	
Air transport (atp)	Air transport (ATP)	
Dwellings (dwe)	Dwellings (DWE)	WP2 (buildings)
Services (serv)	Water (WTR); Trade (TRD); Construction (CNS); Communication (CMN); Financial services nec (OFI); Insurance (ISR); Business services nec (OBS); Recreational and other services (ROS); Public Administration, Defense, Education, Health (OSG)	Partially (but not directly) modeled in EUCalc

The model simulations are computed using the GEMPACK economic modeling software (Harrison and Pearson, 1996, Horridge et al., 2018).

3 Baseline projection and implementation

The purpose of the baseline construction is to establish a likely business-as-usual (BAU) economic global scenario towards 2050, against which the transboundary effects of alternative EU decarbonization pathways can be simulated. In Deliverable 7.1 (Yu and Clora, 2018), we gather, analyze and compare annual GDP projections and the associated main drivers such as population, labor force (skilled and unskilled), capital stock, and total factor productivities for individual world countries, including all EU28 MS. After reviewing several recent model-based projections that can be considered as BAU, i.e. various "reference" scenarios and Shared Socioeconomic Pathway 2 (SSP2)[e] projections (Fricko et al., 2017, O'Neill et al., 2017), the following sources are selected:

- **GDP**: EU Reference Scenario 2016 (European Commission et al., 2016) and OECD-SSP2 (Dellink et al., 2017);
- **Population**: EUROSTAT, EU 2015 Ageing Report (European Commission (DG ECFIN) and Economic Policy Committee (AWG), 2014, European Commission (DG ECFIN) and Economic Policy Committee (AWG), 2015) and SSP2 projections for IIASA (Kc and Lutz, 2017);
- **Labor force**: EUROSTAT, EconMap2.4 (Fouré and Fontagné, 2016) and EU 2015 Ageing Report (European Commission (DG ECFIN) and Economic Policy Committee (AWG), 2015);
  - o Total labor force is divided into skilled and unskilled, drawing from education projections obtained from Fouré and Fontagné (2016), which in turn are a processed version of the ones by Kc and Lutz (2017);
- **Capital stock**: EconMap2.4 (Fouré and Fontagné, 2016);
- **Total factor productivity** (TFP): EconMap2.4 (Fouré and Fontagné, 2016) and EU 2015 Ageing Report (European Commission (DG ECFIN) and Economic Policy Committee (AWG), 2015).

The baseline dataset is stored in an MS Excel file that contains individual worksheets storing annual projections of GDP and the associated main drivers at country level, from 2010 to 2050. This dataset can be accessed by following this link: https://cloud.pik-potsdam.de/index.php/s/e3gYMKycXTY6nzD with the password: *tbd_euc_02*.

We use the GTAP-EUCalc model to project the world economy from 2011, which is the base year of the GTAP-E 9 database (Aguiar et al., 2016), to 2050, in line with the latest available literature (Bekkers et al., 2019, Fouré et al., 2013, Van der Mensbrugghe, 2015). We first project the economy to 2015, then to 2050 in 5-years steps. We target population and labor force projections by directly imposing shocks to the correspondent exogenous GTAP-EUCalc variables. To project GDP, we endogenize TFP in order to target the anticipated GDP levels. Additionally, we do not target directly the changes in capital stock, but opt for endogenizing it via

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[e] The Shared Socioeconomic Pathways describe alternative trends in the evolution of society and ecosystems from 2005 to 2100 at the world and regional levels. The SSPs are part of a framework that the climate change research community has adopted to facilitate the analysis of future climate impacts, vulnerabilities, adaptation, and mitigation. In SSP2, the world would undergo a transformation in which social, technological and economic trends do not deviate much from historical patterns observed over the past century.

the "Baldwin equation" (Francois and McDonald, 1996) in the model to effectively adopt a fixed savings rate closure with capital accumulation.

Besides implementing the macroeconomic projections, two other modeling features accounting for expected structural change for different economies are added to the baseline projections. The first is about the differential productivity growth across sectors, whereas the second deals with fossil fuel prices and supply.

A differential in productivity growth between sectors is recognized in the literature and expected/assumed to continue in many model-based long run projection exercises (e.g. the ones mentioned above). In our work, we implement the differential sectoral productivity estimates of Bekkers et al. (2019), that in turn used the OECD Stan Database for Industrial Analysis and the EU KLEMS database. They estimate a 2.49 percentage points additional annual growth (with respect to average regional TFP growth) for agriculture, 1.51 for manufacture and -0.344 for services, at the world level. In order to map their estimations to the sectoral aggregation used in EUCalc, we calculate the differential sectoral productivities in each country/region as weighted averages of the estimated ones, using as weights the shares of value added in the different sectors.

Fossil fuel prices are typically assumed in long run projections to reflect future oil supplies. As in many other similar modeling exercises, projected changes in fossil fuel prices (IEA, 2012, IEA, 2017) are included in our baseline projections. This is implemented by endogenizing changes in the productivity of the oil, coal and gas sectors while targeting their respective prices, thereby making the supply of these fuels endogenously determined.

4 Integration of GTAP-EUCalc and EUCalc

WP7 aims at quantifying transboundary effects, including intra- and extra-EU trade flows, of EUCalc pathways at sectoral levels as obtained from WPs 1-5 using a CGE modeling framework that simulates exogenous shocks to a projected baseline of the world economy. The GTAP-EUCalc general equilibrium approach differs from the EUCalc modularized approach, in which the lever setting reflects a range of ambition levels expressed by the end-user. Consequently, combining these two approaches adds value to the EUCalc compared to existing calculators.

Difficulties in linking "bottom-up" engineering models to more "top-down" economic models have been recognized in the literature and different methods to solve these issues have been proposed and implemented by different modeling groups (see e.g. review in Labriet et al. (2015)). Three main challenges arise from the interactions between the CGE model and the EUCalc modules. Firstly, the combination of the bottom-up approach used by EUCalc modules for calculating energy demand/supply and emissions across WP1-5 and the top-down approach adopted in GTAP-EUCalc leads to the suppression of sectoral details when calculating the trade-related results. Secondly, the ambition levels specified in a given user-defined EUCalc pathway change the levels and structures of the demand and/or supply of the economy, and may lead to pathways that are considered inconsistent in economic terms. Finally, specific mathematical functional forms employed to characterize the demand, supply and trade behaviors in GTAP-EUCalc (as in most other economic models) limit the extent to which large

changes (e.g. lever settings 3 and 4 representing 'very high ambition' scenarios) can be imposed on the realized outcomes from a given scenarios/pathways envisioned by users of EUCalc.

As the purpose of WP7 is to model the trade effects of user-defined pathways from the "core" EUCalc modules, we opt for simpler linkages between the two modeling approaches by focusing on how the EUCalc pathways can be consistently translated into scenarios to be simulated in GTAP-EUCalc, rather than integrating the inherently different modeling structures. Based on the analysis of sectoral work packages' preliminary modeling work, a conceptual framework for interfacing GTAP-EUCalc and EUCalc was developed in Deliverable 7.2 (Baudry et al., 2018), written in collaboration with the Imperial College London. However, as modules have evolved and preliminary scenarios have been simulated, more advanced interactions have been experimented and implemented. The refined interfaces and the entire integration process are described in Deliverable 8.6 (Clora and Yu, 2019b).

4.1 Integration procedure

As explained above, the interaction between bottom-up and top-down models is not straightforward, given their inherently different architectures. In order to simulate user-defined decarbonization pathways in GTAP-EUCalc, different steps need to be taken (figure 2.1).
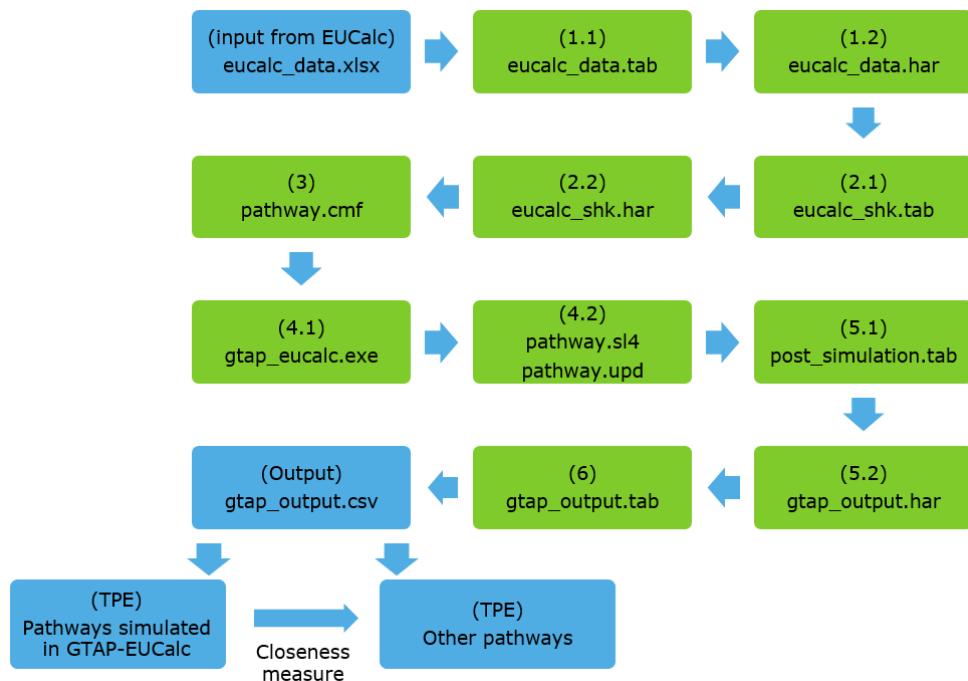
Figure 4.1 – Integration process between GTAP-EUCalc and EUCalc[f]

Step 1 consists in receiving "intermediate" outputs from each EUCalc core module. The data are sent to us in one Excel sheet (*eucalc_data.xlsx*) containing information for 46 pathways, for 29 individual countries (EU28 + Switzerland), for

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[f] The files' names in the figure are only indicative, with the purpose of showing the different file extensions to be used for the scope of integrating the "Transboundary Effects and Trade Flows" module.

487 variables[g], for the year 2050. Once these data are gathered and received, they need to be imported in a format readable by GEMPACK[h] (Horridge et al., 2018). To do so, we write a Tablo Input file[i] (TAB, *eucalc_data.tab*) that allows us to transform the *.xlsx* file into a Header Array file[j] (HAR, *eucalc_data.har*).

In step 2, we develop a TAB file (*eucalc_shk.tab*) to obtain, for each pathway, exogenous shocks expressed as percentage changes in GTAP-EUCalc variables with respect to the baseline in 2050. The inputs to this TAB file are the data from the EUCalc pathways and the disaggregated GTAP v9 (Aguiar et al., 2016), GTAPE v9 (Aguiar et al., 2016) and GTAP-Power v9 (Peters, 2016b) databases. This procedure generates the *eucalc_shk.har* file, containing the sectoral shocks to be simulated in the GTAP-EUCalc model. Step 2 is detailed in section 5, which describes the work performed to convert the individual modules' outputs into exogenous shocks to be simulated in the GTAP-EUCalc CGE model.

In step 3, for each pathway simulated in GTAP-EUCalc, a Command file[k] (CMF) is written. The CMF file is used to communicate information to executable files generated with GEMPACK, such as the GTAP-EUCalc CGE model written in a TAB file (*.tab*) and converted into an executable (*.exe*) in step 4.1 presented below. The GTAP-EUCalc model is solved by using the Gragg's method (Horridge et al., 2018), running separate multi-step calculations with 4, 8 and 12 steps. Each simulation is split into 50 subintervals with minimum subinterval length of 0.0001, and automatic accuracy (Horridge et al., 2018). The standard GTAP-E closure[l] is adopted, with the exception of the addition of exogenous preference shifters and the endogenization of the aggregate regional supply of land[m].

In step 4, for each pathway, a CMF file is used to run the TABLO-generated program (*gtap_eucalc.exe*) derived from the GTAP-EUCalc model described in Deliverable 7.4 (Clora and Yu, 2019a). From each simulation, an updated GTAP-EUCalc database (*pathway.upd*) and a solution file with percentage changes in the variables specified in the model (*pathway.sl4*) are outputted.

An individual simulation in GTAP-EUCalc produces a considerable amount of trade-related results that may be complex to read and use. A concrete way to efficiently exploit these results is to further process them to obtain some indicators that may be meaningful for users and policymakers and easy to present in the online EUCalc TP. In step 5, for each individual pathway, post-simulation calculations are developed (*post-simulation.tab*) and run so to generate these results [n]

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[g] For a complete list of variables, see appendix A.

[h] GEMPACK (General Equilibrium Modeling PACKage) is a suite of economic modeling software. It is especially suitable for computable general equilibrium (CGE) models (Horridge et al., 2018).

[i] The TABLO Input file of the model is the means of communicating the theory of the model to the computer, in particular to the GEMPACK program TABLO. It consists of the equations written in a syntax which is very similar to ordinary algebra. It also contains a description of the data to be read, where it is to be read from, and how this data is to be used to calculate values of parameters and pre-simulation values of the other levels variables occurring in the equations (Horridge et al., 2018).

[j] Data for GEMPACK models are normally stored on files called Header Array (or HAR) files. Header Array files contain one or more arrays each containing data values (Horridge et al., 2018).

[k] Command files are used to communicate information to GEMSIM or TABLO-generated programs about the actions you wish them to carry out. Command files are required to specify and run simulations (Horridge et al., 2018).

[l] The closure of the model is the split of the set of variables into exogenous and endogenous.

[m] See Deliverable 7.4 (Clora and Yu, 2019) for additional information on the preference shifters (also called twist parameters) and the aggregate land supply function.

[n] More information on the trade outputs shown in the TPE can be found in section 7.

(*gtap_output.har*), starting from the baseline GTAP-EUCalc database, the updated database and the solution file.

Steps 6 converts the GTAP-EUCalc final results from HAR files to an Excel-readable spreadsheet file, that is the output sent to and presented in the TPE. In the TPE, for the representative pathways simulated in GTAP-EUCalc, the respective results are shown. For the remaining pathways, results from the "closest" pathway simulated in GTAP-EUCalc are shown. To find the closest pathway to the user-selected one, a closeness measure is developed and implemented in the TPE. This measure is described in section 4.2 below.

4.2   Closeness measure

Owing to the computational complexities of GTAP-EUCalc and the different structures of EUCalc and GTAP-EUCalc, the trade module simulates the transboundary effects of a subset of the user-defined decarbonization pathways to represent the relevant scenarios identified during the co-design process (Clora and Yu, 2019a).

Once the procedure presented in figure 2.1 (from step 1 to step 6) is executed within the GTAP-EUCalc framework, and the trade-related results are calculated for a number of pathways, a so-called "closeness measure" is implemented in the TPE to allow the user to find out the "closest" pathway for which there are GTAP-EUCalc results to the one they selected. The approach is based on a two-steps calculation, described below.

Let us define:

- $M = \{1, \dots, 10^9\}$, being the number of pathways in EUCalc (approximately 1 billion);

- $N = \{1, \dots, 46\}$, being the number of pathways in EUCalc for which GTAP-EUCalc simulates trade-related results (46; see appendix B for the lever positions of the pathways simulated in GTAP-EUCalc);

    o N is a subset of M;

- E_i^m, being the energy consumption by sector i in pathway m in 2050, in EU28+Switzerland;

- $i = \{electricity, transport, buildings, agriculture, industry\}$, being the EUCalc sectors;

- $Base \in M$, being the EUCalc lever settings set at the EUREF pathway.

Step 1 - find each EUCalc pathway's distance with respect to the baseline:

$$\forall m \in M = \{1, \dots, 10^9\}, \; distance_m = \sum_i \left(\frac{E_i^m}{\sum_i E_i^m} - \frac{E_i^{base}}{\sum_i E_i^{base}} \right)^2$$

Distance$_n$ is a subset of *distance$_m$*, as N is subset of M.

Step2 - find the "closest" pathway:

$$\forall m \in M, find\ n\ such\ that \quad \min|distance_m - distance_n|$$

The measure, as presented above, is based on the distance of the sectoral energy consumption shares of a given pathway with respect to the baseline sectoral energy consumption shares. Selecting shares rather than absolute values allows us to better quantify the relative sectoral magnitudes in a changing economy. Internal consistency between the inputs (to the measure and to GTAP-EUCalc) is achieved by using only EUCalc-generated data, and not a mix of EUCalc and GTAP-EUCalc data. Energy demand is used as a quantity of interest for this measure, rather than greenhouse gas emissions; this is due to the fact that energy captures better than emission the effective magnitude of a given sector, which can preserve its "economic relevance" while reducing its emissions. Finally, we opted for the EU-Ref EUCalc pathway (Thurm and Vielle, 2019) as a base, since it is coherent with the economic baseline delineated in Deliverable 7.1 and refined in Deliverable 7.4.

5 Interfaces between GTAP-EUCalc and EUCalc modules

In this section, we detail "step 2", which was introduced in section 4.1.

Based on the analysis of sectoral work packages' seminal modeling work, a conceptual framework for interfacing GTAP-EUCalc and EUCalc was developed in Deliverable 7.2 (Baudry et al., 2018), written in collaboration with the Imperial College London. However, as modules have evolved and preliminary scenarios have been simulated, more refined interactions have been experimented and implemented. These interactions are documented in Deliverable 8.6 (Clora and Yu, 2019b).

Pathways defined in the EUCalc core modules are essentially driven by a set of assumptions (levers) on lifestyle choices on food consumption, transportation, buildings, materials and manufacturing, and direct and indirect energy demand. These lifestyle choices drive the supply side in the individual modules to generate a particular set of emission outcomes. The baseline projections from WP7 provide a set of trade results to be included in the base case calibrations of traded products in the individual modules. The EUCalc model then provides users with a set of levers on both the demand and supply side to create their own decarbonization pathways. The lever settings on the demand side (i.e. lifestyle choices) are essentially considered as changes to the demand curves relative to the baseline in the GTAP-EUCalc model. Changes on the supply side imposed in the sectoral EUCalc modules are modeled in the GTAP-EUCalc as changes in the supply functions either through changes in the cost structure of producers and/or through total or biased productivity progresses. Consistent with the overall set up of WP7 and the generally accepted economic theory, the simultaneous shifts of the demand and supply functions arising from implementing the EUCalc pathways then endogenously determine the excess demand (i.e. imports) or excess supply (exports) of each product and country/region included in the model. In addition, the specific modeling structure featuring the Armington (Armington, 1969) specification allows for generating bilateral trade flows between any pair of trading countries.

The EUCalc pathway with lever settings mimicking the EU-Reference Scenario (European Commission et al., 2016) is selected as a base, given its consistence with the economic baseline delineated in Deliverable 7.1 (Yu and Clora, 2018) in

terms of underlying assumptions. Once the base pathway has been established and its electricity mix reproduced in GTAP-EUCalc, alternative EUCalc pathways are modeled in the GTAP-EUCalc model as counterfactual scenarios relative to the baseline scenario.

5.1 Lifestyle module (WP1)

The lifestyle module makes use of statistical analysis linking socio-economic and individual drivers with concrete metrics such as calorie consumption or travel distance, in order to determine plausible ranges of demand levels. Lifestyle levers evaluated in WP1 are:

- Calories consumed (kcal/cap/day)
- Type of diet (kcal/cap/day)
- Food waste at consumption level (kcal/cap/day)
- Appliance ownership (number)
- Product substitution rate
- Use of paper and packages (ton)
- Living space per person (m^2/cap)
- Passenger travel distance (pkm^o/cap)
- Population (number)
- Share of urban population (%)
- Appliance use (h/day)
- Space cooling & heating (degrees)
- Percentage of cooled living space (%)

The lifestyle levers can be interpreted as changes in preferences, which in turn can be converted into exogenous shocks to demand in the GTAP-EUCalc model. These shocks are implemented in GTAP-EUCalc as percentage changes with respect to the baseline (i.e. the EUREF pathway), by using the "twist" approach (Dixon and Rimmer, 2002) which endogenously modifies the relevant parameters in the demand system so as to target the desired alterations to the demand for the specific products in the demand system. Lever results defined as "per capita" are multiplied by the population projected by WP1, in order to fully account for the changes in aggregated demand for each country in the model.

Calorie requirements, diet composition and food waste, expressed in kcal/cap/day, have a conjoint impact on the demand for 29 food groups in WP1. These food categories are aggregated and mapped onto three GTAP-EUCalc sectors, i.e. "*crops*", "*animal food*", "*non-animal food*" (table 5.1). Changes in demand are implemented both at the private and intermediate level. In fact, food is consumed both at home (thus, private demand is shocked) and through food-related services[p] (thus, intermediate demand for food by the "*services*" sector in GTAP-EUCalc is modified). The average demand shocks for each of the three aggregated

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[o] A passenger-kilometer, abbreviated as pkm, is the unit of measurement representing the transport of one passenger by a defined mode of transport (road, rail, air, sea, inland waterways etc.) over one kilometer.

[p] According to the GTAP database v9 (Aguiar et al., 2016), the GTAP-EUCalc "services" sector, in 2011, accounted for 10.7% of EU and Switzerland consumption of "crops", 8.7% of "animal food", and 15.1% of "non-animal food". In fact, it includes three food-related GTAP service sectors ("Trade services, including retail, wholesale, hotel and restaurants", "Recreation and other services", "Public Administration, Defense, Education, Health").

GTAP-EUCalc sectors are weighted averages of the individual disaggregated shocks, using the 2011 historical regional private demand shares of the underlying individual GTAP-EUCalc commodities as weights.

Table 5.5.1 - Food groups mapping onto GTAP-EUCalc sectors

EUCalc food group	GTAP-EUCalc sector
Fruits	crops
Vegetables	
Oil crops	
Demersal fish	animal food
Freshwater fish	
Pelagic fish	
Seafood	
Other aquatic animals	
Bovine meat	
Mutton and goat meat	
Pig meat	
Poultry meat	
Other meat	
Animal fats	
Eggs	
Milk	
Offals	
Sugar	non-animal food
Sweeteners	
Beer	
Beverages, alcoholic	
Beverages, fermented	
Cereals	
Rice	
Coffee	
Pulses	
Starch	
Stimulants	
Vegetable oils	
Wine	

Living space per person (m^2/cap) is directly converted in GTAP-EUCalc into percentage changes to private demand for "*dwellings*".

Appliance ownership reflects the demand for eight commodity groups (fridge, freezer, washing machine, dryer, dishwasher, television, computer, phone). These commodities are part of the "*electronic equipment*" and "*other machinery & equipment*" GTAP disaggregated sectors. These two sectors, in turn, are

aggregated together with others in a "*manufacture*" sector in GTAP-EUCalc. Table 5.2 shows the mapping exercise from EUCalc to disaggregate GTAP sectors to GTAP-EUCalc sectors, based on WITS database on product concordances (WITS, 2019). Thus, the percentage change in private demand for this aggregated commodity in each EU region is weighted against the 2011 historical regional private demand shares of the GTAP sub-commodities of the aggregated "*manufacture*" sector in GTAP-EUCalc.

Use of paper and packaging refers to both paper, plastic, aluminium and glass consumption, expressed in tons. Changes in paper and aluminium consumption (ton) with respect to the base level are modeled in GTAP-EUCalc with an approach similar to the one used for appliance ownership, as paper and paper products are part of the aggregated sector "*manufacture*". Changes in plastic consumption (ton) are directly converted in GTAP-EUCalc into percentage changes to private demand for "*chemical and rubber products*".

Table 5.5.2 - Manufacture products correspondence (EUCalc to GTAP to GTAP-EUCalc)

EUCalc WP1	GTAP sector	GTAP-EUCalc sector
Freezer	Other Machinery & Equipment (ome)	Manufacture[q]
Fridge		
Dishwasher		
Washing machine		
Dryer		
Television	Electronic equipment (ele)	
Smartphone		
Computer		
Paper	Paper & paper products (ppp)	
Aluminium	Manufacture of fabricated metal products, except machinery and equipment (fmp)	
Glass	Manufacture of other non-metallic mineral products (nmm)	

Appliance use (h/day), space cooling & heating (degrees), and percentage of cooled living space (%) levers have an effect on the private consumption of energy, thus being modelled for the scope of WP7 within the framework of the buildings' module.

Passenger travel distance (pkm/cap) is used as input by the transport module, which differentiates between air, water and road/rail transportation. Thus, the interface is presented in the following section 5.2.

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[q] The "manufacture" sector in GTAP-EUCalc includes also other GTAP subsectors. For more information on the sectoral disaggregation, see table 2.4.

5.2 Transport module (WP2t)

Decarbonizing the transport sector can be realized through various emission reduction ambition levels over a set of different levers, defined and modeled by WP2t in EUCalc as following:

- Total demand for freight (tkm[r]) and for passenger (pkm)
- Vehicle efficiency, for 34 freight technologies and 25 passenger technologies (TJ/km)
- Utilization rate, for 3 freight modes (i.e. HDVH, HDVM, HDVL) and 3 passenger modes (i.e. 2W, LDV, bus) (vkm[s]/vehicle)
- Load factor, for 3 freight modes, i.e. HDVH, HDVM, HDVL (tkm/vkm)
- Occupancy, for 3 passenger modes, i.e. 2W, LDV, bus (pkm/vkm)
- Freight and passenger technology share of new cars (%)
- Freight and passenger modal share (%)
- Fuel mix (%)

This very detailed information cannot be directly fed into GTAP-EUCalc. In fact, the GTAP-EUCalc database describes only three transportation sectors ("*water transport*", "*air transport*", and "*rail and road transport*"), not explicitly distinguishing passenger and freight transportation. Additionally, adding to GTAP-EUCalc a number of variables able to precisely mimic the lever settings is nearly an impossible task. Therefore, aggregation is needed, in terms of both sectoral details and of model "variables" to shock.

As a first step, the technologies modeled in EUCalc (table 5.3 and table 5.4) are mapped onto the three GTAP sectors (i.e. IWW and marine modes onto *"water transport"*, aviation onto *"air transport"*, the rest onto *"rail and road transport"*).

Secondly, a number of "intermediate" outputs due to the lever settings of the EUCalc model, rather than the lever settings themselves, are used to generate economically sensible exogenous shocks to be implemented in the GTAP-EUCalc model. Specifically, we make use of passenger-kilometers (pkm) traveled per passenger technology, tonne-kilometers (tkm) traveled per freight technology, number of vehicles per technology, and energy demand (GWh) per technology to compute these intermediate outputs.

The procedure to generate the shocks and implement them in GTAP-EUCalc, described below, is performed individually for each of the three GTAP-EUCalc transportation sectors, i.e. air, water and other transport, and for each EUCalc region (therefore the two indices are omitted).

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[r] A tonne-kilometer, abbreviated as tkm, is a unit of measure of freight transport which represents the transport of one tonne of goods (including packaging and tare weights of intermodal transport units) by a given transport mode (road, rail, air, sea, inland waterways, pipeline etc.) over a distance of one kilometer.

[s] Vehicle kilometer: unit of measurement representing the movement of a road motor vehicle over one kilometer.

Table 5.5.3 – Technologies modeled in each freight transportation mode

Freight Mode	HDVH	HDVL	HDVM	Rail	IWW	Marine	Aviation
Technologies in each mode	BEV	BEV	BEV	CEV	BEV	BEV	BEV
	CEV	CEV	CEV	ICE	FCEV	FCEV	ICE
	FCEV	FCEV	FCEV		ICE	ICE	
	ICE-diesel	ICE-diesel	ICE-diesel				
	ICE-gas	ICE-gas	ICE-gas				
	ICE-gasoline	ICE-gasoline	ICE-gasoline				
	PHEV-diesel	PHEV-diesel	PHEV-diesel				
	PHEV-gasoline	PHEV-gasoline	PHEV-gasoline				

Table 5.5.4 – Technologies modeled in each passenger transportation mode

Passenger Mode	2W	LDV	Bus	Rail	Metro-tram	Aviation
Technologies in each mode	BEV	BEV	BEV	CEV		BEV
	FCEV	FCEV	FCEV	FCEV		ICE
	ICE-diesel	ICE-diesel	ICE-gas	ICE		
	ICE-gas	ICE-gas	ICE-diesel			
	ICE-gasoline	ICE-gasoline	ICE-gasoline			
	PHEV	PHEV-diesel	PHEV			
		PHEV-gasoline				

Most of the vehicles used to produce the transportation service are defined as fixed capital in the GTAP database. Therefore, given the number of vehicles (*veh*) and the kilometers traveled for each technology (*pkm* for passenger technologies *i*, *tkm* for freight technologies *k*), it is possible to calculate two measures of capital efficiency, for each pathway *j* simulated in GTAP-EUCalc ($Keff_j^F$ for freight technologies, $Keff_j^P$ for passenger technologies):

$$Keff_j^P = \left(\frac{\sum_i pkm_i}{\sum_i veh_i}\right)$$

$$Keff_j^F = \left(\frac{\sum_k tkm_k}{\sum_k veh_k}\right)$$

With
- *i* = technology, passenger (excluding cars and two-wheelers), in EUCalc transport module
- *k* = technology, freight, in EUCalc transport module

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Additionally, in a similar fashion, two measures of energy efficiency for each pathway j simulated in GTAP-EUCalc ($ENYeff_j^F$ for freight technologies, $ENYeff_j^P$ for passenger technologies) can be calculated:

$$ENYeff_j^P = \left(\frac{\sum_i pkm_i}{\sum_i GWh_i}\right)$$

$$ENYeff_j^F = \left(\frac{\sum_k tkm_k}{\sum_k GWh_k}\right)$$

However, as the GTAP-EUCalc transportation sectors aggregate freight and passenger modes, a weighting measure is necessary in order to account for changes derived from WP2t, since *pkm* and *tkm* are not directly comparable. Hence, data from the GTAP-EUCalc 2050 baseline are used. By assuming that private household consumption of transport reflects the magnitude of the passenger modes, and the aggregate intermediate demand by all GTAP-EUCalc sectors mirrors the freight ones, we can define the following weighting coefficient, for each GTAP transport sector:

$$\overline{\alpha} = \frac{\overline{VPM}}{\overline{VPM} + \sum_k \overline{VFM}}$$

With
- k = sector, GTAP-EUCalc (table 2.4)
- $\overline{VFM_k}$ = demand, by sector k, for transport (water, air or rail-road) in a given region, in the GTAP-EUCalc 2050 baseline, expressed in monetary terms
- $\overline{VPM}$ = private demand, for transport (water, air or rail-road) in a given region, in the GTAP-EUCalc 2050 baseline, expressed in monetary terms

The percentage changes in capital efficiency (afK_j) and energy efficiency ($afENY_j$) with respect to the EUREF baseline, for each of the three GTAP-EUCalc transportation sector, are then calculated as follows:

$$afK_j = \overline{\alpha}\left(\frac{Keff_j^P}{Keff_{EUREF}^P} - 1\right) + (1 - \overline{\alpha})\left(\frac{Keff_j^F}{Keff_{EUREF}^F} - 1\right)$$

$$afENY_j = \overline{\alpha}\left(\frac{ENYeff_j^P}{ENYeff_{EUREF}^P} - 1\right) + (1 - \overline{\alpha})\left(\frac{ENYeff_j^F}{ENYeff_{EUREF}^F} - 1\right)$$

These deviations are implemented in GTAP-EUCalc as input (capital and energy) augmenting technical change in the three transportation sectors in each GTAP-EUCalc region.

Additionally, as the fleet structure changes due to EUCalc levers settings combinations, the demand for electricity and oil products by each transport sector varies. This variation is modeled by modifying the intermediate demand for electricity and oil products for each transport sector in GTAP-EUCalc via a so-called twist parameter added to the CES production technologies. The shock representing the change in intermediate demand is calculated as a deviation from the base for oil products and electricity firms' demand, with all the other primary factors and intermediate commodities increasing or decreasing their cost shares accordingly endogenously.

In GTAP, the data is structured so that energy consumed by the private vehicle fleet (i.e. cars and motorbikes) is accounted for in the private household energy demand (mainly "*oil products*"). Changes in the consumption of energy by private cars and motorbikes derived from the EUCalc transport module are reflected in the modeling work by using a twist parameter to modify private energy demand.

Finally, changes in freight demand are implemented in GTAP-EUCalc as a shift in intermediate consumption of transport services by selected sectors[t] via twist parameters. Passenger demand, derived from the lifestyle module, and further modeled in WP2t at the technology level, is implemented in the GTAP-EUCalc model as a change in private demand for each transport sector.

5.3 Buildings module (WP2b)

This module allows the user to act on five sets of levers:

- Building insulation: This lever controls the average heat loss which is reduced by insulation and affects the energy need per floor area;
- Heating and cooling (ventilation) system efficiency: This lever controls the average energy loss in heating, cooling and ventilation systems and district heating generation;
- District heating share: This lever controls the level of heating energy demand covered by district heating;
- Heating technology and fuel switch: This lever controls the mix of technologies used for spare heating, space cooling, hot water, cooking and lighting and district heating;
- Appliances, cooking, lighting efficiency: This lever controls the average rate of energy use for appliances, cooking and lighting;

Table 5.5 defines the scope of the building module in terms of the types of buildings considered, the end uses and the energy sources included in the respective EUCalc module.

By using the input of a combination of the user-defined lever settings, the EUCalc module generates energy demand (MWh) and total building stock (m^2). These outputs are split among residential and non-residential buildings (table 5.5).

Similarly to the approach adopted for the transport module, in order to calculate the trade effects in GTAP-EUCalc, energy demand and building stocks are used to create energy efficiency measures. These indicators are obtained for both residential buildings ("*dwellings*" in the GTAP-EUCalc aggregation) and non-residential buildings (which can be mapped onto the "*services*" sector[u]).

Changes in energy efficiency of buildings are calculated as deviations from the baseline and implemented in GTAP-EUCalc as energy technical efficiency changes in the two sectors mentioned above, in each EUCalc region.

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[t] The sectors shocked are the following: *r_extr, f_anm, f_n_anm, electricity, mnf, crp, otp, wtp, atp, serv.*

[u] In detail, the non-residential buildings modeled in WP2b correspond to the "services" subsectors "Communications", "Other financial intermediation", "Insurance", "Other business services", Recreation and Other services", "Trade" (including hotels and restaurants), "Other services (government)". The shock to the entire service sector is weighted according to the 2011 sectoral output share of the abovementioned ones.

Table 5.5.5 - Scope definition for the buildings module

Building types	Single family homes
	Multiple family homes
	Offices
	Schools
	Educational buildings
	Hospitals
	Health buildings
End uses	Space and water heating
	Space cooling
	Lighting
	Appliances (black and white)
Energy sources and the mix of their heating technology	Heating-oil
	Coal
	Natural gas
	Electricity
	District-heating
	Solar-heat
	Ambient-heat
	Geothermal
	Waste-heat

In the GTAP database, a large share of energy consumption in the residential building (e.g. apartments and houses) is represented in the final energy consumption by the private household (e.g. natural gas, electricity, heat consumption). Changes in consumption of energy by residential buildings, derived from the EUCalc buildings module, are reflected in the modeling approach, by using a twist parameter to modify private energy consumption, jointly with changes derived from the transport module.

5.4 Industry module (WP3)

The industry module identifies and assesses a number of industrial energy-efficiency technologies which significantly contribute to the decarbonization of the manufacturing sectors, with additional benefits ranging from improved quality to a reduction in the use of resources, both primary and secondary.

In detail, the user is allowed to act on nine levers:

- Material switch (%): percentage of material replaced by another in the most relevant products;
- Material efficiency (%): percentage of decrease in material demand due to smart design, use of high strength materials, 3D printing;
- Technology efficiency (%): percentage of manufacturing materials produced with low-carbon technologies;

- Fuel mix (%): percentage of energy consumed by each energy carrier (electricity, coal, oil, gas, biomass, waste, and hydrogen) in each technology;
- Energy efficiency (%): percentage of decrease in energy consumption due to energy efficiency measures for each technology;
- Carbon capture (%): percentage of CO2 equivalent emissions captured with CC in each industry;
- Carbon capture to fuel (%): percentage of the captured carbon that is used, the remaining being stored;
- Domestic material production (%): net import of materials divided by the new demand for materials;
- Domestic manufacturing production (%): net import of manufacturing products divided by the new demand for products.

The manufacturing sector is modeled in EUCalc at a great granularity[v], both in terms of sub-sectors (e.g. steel, cement, ammonia, other chemicals, paper and pulp), energy carriers (electricity, coal, oil, natural gas, liquid biomass, solid biomass, waste, hydrogen), and sub-sectoral production technologies.

The GTAP-EUCalc database presents two manufacturing sectors. "*Chemical products*" corresponds to the "*chemical and rubber products*" GTAP sector, onto which ammonia and other chemicals EUCalc sectors can be mapped. "*Manufacture*" aggregates all other sectors modelled in the industry module[w].

As for the other modules, the levers modeled in the industry module cannot be directly represented in GTAP-EUCalc. In the specific case of WP3, user-determined changes with respect to a BAU scenario in net imports (materials and products) are not modeled in GTAP-EUCalc. These levers are based on a rationale that is not fully coherent with economic principles, thus not included in GTAP-EUCalc simulations. Additionally, carbon capture technologies are not represented in GTAP-EUCalc. Therefore, these levers are set on level 1, i.e. the BAU scenario, and not directly modeled in GTAP-EUCalc.

The combination of the remaining five levers has an impact on the energy consumption of each sub-sector, given its output. Hence, an energy efficiency measure is calculated as the ratio of sectoral output (Mton) and total energy demand (GWh), similarly to the approach presented in 3.2. For each GTAP-EUCalc sub-sector modeled in EUCalc, then, the changes with respect to the base in energy productivity are calculated. Finally, these modifications are weighted against the output share of sub-sectors within the aggregated "*manufacture*" sector in 2011 (historical data) and implemented in GTAP-EUCalc as energy technical changes. In addition, these levers also affect the intermediate consumption of non-electricity commodities (coal, oil, gas, oil products) and the overall energy bundle by the "*chemical and rubber products*" and "*manufacture*" sectors. These changes are modeled via a twist parameter in GTAP-EUCalc, altering the cost structure of the two sectors.

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[v] See detailed list of industries and technologies in Tab. 2 of WP3 content document
[w] A more detailed presentation of the database aggregation can be found in section 2.

5.5 Agriculture module (WP4)

The agriculture module enables the EUCalc user to assess the impact of moving towards a "climate smart agriculture" (CSA). CSA practices are defined by FAO as approaches "*needed to transform and reorient agricultural systems (…) to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible*" (FAO, 2013).

CSA includes practices for crop, livestock, forestry, and fishery systems. The EUCalc user can determine the setting of the following levers:

- Food domestic production (%): sets the food net-import balance (expressed in %) for each food product;
- Climate smart crop production (%): sets the ambition in terms of climate smart agriculture cropping systems (expressed in %). For example, the lever sets ambition for organic farming, conservation agriculture, and agroforestry;
- Climate smart livestock (%): sets the ambition for climate smart livestock systems (expressed in %), including the use of low-carbon feed, feed ration optimization, manure management, etc.;
- Alternative protein sources (%): sets the ambition of alternative protein sources for livestock (% of the livestock diet), including microalgae and insect-based meals;
- Land-management (%): sets the ambition for land management through multiple variables. For example, the land management enables allocating the land-use when there is a land surplus because of lower agriculture land demand;
- Hierarchy of biomass end-uses (#ranking): the biomass hierarchy lever (expressed as a ranking) prioritizes the use of the biomass between the different uses (bioenergy, biomaterials);
- Bioenergy capacity;
- Forestry practices (%): sets the ambition in terms of climate smart forestry.

Taking into account the inherent differences between this EUCalc module and GTAP-EUCalc, as explained for the manufacture module, only trade effects of pathways with the net-import (domestic production) lever set on "BAU" are calculated.

The combination of the remaining levers has an impact on total crop production (for food and for feed), on livestock population, on land used for producing crops, on the livestock yields, and on the total fertilizer and the total energy demand by the agricultural sectors.

Given these intermediate outputs generated by the agriculture module, it is possible to obtain the following efficiency measures:

- Crop yields (ton of crops produced per hectare of land used);
- Livestock yields (ton of edible meat per LSU used);

Variations in these measures between the base scenario and other pathways are generated, and are modeled into GTAP-EUCalc as percentage changes in input technical efficiencies of the two agricultural sectors, "*crops*" and "*livestock*".

Additionally, changes in pesticide and chemical fertilizers consumption by the "*crops*" sector is modeled via a twist parameter modifying its intermediate demand for the "*chemical and rubber products*" commodity.

5.6 Electricity supply module (WP5)

The scope of the electricity supply module is to assess the impact of different electricity generation mixes chosen by the user.

The module investigates the changes in power generation technologies considering phase-out policies and renewable energy potentials. In order to exploit those opportunities, in some cases breakthroughs are needed – not only in technology but policy ambitions, too.

This module allows the user to modify the following levers:

- Wind power generation capacities (GW): capacity additions of wind power generation, including and differentiating on- and off-shore technologies;
- Solar power generation capacity additions (GW): capacity additions of solar power generation, including and differentiating PV (Photovoltaic) and CSP (Concentrated Solar Power) technologies.
- Changes in nuclear power generation capacities (GW): changes in nuclear power capacities and their timing considering the policies of the countries.
- Changes in coal power generation capacities (GW): changes in coal power capacities and their timing considering the policies of the countries.
- Other renewables (GW): composite indicator including capacities of geothermal, marine and hydropower. The reason of combining those was that there are only limited countries with potential both in geothermal and marine power generation, thus the lever most likely relates to one of those depending the country. While hydropower contributes the most to the renewable power generation in EU, further exploitation potential is limited due to already established infrastructures;
- Balancing strategies: this lever describes a portfolio of balancing and storage technologies. The user can select the composition of the technology portfolio defined as ambition levels. The lever includes different amount of available balancing power shared amongst pumped hydroelectric storage, battery, flywheel, compressed air storage and power-to-X technology;
- Charging profiles: with this lever the user can influence the charging patterns of electric vehicles, thus influencing when charging happens and its ability to shift demand;
- Carbon capture ratio in power (%): ratio of CO_2 emission from fossil fuel based power plant capacities and oil refineries captured.

Different EUCalc levers combinations lead to diverse electricity generation mixes. These changes have a profound effect on the overall sectoral and overall economic structure of a region, and accounting them is fundamental when evaluating trade effect of decarbonization pathways.

GTAP-EUCalc (as GTAP-E) does not differentiate between electricity production technologies, but aggregates them to one "*electricity*" sector, with an "average" electricity-generating technology. However, the GTAP-Power database (Peters, 2016b) and the GTAP-E-Power CGE model based on it (Peters, 2016a) model directly 11 generation technologies, plus transmission and distribution. The

generation technologies represent both base load generation (nuclear, coal, gas, oil, hydro, wind, other) and peak generation (gas, oil, hydro, solar).

Table 5.5.6 - Electricity-generating technologies mapping (EUCalc to GTAP-Power to GTAP-EUCalc)

EUCalc generation technology	GTAP-Power sector	GTAP-EUCalc sector
Coal	Coal-generated electricity	Electricity
Gas	Gas-generated electricity	
Oil	Oil-generated electricity	
Nuclear	Nuclear	
Hydropower	Hydro	
Concentrated Solar Panels	Solar	
Photovoltaic		
Wind. Offshore	Wind	
Wind. Onshore		
Geothermal	Other electricity	
Marine		

The approach we adopt for translating this module into economically sensible shocks to implement in the GTAP-EUCalc is slightly different from the other supply-side modules.

Firstly, the generating technologies modeled in EUCalc are mapped onto a sensible aggregation of the GTAP-Power electricity-producing technologies (table 5.6).

Secondly, given the generation mix resulting from the user-selected EUCalc pathways and keeping unchanged the GTAP-Power cost structure of the transmission and distribution sub-sector, the electricity output share of each technology is calculated. These shares, together with the unit cost structures for each generation technology available in GTAP-Power onto which EUCalc technologies are mapped, allows us to calculate the new "average" cost structure for the aggregate electricity sector in GTAP-EUCalc, also taking into account the cost structure of transmission and distribution.

By analyzing the GTAP-Power database, we observed that in the electricity sector the inputs with the highest cost share and variating the most due to changes in the electricity-generating mix are capital, coal, oil, gas, oil products and services. Thus, for each of scenarios simulated in GTAP-EUCalc, we target the new "average" cost share of these intermediate inputs via the so-called twist parameter approach (Dixon and Rimmer, 2002), also introduced in Deliverable 7.4 (Clora and Yu, 2019a).

Implementing changes to the cost share of coal used in the electricity sector modifies the demand for both domestic and imported coal. However, some EU28+Switzerland countries/regions do not produce coal, meaning that there is a risk of incurring in corner solutions when the economy undergoes major structural changes. To solve this potential issue, a twist parameter in the upper Armington specification is introduced in the production structure, similarly to (Aguiar et al., 2019). This parameter is used to limit the magnitude of the shock to the domestically produced coal demanded by the electricity sector in

EU28+Switzerland countries/regions that have negligible coal reserves[x], allowing to significantly shock only the consumption of imported coal by the electricity sector in these countries/regions. This and other negligible ad hoc modifications to the shock files have been carried out to overcome data issues[y] and avoid corner solutions.

6 Selected EUCalc pathways simulated in GTAP-EUCalc

EUCalc can potentially generate billions of results, given the nearly infinite possibilities of combining its levers. This is not possible in GTAP-EUCalc, which requires a precise calibration of the modifications implemented. Additionally, CGE simulations are time-expensive, depending on the sectoral and regional aggregation and on a set of other parameters.

Owing to the size and computational complexities of GTAP-EUCalc, the trade module focuses on simulating the transboundary effects of a subset of the user-defined decarbonization pathways to represent the interesting and relevant scenarios identified during the co-design process.

In EUCalc Deliverable 7.2 (Baudry et al., 2018), three sets of potential scenarios to be simulated in GTAP-EUCalc were proposed:

- The first set simulates scenarios with identical ambition levels in all sectors and countries (i.e. 4 scenarios deriving from the 4 lever settings);
- The second set simulates different ambitions across the sectors, with sectoral ambition levels being kept the same across EU MS;
- The third set simulates scenarios with deviations by individual countries from the EU-wide ambition, i.e. each EU MS is assumed to deviate its level settings (uniform across sectors) from the common level setting assumed for all other MS in the core scenario.

In the expert workshop held on November 22nd, 2019 (whose discussions and results are described in Deliverable 7.3 (Yu and Clora, 2019)), this proposal was discussed with policymakers, representatives of EU and international institutions, and with economics experts in the field of international trade modeling. Commenting on the three proposed sets of scenarios, the experts emphasized the need to pay attention to the pathways that are likely to be interesting to the users, especially to policymakers. One suggestion was to aggregate along the MS dimension and focus mainly on sectoral decarbonization differences, effectively further reducing the number of scenarios to be modeled. Another suggestion was

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[x] The value of purchases of natural resource by the coal sector, at both agents' and market prices, both in 2011 in the GTAP v9 (Aguiar et al. 2016) and in our projected 2050 baseline is below 100 USD million for the following EU28+Switzerland countries: Austria, Denmark, Finland, France, Ireland, Italy, Netherlands, Portugal, Sweden, Switzerland, BeLux (Belgium and Luxembourg). The negligible coal production in these countries can be also observed in EIA data (https://www.eia.gov/international/data/world).

[y] For example, the value of export of gas from the region bk_s_se_eu to all other countries/regions (excluding Italy, for which the value is 90 USD mln) is between 0.0006 and 2.4256 USD mln in the EUREF 2050 baseline. Therefore, major shocks undergone by the gas sector in bk_s_se_eu (e.g. pathways with high ambitions in the EU28+Switzerland electricity generation mixes) risk to lead to corner solutions.

to model an even smaller set of scenarios and list them as pre-defined pathways in the EUCalc pathway explorer. These suggestions have been communicated, discussed and agreed upon within the EUCalc project consortium.

Based on these suggestions and discussions with experts and EUCalc partners, a number of representative pathways is formulated and simulated in GTAP-EUCalc. Given the baseline being the EUCalc pathway calibrated on the EU Reference Scenario, in Deliverable 7.4 (Clora and Yu, 2019a), 34 scenarios to be simulated in GTAP-EUCalc are presented[z]. These pathways for which trade-related results are calculated can be divided into four sets, as shown in Table 6.1[aa] and described below. Results from these simulations are accessible in the TPE.

The first set of scenarios to be simulated corresponds to the pathways that specify uniform lever settings across all EU28+Switzerland countries for all relevant sectors, with identical ambition levels. More specifically, against the baseline scenario, each of these scenarios/pathways will correspond to a particular identical level setting for all levers in each and every sector across all EU28+Switzerland countries. There are four such scenarios/pathways, corresponding to the four ambition levels of the EUCalc model. These scenarios/pathways are designed to reflect a set of common decarbonization strategies across the member states and sectors. By varying the ambition levels across the different scenarios but keeping them uniform across member states and sectors, we illustrate how economic interdependencies between the EU and the ROW as well as within the EU would respond to these common ambition levels.

In the second set of scenarios, the levers in each pathway are assembled into two groups: demand-side and supply-side levers. Within a given pathway, all the demand-side levers are set at the same level, whereas all the supply-side levers are also set at the same level (albeit different from the level of the demand-side levers). Note that the pathways where all demand-side and supply-side levels are set at the same levels belong to the first set of pathways. This set of pathways explores different mixes of demand-side and supply-side emissions abatement actions, allowing the user to observe the differences in their relevance in terms of both GHG mitigation and transboundary flows.

The third set of scenarios is designed to explore potential sectoral sensitivities in evaluation decarbonization pathways in the EU context, as different sectors may have different emission-reduction potentials and/or may face different constraints in reaching a particular ambition level, or users may have different focus in exploring particular combinations of ambition levels across sectors. Therefore, even though an EU-wide decarbonization pathway is envisioned, such pathway may feature different lever settings for different sectors. In this set of scenarios, each pathway will contain a set of sectoral ambition levels imposed uniformly across the EU28+Switzerland (i.e. the ambition levels for any given sector is common across member countries); however, differences in ambition levels across sectors are allowed. As lever settings 2 and 3 represents respectively intermediate

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[z] Pathways additional to what is presented in D7.4 are simulated and shown in the TPE. Their lever settings are available in Appendix B.
[aa] See Appendix B for a detailed representation of lever positions for pathways simulated with GTAP-EUCalc.

and high ambitions that are also considered to be "realistic"[bb,cc], they are used as the reference settings for all but one sectors whereas the remaining sector is allowed to deviate with a higher ambition. Furthermore, in these pathways, an additional constraint is imposed so that the demand and supply levers for the same sector are set at the same level (e.g. the demand side lever "travel" has be to set at the same level as the supply side lever "transportation"). For instance, all levers but "travel" and "transportation" (set at level 3) in pathway P17 are set at level 2, as shown in Table 6.1. Such a design allows users to appreciate the sensitivities of emission-reduction outcomes arising from changing the ambition level in both the demand and supply of a particular sector, conditional upon a common setting for other sectors.

The fourth and final set of pathways simulated in GTAP-EUCalc corresponds to the lever settings mimicking three of the European Long Term Strategies for a climate neutral economy (European Commission, 2018a, European Commission, 2018b). After EUCalc core modelers match their levers to represent sectoral actions and outcomes of EU LTSs, we use data derived from their lever positions (i.e. pathways) to simulate three scenarios:

- COMBO: it combines demand-side and supply-side actions without reaching though the maximum abatement ambition and full deployment of each technology modeled, aiming for net GHG emissions reduction (including LULUCF) in 2050 close to 90% compared to 1990;
- 1.5TECH: it aims to further increase the contribution of all the technology options (i.e. supply-side actions) in order to reach net zero emissions in 2050, thus pursuing efforts to achieve a 1.5C temperature change.
- 1.5LIFE: it relies less on the technology options of 1.5TECH, but assumes a drive by EU business and consumption patterns. In fact, it is underlined buy the increase in climate awareness of EU citizens, which translates in lifestyle changes and consumer choices more beneficial for the climate.

Most of the levers specified in the EUCalc model will be reflected in the pathways presented above; however, there are a few levers specified in EUCalc whose level settings other than the BAU levels are not compatible with the CGE framework. To avoid these incompatibilities, these levers are fixed to their BAU level in all the pathways presented in Table 6.1. In essence, the representative pathways only reflect scenarios of the following levers being set at their respective BAU levels, as follows:

- Population and Urbanization on B (BAU);
- Domestic food on B (BAU);
- Domestic production of manufacture products and materials on B (BAU);
- Land prioritization on A;
- Global mitigation effort on A (i.e. the rest of the world does not make any change in terms of mitigation efforts).

[bb] This level is an intermediate scenario, more ambitious than business as usual but not reaching the full potential of available solutions.
[cc] This level is considered very ambitious but realistic, given the current technology evolutions and the best practices observed in some geographical areas.

Table 6.6.1 - EUCalc pathways simulated in GTAP-EUCalc

Pathway	Demand-side groups of levers				Supply-side groups of levers					
	Travel	Homes	Diet	Cons[dd]	Transp[ee]	Bld[ff]	Mnf[gg]	Power	Land & Food	Biodiv[hh]
p1	1	1	1	1	1	1	1	1	1	1
p2	2	2	2	2	2	2	2	2	2	2
p3	3	3	3	3	3	3	3	3	3	3
p4	4	4	4	4	4	4	4	4	4	4
Set 2 (demand vs supply efforts)										
p5	1	1	1	1	2	2	2	2	2	2
p6	1	1	1	1	3	3	3	3	3	3
p7	1	1	1	1	4	4	4	4	4	4
p8	2	2	2	2	1	1	1	1	1	1
p9	2	2	2	2	3	3	3	3	3	3
p10	2	2	2	2	4	4	4	4	4	4
p11	3	3	3	3	1	1	1	1	1	1
p12	3	3	3	3	2	2	2	2	2	2
p13	3	3	3	3	4	4	4	4	4	4
p14	4	4	4	4	1	1	1	1	1	1
p15	4	4	4	4	2	2	2	2	2	2
p16	4	4	4	4	3	3	3	3	3	3
Set 3 (D&S sectoral combo)										
p17	3	2	2	2	3	2	2	2	2	2
p18	2	3	2	2	2	3	2	2	2	2
p19	2	2	3	2	2	2	2	2	3	2
p20	2	2	2	3	2	2	3	2	2	2
p21	2	2	2	2	2	2	2	3	2	2
p22	4	2	2	2	4	2	2	2	2	2
p23	2	4	2	2	2	4	2	2	2	2
p24	2	2	4	2	2	2	2	2	4	2
p25	2	2	2	4	2	2	4	2	2	2
p26	2	2	2	2	2	2	2	4	2	2
p27	4	3	3	3	4	3	3	3	3	3
p28	3	4	3	3	3	4	3	3	3	3
p29	3	3	4	3	3	3	3	3	4	3
p30	3	3	3	4	3	3	4	3	3	3
p31	3	3	3	3	3	3	3	4	3	3
Set 4 (EU LTS)										
COMBO	COMBO	COMBO	COMBO	COMBO	COMBO	COMBO	COMBO	COMBO	COMBO	COMBO
1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE	1.5LIFE
1.5TECH	1.5TECH	1.5TECH	1.5TECH	1.5TECH	1.5TECH	1.5TECH	1.5TECH	1.5TECH	1.5TECH	1.5TECH

[dd] Cons: consumption
[ee] Transp: transport
[ff] Bld: buildings
[gg] Mnf: manufacture
[hh] Biodiv: biodiversity

Additionally, some of the "land and food levers", of which the ABCD (rather than 1234) structure is based on a different rationale and is not directly tied to the emission efforts, albeit likely to follow similar patterns, are chosen to move with the above mentioned pathways according to the following concordances: A=1, B=2, C=3, D=4. In detail, these levers are "Climate Smart Livestock", "Climate Smart Cropping", "Climate Smart fisheries and aquaculture", "Hierarchy for biomass end-uses".

Finally, there are two lever positions included in the TPE but exert no influence on the part of the EUCalc results that are used as inputs for GTAP-EUCalc. These are "EU emissions after 2050", that sets the emission trend after 2050, and "discount factor", that determines cost actualization for the EUCalc cost calculations. As such, these levers are not considered in our simulations.

7 Module outputs shown in the TPE

A single simulation in GTAP-EUCalc generates a substantial amount of trade-related results which, if not properly presented to the EUCalc users, may be difficult to read and use. This would hamper one of the objectives of the EUCalc (i.e. accessibility) and would deprive EUCalc of part of its uniqueness in the family of calculators, i.e. computing trade effects arising from different EU decarbonization pathways. Therefore, a practical way to effectively exploit the results derived from GTAP-EUCalc is to further process the results to obtain some indicators that may be meaningful for users and policymakers and easy to present in the online EUCalc Transition Pathway Explorer.

A number of suggestions from the expert workshop are described in Deliverable 7.3 (Yu and Clora, 2019). These proposals were considered when, together with the partners of Climate Media Factory, the more relevant indicators were selected.

For each of the pathways simulated in GTAP-EUCalc, four core results are shown in the TPE, namely:

- Aggregate EU+Switzerland exports, imports, and resulting trade balance, with 15 ROW countries/regions;
- EU+Switzerland trade with one aggregated ROW region for selected sectors;
- Compositions of intra-EU and extra-EU trade by EU MS and Switzerland;
- EU+Switzerland carbon leakages to ROW, computed following the formula proposed by Kuik and Hofkes (2010).

The first set of results allows to observe the linkages of the aggregate EU28+Switzerland with individual external economies, accounting for overall changes in trade patterns and potential future economic partnerships emerging from EU decarbonization pathways.

The second series of results concern international trade in goods and services, from an "EU vs ROW" perspective. In fact, the change in the aggregate regional trade patterns are not sufficient to explain potential modifications to the world production structures and flows of goods and commodities. New EU consumption pattern and technological advancements will shape expansively the international trade of certain categories of commodities.

Even if the emission abatement ambitions in pathways simulated in GTAP-EUCalc are fixed at the EU-wide level (i.e. countries do not deviate from the overall EU

decarbonization ambition), modifications are modeled at the EU country/region level. This is due to the fact that the same ambition level across the EU leads to different changes to demand and supply, both in absolute and in relative terms, at the country/regional granularity. In turn, these modifications affect differently the composition of trade flows (imports and exports) in each EU country/region, altering the shares of aggregate imports and exports from/to the other EU countries/regions (i.e. intra-EU trade) and from/to the rest of the world (i.e. extra-EU trade). The composition of intra-EU and extra-EU trade flows (both imports and exports) for each country/region provides additional insights into understanding how different EU decarbonization pathways would influence member states' dependence on the EU single market, as increased share of intra-EU trade signals increased dependence on the EU single market whereas decreased share points to the other direction. These results are included as the third series of trade results shown in the TPE.

Finally, as the EUCalc project aims at exploring EU decarbonization pathways, it is necessary to take into account how the rest of the world reacts to EU GHG abatement ambitions. In fact, efforts to reduce GHG emissions in a single country/region usually lead to increased emissions in other countries/regions. This phenomenon is called "carbon leakage" (even though it refers to all GHG emissions, not only to CO_2). Current literature suggests that the carbon leakage rates vary widely across sectors and countries, as well as across different methodologies and models (Karp, 2011, Mattoo et al., 2009, Baylis et al., 2014). The last set of results, thus, allows the user to observe, in a general equilibrium framework, the degree of "emission effectiveness" of EU decarbonization pathways from a global emissions perspective.

The results obtained with GTAP-EUCalc are expressed in 2011 US dollars (USD). When shown in the TPE, these results are converted into 2011 euro (EUR), using the exchange rate in date 31-12-2011[ii].

[ii] The value of the exchange rate in date 31-01-2011 is available from the European Central Bank website:
https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

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9 Appendix A – Intermediate EUCalc core modules' variables used to generate exogenous shocks in GTAP-EUCalc

Table 9.1 – EUCalc modules' outputs used to generate exogenous shocks to be implemented in the GTAP-EUCalc CGE model

Variable, short name	Variable, long name
L_paper_sn	lfs_paper-san[t]
L_paper_pr	lfs_paper-print[t]
L_plast_p	lfs_plast-pack[t]
L_paper_p	lfs_paper-pack[t]
L_alu_p	lfs_aluminium-pack[t]
L_glass_p	lfs_glass-pack[t]
L_fridge	lfs_appliance-own_fridge[num]
L_freezer	lfs_appliance-own_freezer[num]
L_wmachine	lfs_appliance-own_wmachine[num]
L_dryer	lfs_appliance-own_dryer[num]
L_dishwasher	lfs_appliance-own_dishwasher[num]
L_tv	lfs_appliance-own_tv[num]
L_comp	lfs_appliance-own_comp[num]
L_phone	lfs_appliance-own_phone[num]
L_pop	lfs_pop_population[inhabitants]
L_pkm	lfs_pkm_pkm[pkm/cap]
L_fruits	lfs_diet_fruits[kcal/cap/day]
L_sugar	lfs_diet_sugar[kcal/cap/day]
L_sweet	lfs_diet_sweet[kcal/cap/day]
L_veg	lfs_diet_veg[kcal/cap/day]
L_dfish	lfs_diet_dfish[kcal/cap/day]
L_ffish	lfs_diet_ffish[kcal/cap/day]
L_pfish	lfs_diet_pfish[kcal/cap/day]
L_seafood	lfs_diet_seafood[kcal/cap/day]
L_oth_aq_an	lfs_diet_oth-aq-animals[kcal/cap/day]
L_bov	lfs_diet_bov[kcal/cap/day]
L_sheep	lfs_diet_sheep[kcal/cap/day]
L_pigs	lfs_diet_pigs[kcal/cap/day]
L_poultry	lfs_diet_poultry[kcal/cap/day]
L_oth_an	lfs_diet_oth-animals[kcal/cap/day]
L_afats	lfs_diet_afats[kcal/cap/day]
L_beer	lfs_diet_beer[kcal/cap/day]
L_bev_alc	lfs_diet_bev-alc[kcal/cap/day]
L_bev_fer	lfs_diet_bev-fer[kcal/cap/day]
L_cereals	lfs_diet_cereals[kcal/cap/day]

L_coffee	lfs_diet_coffee[kcal/cap/day]
L_egg	lfs_diet_egg[kcal/cap/day]
L_milk	lfs_diet_milk[kcal/cap/day]
L_offal	lfs_diet_offal[kcal/cap/day]
L_oilcrops	lfs_diet_oilcrops[kcal/cap/day]
L_pulses	lfs_diet_pulses[kcal/cap/day]
L_starch	lfs_diet_starch[kcal/cap/day]
L_stm	lfs_diet_stm[kcal/cap/day]
L_voil	lfs_diet_voil[kcal/cap/day]
L_wine	lfs_diet_wine[kcal/cap/day]
L_rice	lfs_diet_rice[kcal/cap/day]
L_res_floor	lfs_floor-intensity_space-cap[m2/cap]
bnresedum2	bld_floor-area_non-residential_education[me]
bnresheam2	bld_floor-area_non-residential_health[me]
bnreshotm2	bld_floor-area_non-residential_hotels[me]
bnresoffm2	bld_floor-area_non-residential_offices[me]
bnresothm2	bld_floor-area_non-residential_other[me]
bnrestram2	bld_floor-area_non-residential_trade[me]
bresmfhm2	bld_floor-area_residential_mfh[me]
bressfhm2	bld_floor-area_residential_sfh[me]
bedueleMWh	energy-demand_non-residential_education_electricity[MWh]
bheaeleMWh	energy-demand_non-residential_education_gas-ff-natural[MWh]
bhoteleMWh	energy-demand_non-residential_education_liquid-ff-heatingoil[MWh]
boffeleMWh	energy-demand_non-residential_education_solid-bio-pellets[MWh]
botheleMWh	energy-demand_non-residential_education_solid-bio-woodlog[MWh]
btraeleMWh	energy-demand_non-residential_education_solid-ff-coal[MWh]
bedugasMWh	energy-demand_non-residential_health_electricity[MWh]
bheagasMWh	energy-demand_non-residential_health_gas-ff-natural[MWh]
bhotgasMWh	energy-demand_non-residential_health_liquid-ff-heatingoil[MWh]
boffgasMWh	energy-demand_non-residential_health_solid-bio-pellets[MWh]
bothgasMWh	energy-demand_non-residential_health_solid-bio-woodlog[MWh]
btragasMWh	energy-demand_non-residential_health_solid-ff-coal[MWh]
beduoilMWh	energy-demand_non-residential_hotels_electricity[MWh]
bheaoilMWh	energy-demand_non-residential_hotels_gas-ff-natural[MWh]
bhotoilMWh	energy-demand_non-residential_hotels_liquid-ff-heatingoil[MWh]
boffoilMWh	energy-demand_non-residential_hotels_solid-bio-pellets[MWh]
bothoilMWh	energy-demand_non-residential_hotels_solid-bio-woodlog[MWh]
btraoilMWh	energy-demand_non-residential_hotels_solid-ff-coal[MWh]
bedupelMWh	energy-demand_non-residential_offices_electricity[MWh]
bheapelMWh	energy-demand_non-residential_offices_gas-ff-natural[MWh]
bhotpelMWh	energy-demand_non-residential_offices_liquid-ff-heatingoil[MWh]
boffpelMWh	energy-demand_non-residential_offices_solid-bio-pellets[MWh]
bothpelMWh	energy-demand_non-residential_offices_solid-bio-woodlog[MWh]
btrapelMWh	energy-demand_non-residential_offices_solid-ff-coal[MWh]
bedulogMWh	energy-demand_non-residential_other_electricity[MWh]
bhealogMWh	energy-demand_non-residential_other_gas-ff-natural[MWh]

bhotlogMWh	energy-demand_non-residential_other_liquid-ff-heatingoil[MWh]
bofflogMWh	energy-demand_non-residential_other_solid-bio-pellets[MWh]
bothlogMWh	energy-demand_non-residential_other_solid-bio-woodlog[MWh]
btralogMWh	energy-demand_non-residential_other_solid-ff-coal[MWh]
beducoaMWh	energy-demand_non-residential_trade_electricity[MWh]
bheacoaMWh	energy-demand_non-residential_trade_gas-ff-natural[MWh]
bhotcoaMWh	energy-demand_non-residential_trade_liquid-ff-heatingoil[MWh]
boffcoaMWh	energy-demand_non-residential_trade_solid-bio-pellets[MWh]
bothcoaMWh	energy-demand_non-residential_trade_solid-bio-woodlog[MWh]
btracoaMWh	energy-demand_non-residential_trade_solid-ff-coal[MWh]
breseleMWh	energy-demand_residential_electricity[MWh]
bresgasMWh	energy-demand_residential_gas-ff-natural[MWh]
bresoilMWh	energy-demand_residential_liquid-ff-heatingoil[MWh]
brespelMWh	energy-demand_residential_solid-bio-pellets[MWh]
breslogMWh	energy-demand_residential_solid-bio-woodlog[MWh]
brescoaMWh	energy-demand_residential_solid-ff-coal[MWh]
dcoprodpow	dhg_energy-demand_heat-co-product-from-power[MWh]
dcoprodind	dhg_energy-demand_heat-co-product-from-industry[MWh]
dadddhggas	dhg_energy-demand_added-district-heat_gas-ff-natural[MWh]
dadddhgoil	dhg_energy-demand_added-district-heat_liquid-ff-heatingoil[MWh]
dadddhgcoa	dhg_energy-demand_added-district-heat_solid-ff-coal[MWh]
dadddhgbio	dhg_energy-demand_added-district-heat_solid-bio[MWh]
dadddhgamb	dhg_energy-demand_added-district-heat_heat-ambient[MWh]
dadddhgsol	dhg_energy-demand_added-district-heat_heat-solar[MWh]
dadddhggeo	dhg_energy-demand_added-district-heat_heat-geothermal[MWh]
TfAev@tkm	tra_freight_aviation_BEV[tkm]
TfAi@tkm	tra_freight_aviation_ICE[tkm]
TfBI@tkm	tra_freight_bike[tkm]
TfAev@GWh	tra_freight_energy-demand_aviation_BEV[GWh]
TfAieK@GWh	tra_freight_energy-demand_aviation_ICE_e-kerosene[GWh]
TfAiBK@GWh	tra_freight_energy-demand_aviation_ICE-biokerosene[GWh]
TfAiK@GWh	tra_freight_energy-demand_aviation_ICE-kerosene[GWh]
TfHHev@GWh	tra_freight_energy-demand_HDVH_BEV[GWh]
TfHHCEV@GWh	tra_freight_energy-demand_HDVH_CEV[GWh]
TfHHfc@GWh	tra_freight_energy-demand_HDVH_FCEV[GWh]
TfHHiD@GWh	tra_freight_energy-demand_HDVH_ICE-diesel[GWh]
TfHHiG@GWh	tra_freight_energy-demand_HDVH_ICE-gas[GWh]
TfHHiGA@GWh	tra_freight_energy-demand_HDVH_ICE-gasoline[GWh]
TfHHphD@GWh	tra_freight_energy-demand_HDVH_PHEV-diesel[GWh]
TfHHphE@GWh	tra_freight_energy-demand_HDVH_PHEV-elec[GWh]
TfHHphGA@GWh	tra_freight_energy-demand_HDVH_PHEV-gasoline[GWh]
TfHLev@GWh	tra_freight_energy-demand_HDVL_BEV[GWh]
TfHLCEV@GWh	tra_freight_energy-demand_HDVL_CEV[GWh]
TfHLfc@GWh	tra_freight_energy-demand_HDVL_FCEV[GWh]
TfHLiD@GWh	tra_freight_energy-demand_HDVL_ICE-diesel[GWh]
TfHLiG@GWh	tra_freight_energy-demand_HDVL_ICE-gas[GWh]

TfHLiGA@GWh	tra_freight_energy-demand_HDVL_ICE-gasoline[GWh]
TfHLphD@GWh	tra_freight_energy-demand_HDVL_PHEV-diesel[GWh]
TfHLphE@GWh	tra_freight_energy-demand_HDVL_PHEV-elec[GWh]
TfHLphGA@GWh	tra_freight_energy-demand_HDVL_PHEV-gasoline[GWh]
TfHMev@GWh	tra_freight_energy-demand_HDVM_BEV[GWh]
TfHMCEV@GWh	tra_freight_energy-demand_HDVM_CEV[GWh]
TfHMfc@GWh	tra_freight_energy-demand_HDVM_FCEV[GWh]
TfHMiD@GWh	tra_freight_energy-demand_HDVM_ICE-diesel[GWh]
TfHMiG@GWh	tra_freight_energy-demand_HDVM_ICE-gas[GWh]
TfHMiGA@GWh	tra_freight_energy-demand_HDVM_ICE-gasoline[GWh]
TfHMphD@GWh	tra_freight_energy-demand_HDVM_PHEV-diesel[GWh]
TfHMphE@GWh	tra_freight_energy-demand_HDVM_PHEV-elec[GWh]
TfHMphGA@GWh	tra_freight_energy-demand_HDVM_PHEV-gasoline[GWh]
TfIWev@GWh	tra_freight_energy-demand_IWW_BEV[GWh]
TfIWfc@GWh	tra_freight_energy-demand_IWW_FCEV[GWh]
TfIWi@GWh	tra_freight_energy-demand_IWW_ICE[GWh]
TfIWiBMF@GWh	tra_freight_energy-demand_IWW_ICE_bio-marinefueloil[GWh]
TfIWieMF@GWh	tra_freight_energy-demand_IWW_ICE_e-marinefueloil[GWh]
TfMAev@GWh	tra_freight_energy-demand_marine_BEV[GWh]
TfMAfc@GWh	tra_freight_energy-demand_marine_FCEV[GWh]
TfMAi@GWh	tra_freight_energy-demand_marine_ICE[GWh]
TfMAiBMF@GWh	tra_freight_energy-demand_marine_ICE_bio-marinefueloil[GWh]
TfMAieMF@GWh	tra_freight_energy-demand_marine_ICE_e-marinefueloil[GWh]
TfRCEV@GWh	tra_freight_energy-demand_rail_CEV[GWh]
TfRiD@GWh	tra_freight_energy-demand_rail_ICE-diesel[GWh]
TfHHev@tkm	tra_freight_HDVH_BEV[tkm]
TfHHCEV@tkm	tra_freight_HDVH_CEV[tkm]
TfHHfc@tkm	tra_freight_HDVH_FCEV[tkm]
TfHHiD@tkm	tra_freight_HDVH_ICE-diesel[tkm]
TfHHiG@tkm	tra_freight_HDVH_ICE-gas[tkm]
TfHHiGA@tkm	tra_freight_HDVH_ICE-gasoline[tkm]
TfHHphD@tkm	tra_freight_HDVH_PHEV-diesel[tkm]
TfHHphGA@tkm	tra_freight_HDVH_PHEV-gasoline[tkm]
TfHLev@tkm	tra_freight_HDVL_BEV[tkm]
TfHLCEV@tkm	tra_freight_HDVL_CEV[tkm]
TfHLfc@tkm	tra_freight_HDVL_FCEV[tkm]
TfHLiD@tkm	tra_freight_HDVL_ICE-diesel[tkm]
TfHLiG@tkm	tra_freight_HDVL_ICE-gas[tkm]
TfHLiGA@tkm	tra_freight_HDVL_ICE-gasoline[tkm]
TfHLphD@tkm	tra_freight_HDVL_PHEV-diesel[tkm]
TfHLphGA@tkm	tra_freight_HDVL_PHEV-gasoline[tkm]
TfHMev@tkm	tra_freight_HDVM_BEV[tkm]
TfHMCEV@tkm	tra_freight_HDVM_CEV[tkm]
TfHMfc@tkm	tra_freight_HDVM_FCEV[tkm]
TfHMiD@tkm	tra_freight_HDVM_ICE-diesel[tkm]
TfHMiG@tkm	tra_freight_HDVM_ICE-gas[tkm]

TfHMiGA@tkm	tra_freight_HDVM_ICE-gasoline[tkm]
TfHMphD@tkm	tra_freight_HDVM_PHEV-diesel[tkm]
TfHMphGA@tkm	tra_freight_HDVM_PHEV-gasoline[tkm]
TfIWev@tkm	tra_freight_IWW_BEV[tkm]
TfIWfc@tkm	tra_freight_IWW_FCEV[tkm]
TfIWi@tkm	tra_freight_IWW_ICE[tkm]
TfMAev@tkm	tra_freight_marine_BEV[tkm]
TfMAfc@tkm	tra_freight_marine_FCEV[tkm]
TfMAi@tkm	tra_freight_marine_ICE[tkm]
TfRCEV@tkm	tra_freight_rail_CEV[tkm]
TfAev@num	tra_freight_vehicle-fleet_aviation_BEV[number]
TfAi@num	tra_freight_vehicle-fleet_aviation_ICE[number]
TfHHev@num	tra_freight_vehicle-fleet_HDVH_BEV[number]
TfHHCEV@num	tra_freight_vehicle-fleet_HDVH_CEV[number]
TfHHfc@num	tra_freight_vehicle-fleet_HDVH_FCEV[number]
TfHHiD@num	tra_freight_vehicle-fleet_HDVH_ICE-diesel[number]
TfHHiG@num	tra_freight_vehicle-fleet_HDVH_ICE-gas[number]
TfHHiGA@num	tra_freight_vehicle-fleet_HDVH_ICE-gasoline[number]
TfHHphD@num	tra_freight_vehicle-fleet_HDVH_PHEV-diesel[number]
TfHHphGA@num	tra_freight_vehicle-fleet_HDVH_PHEV-gasoline[number]
TfHLev@num	tra_freight_vehicle-fleet_HDVL_BEV[number]
TfHLCEV@num	tra_freight_vehicle-fleet_HDVL_CEV[number]
TfHLfc@num	tra_freight_vehicle-fleet_HDVL_FCEV[number]
TfHLiD@num	tra_freight_vehicle-fleet_HDVL_ICE-diesel[number]
TfHLiG@num	tra_freight_vehicle-fleet_HDVL_ICE-gas[number]
TfHLiGA@num	tra_freight_vehicle-fleet_HDVL_ICE-gasoline[number]
TfHLphD@num	tra_freight_vehicle-fleet_HDVL_PHEV-diesel[number]
TfHLphGA@num	tra_freight_vehicle-fleet_HDVL_PHEV-gasoline[number]
TfHMev@num	tra_freight_vehicle-fleet_HDVM_BEV[number]
TfHMCEV@num	tra_freight_vehicle-fleet_HDVM_CEV[number]
TfHMfc@num	tra_freight_vehicle-fleet_HDVM_FCEV[number]
TfHMiD@num	tra_freight_vehicle-fleet_HDVM_ICE-diesel[number]
TfHMiG@num	tra_freight_vehicle-fleet_HDVM_ICE-gas[number]
TfHMiGA@num	tra_freight_vehicle-fleet_HDVM_ICE-gasoline[number]
TfHMphD@num	tra_freight_vehicle-fleet_HDVM_PHEV-diesel[number]
TfHMphGA@num	tra_freight_vehicle-fleet_HDVM_PHEV-gasoline[number]
TfIWev@num	tra_freight_vehicle-fleet_IWW_BEV[number]
TfIWfc@num	tra_freight_vehicle-fleet_IWW_FCEV[number]
TfIWi@num	tra_freight_vehicle-fleet_IWW_ICE[number]
TfMAev@num	tra_freight_vehicle-fleet_marine_BEV[number]
TfMAfc@num	tra_freight_vehicle-fleet_marine_FCEV[number]
TfMAi@num	tra_freight_vehicle-fleet_marine_ICE[number]
TfRCEV@num	tra_freight_vehicle-fleet_rail_CEV[number]
Tp2ev@pkm	tra_passenger_2W_BEV[pkm]
Tp2fc@pkm	tra_passenger_2W_FCEV[pkm]
Tp2iD@pkm	tra_passenger_2W_ICE-diesel[pkm]

Tp2iG@pkm	tra_passenger_2W_ICE-gas[pkm]
Tp2iGA@pkm	tra_passenger_2W_ICE-gasoline[pkm]
Tp2ph@pkm	tra_passenger_2W_PHEV[pkm]
TpAev@pkm	tra_passenger_aviation_BEV[pkm]
TpAi@pkm	tra_passenger_aviation_ICE[pkm]
TpBI@pkm	tra_passenger_bike[pkm]
TpBev@pkm	tra_passenger_bus_BEV[pkm]
TpBfc@pkm	tra_passenger_bus_FCEV[pkm]
TpBiD@pkm	tra_passenger_bus_ICE-diesel[pkm]
TpBiG@pkm	tra_passenger_bus_ICE-gas[pkm]
TpBiGA@pkm	tra_passenger_bus_ICE-gasoline[pkm]
Tp2ev@GWh	tra_passenger_energy-demand_2W_BEV[GWh]
Tp2fc@GWh	tra_passenger_energy-demand_2W_FCEV[GWh]
Tp2iD@GWh	tra_passenger_energy-demand_2W_ICE-diesel[GWh]
Tp2iG@GWh	tra_passenger_energy-demand_2W_ICE-gas[GWh]
Tp2iGA@GWh	tra_passenger_energy-demand_2W_ICE-gasoline[GWh]
Tp2ph@GWh	tra_passenger_energy-demand_2W_PHEV[GWh]
Tp2phB@GWh	tra_passenger_energy-demand_2W_PHEV_bio[GWh]
Tp2phe@GWh	tra_passenger_energy-demand_2W_PHEV_e[GWh]
Tp2phE@GWh	tra_passenger_energy-demand_2W_PHEV-elec[GWh]
TpAev@GWh	tra_passenger_energy-demand_aviation_BEV[GWh]
TpAieK@GWh	tra_passenger_energy-demand_aviation_ICE_e-kerosene[GWh]
TpAiBK@GWh	tra_passenger_energy-demand_aviation_ICE-biokerosene[GWh]
TpAiK@GWh	tra_passenger_energy-demand_aviation_ICE-kerosene[GWh]
TpBev@GWh	tra_passenger_energy-demand_bus_BEV[GWh]
TpBfc@GWh	tra_passenger_energy-demand_bus_FCEV[GWh]
TpBiD@GWh	tra_passenger_energy-demand_bus_ICE-diesel[GWh]
TpBiG@GWh	tra_passenger_energy-demand_bus_ICE-gas[GWh]
TpBiGA@GWh	tra_passenger_energy-demand_bus_ICE-gasoline[GWh]
TpBphD@GWh	tra_passenger_energy-demand_bus_PHEV-diesel[GWh]
TpBphE@GWh	tra_passenger_energy-demand_bus_PHEV-elec[GWh]
TpLev@GWh	tra_passenger_energy-demand_LDV_BEV[GWh]
TpLfc@GWh	tra_passenger_energy-demand_LDV_FCEV[GWh]
TpLiD@GWh	tra_passenger_energy-demand_LDV_ICE-diesel[GWh]
TpLiG@GWh	tra_passenger_energy-demand_LDV_ICE-gas[GWh]
TpLiGA@GWh	tra_passenger_energy-demand_LDV_ICE-gasoline[GWh]
TpLphD@GWh	tra_passenger_energy-demand_LDV_PHEV-diesel[GWh]
TpLphE@GWh	tra_passenger_energy-demand_LDV_PHEV-elec[GWh]
TpLphGA@GWh	tra_passenger_energy-demand_LDV_PHEV-gasoline[GWh]
TpME@GWh	tra_passenger_energy-demand_metro-tram[GWh]
TpRCEV@GWh	tra_passenger_energy-demand_rail_CEV[GWh]
TpRfc@GWh	tra_passenger_energy-demand_rail_FCEV[GWh]
TpRiD@GWh	tra_passenger_energy-demand_rail_ICE-diesel[GWh]
TpLev@pkm	tra_passenger_LDV_BEV[pkm]
TpLfc@pkm	tra_passenger_LDV_FCEV[pkm]
TpLiD@pkm	tra_passenger_LDV_ICE-diesel[pkm]

TpLiG@pkm	tra_passenger_LDV_ICE-gas[pkm]
TpLiGA@pkm	tra_passenger_LDV_ICE-gasoline[pkm]
TpLphD@pkm	tra_passenger_LDV_PHEV-diesel[pkm]
TpLphGA@pkm	tra_passenger_LDV_PHEV-gasoline[pkm]
TpRCEV@pkm	tra_passenger_rail_CEV[pkm]
TpRfc@pkm	tra_passenger_rail_FCEV[pkm]
Tp2ev@num	tra_passenger_vehicle-fleet_2W_BEV[number]
Tp2fc@num	tra_passenger_vehicle-fleet_2W_FCEV[number]
Tp2iD@num	tra_passenger_vehicle-fleet_2W_ICE-diesel[number]
Tp2iG@num	tra_passenger_vehicle-fleet_2W_ICE-gas[number]
Tp2iGA@num	tra_passenger_vehicle-fleet_2W_ICE-gasoline[number]
Tp2ph@num	tra_passenger_vehicle-fleet_2W_PHEV[number]
TpAev@num	tra_passenger_vehicle-fleet_aviation_BEV[number]
TpAi@num	tra_passenger_vehicle-fleet_aviation_ICE[number]
TpBev@num	tra_passenger_vehicle-fleet_bus_BEV[number]
TpBfc@num	tra_passenger_vehicle-fleet_bus_FCEV[number]
TpBiD@num	tra_passenger_vehicle-fleet_bus_ICE-diesel[number]
TpBiG@num	tra_passenger_vehicle-fleet_bus_ICE-gas[number]
TpBiGA@num	tra_passenger_vehicle-fleet_bus_ICE-gasoline[number]
TpLev@num	tra_passenger_vehicle-fleet_LDV_BEV[number]
TpLfc@num	tra_passenger_vehicle-fleet_LDV_FCEV[number]
TpLiD@num	tra_passenger_vehicle-fleet_LDV_ICE-diesel[number]
TpLiG@num	tra_passenger_vehicle-fleet_LDV_ICE-gas[number]
TpLiGA@num	tra_passenger_vehicle-fleet_LDV_ICE-gasoline[number]
TpLphD@num	tra_passenger_vehicle-fleet_LDV_PHEV-diesel[number]
TpLphGA@num	tra_passenger_vehicle-fleet_LDV_PHEV-gasoline[number]
TpRCEV@num	tra_passenger_vehicle-fleet_rail_CEV[number]
TpRfc@num	tra_passenger_vehicle-fleet_rail_FCEV[number]
TpWA@pkm	tra_passenger_walk[pkm]
I_nrg_st_el	industry_energy_iron-steel_electricity[GWh]
I_nrg_st_cl	industry_energy_iron-steel_solid-ff-coal[GWh]
I_nrg_st_ol	industry_energy_iron-steel_liquid_ff-oil[GWh]
I_nrg_st_ga	industry_energy_iron-steel_gas-ff-natural[GWh]
I_nrg_st_sb	industry_energy_iron-steel_solid-bio[GWh]
I_nrg_st_lb	industry_energy_iron-steel_liquid-bio[GWh]
I_nrg_st_gb	industry_energy_iron-steel_gas-bio[GWh]
I_nrg_st_sw	industry_energy_iron-steel_solid-waste[GWh]
I_nrg_st_hy	industry_energy_iron-steel_hydrogen[GWh]
I_nrg_ce_el	industry_energy_cement_electricity[GWh]
I_nrg_ce_cl	industry_energy_cement_solid-ff-coal[GWh]
I_nrg_ce_ol	industry_energy_cement_liquid_ff-oil[GWh]
I_nrg_ce_ga	industry_energy_cement_gas-ff-natural[GWh]
I_nrg_ce_sb	industry_energy_cement_solid-bio[GWh]
I_nrg_ce_lb	industry_energy_cement_liquid-bio[GWh]
I_nrg_ce_gb	industry_energy_cement_gas-bio[GWh]
I_nrg_ce_sw	industry_energy_cement_solid-waste[GWh]

I_nrg_ce_hy	industry_energy_cement_hydrogen[GWh]
I_nrg_ch_el	industry_energy_chemicals_electricity[GWh]
I_nrg_ch_cl	industry_energy_chemicals_solid-ff-coal[GWh]
I_nrg_ch_ol	industry_energy_chemicals_liquid_ff-oil[GWh]
I_nrg_ch_ga	industry_energy_chemicals_gas-ff-natural[GWh]
I_nrg_ch_sb	industry_energy_chemicals_solid-bio[GWh]
I_nrg_ch_lb	industry_energy_chemicals_liquid-bio[GWh]
I_nrg_ch_gb	industry_energy_chemicals_gas-bio[GWh]
I_nrg_ch_sw	industry_energy_chemicals_solid-waste[GWh]
I_nrg_ch_hy	industry_energy_chemicals_hydrogen[GWh]
I_nrg_pa_el	industry_energy_paper-pulp_electricity[GWh]
I_nrg_pa_cl	industry_energy_paper-pulp_solid-ff-coal[GWh]
I_nrg_pa_ol	industry_energy_paper-pulp_liquid_ff-oil[GWh]
I_nrg_pa_ga	industry_energy_paper-pulp_gas-ff-natural[GWh]
I_nrg_pa_sb	industry_energy_paper-pulp_solid-bio[GWh]
I_nrg_pa_lb	industry_energy_paper-pulp_liquid-bio[GWh]
I_nrg_pa_gb	industry_energy_paper-pulp_gas-bio[GWh]
I_nrg_pa_sw	industry_energy_paper-pulp_solid-waste[GWh]
I_nrg_pa_hy	industry_energy_paper-pulp_hydrogen[GWh]
I_nrg_al_el	industry_energy_aluminium_electricity[GWh]
I_nrg_al_cl	industry_energy_aluminium_solid-ff-coal[GWh]
I_nrg_al_ol	industry_energy_aluminium_liquid_ff-oil[GWh]
I_nrg_al_ga	industry_energy_aluminium_gas-ff-natural[GWh]
I_nrg_al_sb	industry_energy_aluminium_solid-bio[GWh]
I_nrg_al_lb	industry_energy_aluminium_liquid-bio[GWh]
I_nrg_al_gb	industry_energy_aluminium_gas-bio[GWh]
I_nrg_al_sw	industry_energy_aluminium_solid-waste[GWh]
I_nrg_al_hy	industry_energy_aluminium_hydrogen[GWh]
I_nrg_gl_el	industry_energy_glass_electricity[GWh]
I_nrg_gl_cl	industry_energy_glass_solid-ff-coal[GWh]
I_nrg_gl_ol	industry_energy_glass_liquid_ff-oil[GWh]
I_nrg_gl_ga	industry_energy_glass_gas-ff-natural[GWh]
I_nrg_gl_sb	industry_energy_glass_solid-bio[GWh]
I_nrg_gl_lb	industry_energy_glass_liquid-bio[GWh]
I_nrg_gl_gb	industry_energy_glass_gas-bio[GWh]
I_nrg_gl_sw	industry_energy_glass_solid-waste[GWh]
I_nrg_gl_hy	industry_energy_glass_hydrogen[GWh]
I_nrg_li_el	industry_energy_lime_electricity[GWh]
I_nrg_li_cl	industry_energy_lime_solid-ff-coal[GWh]
I_nrg_li_ol	industry_energy_lime_liquid_ff-oil[GWh]
I_nrg_li_ga	industry_energy_lime_gas-ff-natural[GWh]
I_nrg_li_sb	industry_energy_lime_solid-bio[GWh]
I_nrg_li_lb	industry_energy_lime_liquid-bio[GWh]
I_nrg_li_gb	industry_energy_lime_gas-bio[GWh]
I_nrg_li_sw	industry_energy_lime_solid-waste[GWh]
I_nrg_li_hy	industry_energy_lime_hydrogen[GWh]

I_nrg_tr_el	industry_energy_transport-equipment_electricity[GWh]
I_nrg_tr_cl	industry_energy_transport-equipment_solid-ff-coal[GWh]
I_nrg_tr_ol	industry_energy_transport-equipment_liquid_ff-oil[GWh]
I_nrg_tr_ga	industry_energy_transport-equipment_gas-ff-natural[GWh]
I_nrg_tr_sb	industry_energy_transport-equipment_solid-bio[GWh]
I_nrg_tr_lb	industry_energy_transport-equipment_liquid-bio[GWh]
I_nrg_tr_gb	industry_energy_transport-equipment_gas-bio[GWh]
I_nrg_tr_sw	industry_energy_transport-equipment_solid-waste[GWh]
I_nrg_tr_hy	industry_energy_transport-equipment_hydrogen[GWh]
I_nrg_fb_el	industry_energy_food-beverages-tobacco_electricity[GWh]
I_nrg_fb_cl	industry_energy_food-beverages-tobacco_solid-ff-coal[GWh]
I_nrg_fb_ol	industry_energy_food-beverages-tobacco_liquid_ff-oil[GWh]
I_nrg_fb_ga	industry_energy_food-beverages-tobacco_gas-ff-natural[GWh]
I_nrg_fb_sb	industry_energy_food-beverages-tobacco_solid-bio[GWh]
I_nrg_fb_lb	industry_energy_food-beverages-tobacco_liquid-bio[GWh]
I_nrg_fb_gb	industry_energy_food-beverages-tobacco_gas-bio[GWh]
I_nrg_fb_sw	industry_energy_food-beverages-tobacco_solid-waste[GWh]
I_nrg_fb_hy	industry_energy_food-beverages-tobacco_hydrogen[GWh]
I_nrg_tx_el	industry_energy_textiles-leather_electricity[GWh]
I_nrg_tx_cl	industry_energy_textiles-leather_solid-ff-coal[GWh]
I_nrg_tx_ol	industry_energy_textiles-leather_liquid_ff-oil[GWh]
I_nrg_tx_ga	industry_energy_textiles-leather_gas-ff-natural[GWh]
I_nrg_tx_sb	industry_energy_textiles-leather_solid-bio[GWh]
I_nrg_tx_lb	industry_energy_textiles-leather_liquid-bio[GWh]
I_nrg_tx_gb	industry_energy_textiles-leather_gas-bio[GWh]
I_nrg_tx_sw	industry_energy_textiles-leather_solid-waste[GWh]
I_nrg_tx_hy	industry_energy_textiles-leather_hydrogen[GWh]
I_nrg_me_el	industry_energy_machinery-equipment_electricity[GWh]
I_nrg_me_cl	industry_energy_machinery-equipment_solid-ff-coal[GWh]
I_nrg_me_ol	industry_energy_machinery-equipment_liquid_ff-oil[GWh]
I_nrg_me_ga	industry_energy_machinery-equipment_gas-ff-natural[GWh]
I_nrg_me_sb	industry_energy_machinery-equipment_solid-bio[GWh]
I_nrg_me_lb	industry_energy_machinery-equipment_liquid-bio[GWh]
I_nrg_me_gb	industry_energy_machinery-equipment_gas-bio[GWh]
I_nrg_me_sw	industry_energy_machinery-equipment_solid-waste[GWh]
I_nrg_me_hy	industry_energy_machinery-equipment_hydrogen[GWh]
I_nrg_ww_el	industry_energy_wood-woodproducts_electricity[GWh]
I_nrg_ww_cl	industry_energy_wood-woodproducts_solid-ff-coal[GWh]
I_nrg_ww_ol	industry_energy_wood-woodproducts_liquid_ff-oil[GWh]
I_nrg_ww_ga	industry_energy_wood-woodproducts_gas-ff-natural[GWh]
I_nrg_ww_sb	industry_energy_wood-woodproducts_solid-bio[GWh]
I_nrg_ww_lb	industry_energy_wood-woodproducts_liquid-bio[GWh]
I_nrg_ww_gb	industry_energy_wood-woodproducts_gas-bio[GWh]
I_nrg_ww_sw	industry_energy_wood-woodproducts_solid-waste[GWh]
I_nrg_ww_hy	industry_energy_wood-woodproducts_hydrogen[GWh]
I_nrg_oi_el	industry_energy_other-industries_electricity[GWh]

I_nrg_oi_cl	industry_energy_other-industries_solid-ff-coal[GWh]
I_nrg_oi_ol	industry_energy_other-industries_liquid_ff-oil[GWh]
I_nrg_oi_ga	industry_energy_other-industries_gas-ff-natural[GWh]
I_nrg_oi_sb	industry_energy_other-industries_solid-bio[GWh]
I_nrg_oi_lb	industry_energy_other-industries_liquid-bio[GWh]
I_nrg_oi_gb	industry_energy_other-industries_gas-bio[GWh]
I_nrg_oi_sw	industry_energy_other-industries_solid-waste[GWh]
I_nrg_oi_hy	industry_energy_other-industries_hydrogen[GWh]
I_nrg_co_el	industry_energy_copper_electricity[GWh]
I_nrg_co_cl	industry_energy_copper_solid-ff-coal[GWh]
I_nrg_co_ol	industry_energy_copper_liquid_ff-oil[GWh]
I_nrg_co_ga	industry_energy_copper_gas-ff-natural[GWh]
I_nrg_co_sb	industry_energy_copper_solid-bio[GWh]
I_nrg_co_lb	industry_energy_copper_liquid-bio[GWh]
I_nrg_co_gb	industry_energy_copper_gas-bio[GWh]
I_nrg_co_sw	industry_energy_copper_solid-waste[GWh]
I_nrg_co_hy	industry_energy_copper_hydrogen[GWh]
I_mat_al	industry_material_aluminium[Mt]
I_mat_ce	industry_material_cement[Mt]
I_mat_ch	industry_material_chemicals[Mt]
I_mat_co	industry_material_copper[Mt]
I_mat_gl	industry_material_glass[Mt]
I_mat_li	industry_material_lime[Mt]
I_mat_pa	industry_material_paper-pulp[Mt]
I_mat_st	industry_material_iron-steel[Mt]
Adp_afat	agr_domestic-production_liv_abp_processed_afat[kcal]
Adp_egg	agr_domestic-production_liv_abp_hens-egg[kcal]
Adp_milk	agr_domestic-production_liv_abp_dairy-milk[kcal]
Adp_offal	agr_domestic-production_liv_abp_processed_offal[kcal]
Adp_bovine	agr_domestic-production_liv_meat_bovine[kcal]
Adp_sheep	agr_domestic-production_liv_meat_sheep[kcal]
Adp_pig	agr_domestic-production_liv_meat_pig[kcal]
Adp_poultry	agr_domestic-production_liv_meat_poultry[kcal]
Adp_othals	agr_domestic-production_liv_meat_oth-animals[kcal]
Adp_algae	agr_domestic-production_afw_algae[kcal]
Adp_insect	agr_domestic-production_liv_insect[kcal]
Adp_rice	agr_domestic-production_afw_rice[kcal]
Adp_cereal	agr_domestic-production_afw_cereal[kcal]
Adp_oilcrop	agr_domestic-production_afw_oilcrop[kcal]
Adp_pulse	agr_domestic-production_afw_pulse[kcal]
Adp_fruit	agr_domestic-production_afw_fruit[kcal]
Adp_veg	agr_domestic-production_afw_veg[kcal]
Adp_starch	agr_domestic-production_afw_starch[kcal]
Adp_sgrcrop	agr_domestic-production_afw_sugarcrop[kcal]
Adp_enrcrop	agr_domestic-production_afw_gas_energycrop[kcal]
Adp_lgncrop	agr_domestic-production_afw_lgn_energycrop[kcal]

Ai_nitrogen	agr_fertilizer_nitrogen[t]
Ai_phosphate	agr_fertilizer_phosphore[t]
Ai_potash	agr_fertilizer_potash[t]
Ai_pesticide	agr_chemical_pesticide[t]
Ai_agrland	agr_lus_land-use[ha]
Aliv_dairy	agr_liv-population_abp_dairy-milk[lsu]
Aliv_hens	agr_liv-population_abp_hens-egg[lsu]
Aliv_bovine	agr_liv-population_meat_bovine[lsu]
Aliv_pig	agr_liv-population_meat_pig[lsu]
Aliv_poultry	agr_liv-population_meat_poultry[lsu]
Aliv_sheep	agr_liv-population_meat_sheep[lsu]
Aliv_othals	agr_liv-population_meat_oth-animals[lsu]
Aenr_gsline	agr_energy-demand_liquid-ff-gasoline[MWh]
Aenr_elec	agr_energy-demand_electricity[MWh]
Aenr_gas	agr_energy-demand_gas-ff-natural[MWh]
Aenr_coal	agr_energy-demand_solid-ff-coal[MWh]
Aenr_wood	agr_energy-demand_bioenergy-solid-wood[MWh]
Aenr_heat	agr_energy-demand_heat[MWh]
Aenr_biod	agr_energy-demand_bioenergy-liquid_biodiesels[MWh]
Aenr_biogas	agr_energy-demand_bioenergy-gas_biogas[MWh]
Aenr_eth	agr_energy-demand_bioenergy-liquid_ethanol[MWh]
Aenr_lpg	agr_energy-demand_liquid-ff-lpg[MWh]
Aenr_fueloil	agr_energy-demand_liquid-ff-fuel-oil[MWh]
Aenr_diesel	agr_energy-demand_liquid-ff-diesel[MWh]
Aenr_oth	agr_energy-demand_oth[MWh]
Aenr_biooth	agr_energy-demand_bioenergy-liquid_oth[MWh]
E_geo_GWh	elc_supply_RES_other_geothermal[GWh]
E_hydro_GWh	elc_supply_RES_other_hydroelectric[GWh]
E_wave_GWh	elc_supply_RES_other_marine[GWh]
E_csp_GWh	elc_supply_RES_solar_csp[GWh]
E_pv_GWh	elc_supply_RES_solar_pv[GWh]
E_w_off_GWh	elc_supply_RES_wind_offshore[GWh]
E_w_on_GWh	elc_supply_RES_wind_onshore[GWh]
E_coal_GWh	elc_supply_fossil_coal[GWh]
E_gas_GWh	elc_supply_fossil_gas[GWh]
E_oil_GWh	elc_supply_fossil_oil[GWh]
E_uran_GWh	elc_supply_nuclear[GWh]
E_bio_GWh	elc_supply_biomass[GWh]

10 Appendix B – Detailed lever positions for pathways simulated with GTAP-EUCalc

In the tables below (10.1, 10.2, 10.3, 10.4, 10.5), within each group in the TPE, the lever settings are specified for the pathways simulated with the GTAP-EUCalc model. Pathways numbering is the same as in table 6.1.

For simplicity, the levers with an "ABCD" structure have been converted to a "1234" structure, by using the following concordances: A=1, B=2, C=3, D=4.

As explained in section 6, the following levers are fixed at their BAU levels:

- Population on B;
- Urbanization on B;
- Domestic food on B;
- Domestic production of manufacture products and materials on B;
- Land prioritization on A;
- Global mitigation effort on A (i.e. the rest of the world does not make any change in terms of mitigation efforts).

Two lever positions are uninfluential on the EUCalc results that are inputs for GTAP-EUCalc. These are "EU emissions after 2050", that sets the emission trend after 2050, and "discount factor", that determines cost actualization for the EUCalc cost calculations. In the tables included in this appendix, the independence between GTAP-EUCalc results and the lever position is signaled by an "x".

The detailed lever positions, especially for the baseline pathway (i.e. EU Reference Scenario) and for the predefined pathways (i.e. LTS Combo, LTS 1.5 Lifestyle, LTS 1.5 Technology), may be subject to adjustments in the final version of the model, due to improvements to computational speed and to the user-experience in the TPE.

Table 10.1 – Lever settings for pathways from P1 to P8

Group	Lever	p1	p2	p3	p4	p5	p6	p7	p8
Travel	Passenger distance	1	2	3	4	1	1	1	2
Travel	Mode of transport	1	2	3	4	1	1	1	2
Travel	Occupancy	1	2	3	4	1	1	1	2
Travel	Car own or hire	1	2	3	4	1	1	1	2
Homes	Living space per person	1	2	3	4	1	1	1	2
Homes	Percentage of cooled living space	1	2	3	4	1	1	1	2
Homes	Space cooling & heating	1	2	3	4	1	1	1	2
Homes	Appliances owned	1	2	3	4	1	1	1	2
Homes	Appliance use	1	2	3	4	1	1	1	2
Diet	Calories consumed	1	2	3	4	1	1	1	2
Diet	Type of diet	1	2	3	4	1	1	1	2
Consumption	Use of paper and packaging	1	2	3	4	1	1	1	2
Consumption	Product substitution rate	1	2	3	4	1	1	1	2
Consumption	Food waste at consumption level	1	2	3	4	1	1	1	2
Consumption	Freight distance	1	2	3	4	1	1	1	2
Transport	Passenger efficiency	1	2	3	4	2	3	4	1
Transport	Passenger technology	1	2	3	4	2	3	4	1
Transport	Freight efficiency	1	2	3	4	2	3	4	1
Transport	Freight technology share	1	2	3	4	2	3	4	1
Transport	Freight mode	1	2	3	4	2	3	4	1
Transport	Freight utilization rate	1	2	3	4	2	3	4	1
Transport	Fuel mix	1	2	3	4	2	3	4	1
Buildings	Building envelope	1	2	3	4	2	3	4	1
Buildings	District heating share	1	2	3	4	2	3	4	1
Buildings	Technology and fuel share	1	2	3	4	2	3	4	1
Buildings	Heating and cooling efficiency	1	2	3	4	2	3	4	1
Buildings	Appliances efficiency	1	2	3	4	2	3	4	1
Manufacturing	Material efficiency	1	2	3	4	2	3	4	1
Manufacturing	Material switch	1	2	3	4	2	3	4	1
Manufacturing	Technology efficiency	1	2	3	4	2	3	4	1
Manufacturing	Energy efficiency	1	2	3	4	2	3	4	1
Manufacturing	Fuel mix	1	2	3	4	2	3	4	1
Manufacturing	Carbon Capture in manufacturing	1	1	1	1	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	1	1	1	1	1	1	1
Power	Coal phase out	1	2	3	4	2	3	4	1
Power	Carbon Capture ratio in power	1	1	1	1	1	1	1	1
Power	Nuclear	1	2	3	4	2	3	4	1
Power	Wind	1	2	3	4	2	3	4	1
Power	Solar	1	2	3	4	2	3	4	1
Power	Hydro, geo & tidal	1	2	3	4	2	3	4	1
Power	Balancing strategies	1	2	3	4	2	3	4	1
Power	Charging profiles	1	2	3	4	2	3	4	1
Land and food	Climate smart crop production	1	2	3	4	2	3	4	1
Land and food	Climate smart livestock	1	2	3	4	2	3	4	1
Land and food	Bioenergy capacity	1	2	3	4	2	3	4	1
Land and food	Alternative protein source	1	2	3	4	2	3	4	1
Land and food	Forestry practices	1	2	3	4	2	3	4	1
Land and food	Land management	1	2	3	4	2	3	4	1
Land and food	Hierarchy for biomass end-uses	1	2	3	4	2	3	4	1
Water and biodiversity	Biodiversity	1	2	3	4	2	3	4	1
Water and biodiversity	Land prioritization	1	1	1	1	1	1	1	1
Demographics & long-term	Population	2	2	2	2	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2	2	2	2	2
Demographics & long-term	EU emissions after 2050	x	x	x	x	x	x	x	x
Domestic production	Domestic food production	2	2	2	2	2	2	2	2
Domestic production	Domestic product output	2	2	2	2	2	2	2	2
Domestic production	Domestic material production	2	2	2	2	2	2	2	2
Constraints	Global mitigation effort	1	1	1	1	1	1	1	1
Constraints	Discount factor	x	x	x	x	x	x	x	x

Table 10.2 - Lever settings for pathways from P9 to P16

Group	Lever	p9	p10	p11	p12	p13	p14	p15	p16
Travel	Passenger distance	2	2	3	3	3	4	4	4
Travel	Mode of transport	2	2	3	3	3	4	4	4
Travel	Occupancy	2	2	3	3	3	4	4	4
Travel	Car own or hire	2	2	3	3	3	4	4	4
Homes	Living space per person	2	2	3	3	3	4	4	4
Homes	Percentage of cooled living space	2	2	3	3	3	4	4	4
Homes	Space cooling & heating	2	2	3	3	3	4	4	4
Homes	Appliances owned	2	2	3	3	3	4	4	4
Homes	Appliance use	2	2	3	3	3	4	4	4
Diet	Calories consumed	2	2	3	3	3	4	4	4
Diet	Type of diet	2	2	3	3	3	4	4	4
Consumption	Use of paper and packaging	2	2	3	3	3	4	4	4
Consumption	Product substitution rate	2	2	3	3	3	4	4	4
Consumption	Food waste at consumption level	2	2	3	3	3	4	4	4
Consumption	Freight distance	2	2	3	3	3	4	4	4
Transport	Passenger efficiency	3	4	1	2	4	1	2	3
Transport	Passenger technology	3	4	1	2	4	1	2	3
Transport	Freight efficiency	3	4	1	2	4	1	2	3
Transport	Freight technology share	3	4	1	2	4	1	2	3
Transport	Freight mode	3	4	1	2	4	1	2	3
Transport	Freight utilization rate	3	4	1	2	4	1	2	3
Transport	Fuel mix	3	4	1	2	4	1	2	3
Buildings	Building envelope	3	4	1	2	4	1	2	3
Buildings	District heating share	3	4	1	2	4	1	2	3
Buildings	Technology and fuel share	3	4	1	2	4	1	2	3
Buildings	Heating and cooling efficiency	3	4	1	2	4	1	2	3
Buildings	Appliances efficiency	3	4	1	2	4	1	2	3
Manufacturing	Material efficiency	3	4	1	2	4	1	2	3
Manufacturing	Material switch	3	4	1	2	4	1	2	3
Manufacturing	Technology efficiency	3	4	1	2	4	1	2	3
Manufacturing	Energy efficiency	3	4	1	2	4	1	2	3
Manufacturing	Fuel mix	3	4	1	2	4	1	2	3
Manufacturing	Carbon Capture in manufacturing	1	1	1	1	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	1	1	1	1	1	1	1
Power	Coal phase out	3	4	1	2	4	1	2	3
Power	Carbon Capture ratio in power	1	1	1	1	1	1	1	1
Power	Nuclear	3	4	1	2	4	1	2	3
Power	Wind	3	4	1	2	4	1	2	3
Power	Solar	3	4	1	2	4	1	2	3
Power	Hydro, geo & tidal	3	4	1	2	4	1	2	3
Power	Balancing strategies	3	4	1	2	4	1	2	3
Power	Charging profiles	3	4	1	2	4	1	2	3
Land and food	Climate smart crop production	3	4	1	2	4	1	2	3
Land and food	Climate smart livestock	3	4	1	2	4	1	2	3
Land and food	Bioenergy capacity	3	4	1	2	4	1	2	3
Land and food	Alternative protein source	3	4	1	2	4	1	2	3
Land and food	Forestry practices	3	4	1	2	4	1	2	3
Land and food	Land management	3	4	1	2	4	1	2	3
Land and food	Hierarchy for biomass end-uses	3	4	1	2	4	1	2	3
Water and biodiversity	Biodiversity	3	4	1	2	4	1	2	3
Water and biodiversity	Land prioritization	1	1	1	1	1	1	1	1
Demographics & long-term	Population	2	2	2	2	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2	2	2	2	2
Demographics & long-term	EU emissions after 2050	x	x	x	x	x	x	x	x
Domestic production	Domestic food production	2	2	2	2	2	2	2	2
Domestic production	Domestic product output	2	2	2	2	2	2	2	2
Domestic production	Domestic material production	2	2	2	2	2	2	2	2
Constraints	Global mitigation effort	1	1	1	1	1	1	1	1
Constraints	Discount factor	x	x	x	x	x	x	x	x

Table 10.3 - Lever settings for pathways from P17 to P24

Group	Lever	p17	p18	p19	p20	p21	p22	p23	p24
Travel	Passenger distance	3	2	2	2	2	4	2	2
Travel	Mode of transport	3	2	2	2	2	4	2	2
Travel	Occupancy	3	2	2	2	2	4	2	2
Travel	Car own or hire	3	2	2	2	2	4	2	2
Homes	Living space per person	2	3	2	2	2	2	4	2
Homes	Percentage of cooled living space	2	3	2	2	2	2	4	2
Homes	Space cooling & heating	2	3	2	2	2	2	4	2
Homes	Appliances owned	2	3	2	2	2	2	4	2
Homes	Appliance use	2	3	2	2	2	2	4	2
Diet	Calories consumed	2	2	3	2	2	2	2	4
Diet	Type of diet	2	2	3	2	2	2	2	4
Consumption	Use of paper and packaging	2	2	2	3	2	2	2	2
Consumption	Product substitution rate	2	2	2	3	2	2	2	2
Consumption	Food waste at consumption level	2	2	2	3	2	2	2	2
Consumption	Freight distance	2	2	2	3	2	2	2	2
Transport	Passenger efficiency	3	2	2	2	2	4	2	2
Transport	Passenger technology	3	2	2	2	2	4	2	2
Transport	Freight efficiency	3	2	2	2	2	4	2	2
Transport	Freight technology share	3	2	2	2	2	4	2	2
Transport	Freight mode	3	2	2	2	2	4	2	2
Transport	Freight utilization rate	3	2	2	2	2	4	2	2
Transport	Fuel mix	3	2	2	2	2	4	2	2
Buildings	Building envelope	2	3	2	2	2	2	4	2
Buildings	District heating share	2	3	2	2	2	2	4	2
Buildings	Technology and fuel share	2	3	2	2	2	2	4	2
Buildings	Heating and cooling efficiency	2	3	2	2	2	2	4	2
Buildings	Appliances efficiency	2	3	2	2	2	2	4	2
Manufacturing	Material efficiency	2	2	2	3	2	2	2	2
Manufacturing	Material switch	2	2	2	3	2	2	2	2
Manufacturing	Technology efficiency	2	2	2	3	2	2	2	2
Manufacturing	Energy efficiency	2	2	2	3	2	2	2	2
Manufacturing	Fuel mix	2	2	2	3	2	2	2	2
Manufacturing	Carbon Capture in manufacturing	1	1	1	1	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	1	1	1	1	1	1	1
Power	Coal phase out	2	2	2	2	3	2	2	2
Power	Carbon Capture ratio in power	1	1	1	1	1	1	1	1
Power	Nuclear	2	2	2	2	3	2	2	2
Power	Wind	2	2	2	2	3	2	2	2
Power	Solar	2	2	2	2	3	2	2	2
Power	Hydro, geo & tidal	2	2	2	2	3	2	2	2
Power	Balancing strategies	2	2	2	2	3	2	2	2
Power	Charging profiles	2	2	2	2	3	2	2	2
Land and food	Climate smart crop production	2	2	3	2	2	2	2	4
Land and food	Climate smart livestock	2	2	3	2	2	2	2	4
Land and food	Bioenergy capacity	2	2	3	2	2	2	2	4
Land and food	Alternative protein source	2	2	3	2	2	2	2	4
Land and food	Forestry practices	2	2	3	2	2	2	2	4
Land and food	Land management	2	2	3	2	2	2	2	4
Land and food	Hierarchy for biomass end-uses	2	2	3	2	2	2	2	4
Water and biodiversity	Biodiversity	2	2	2	2	2	2	2	2
Water and biodiversity	Land prioritization	1	1	1	1	1	1	1	1
Demographics & long-term	Population	2	2	2	2	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2	2	2	2	2
Demographics & long-term	EU emissions after 2050	x	x	x	x	x	x	x	x
Domestic production	Domestic food production	2	2	2	2	2	2	2	2
Domestic production	Domestic product output	2	2	2	2	2	2	2	2
Domestic production	Domestic material production	2	2	2	2	2	2	2	2
Constraints	Global mitigation effort	1	1	1	1	1	1	1	1
Constraints	Discount factor	x	x	x	x	x	x	x	x

Table 10.4 - Lever settings for pathways from P25 to P31

Group	Lever	p25	p26	p27	p28	p29	p30	p31
Travel	Passenger distance	2	2	4	3	3	3	3
Travel	Mode of transport	2	2	4	3	3	3	3
Travel	Occupancy	2	2	4	3	3	3	3
Travel	Car own or hire	2	2	4	3	3	3	3
Homes	Living space per person	2	2	3	4	3	3	3
Homes	Percentage of cooled living space	2	2	3	4	3	3	3
Homes	Space cooling & heating	2	2	3	4	3	3	3
Homes	Appliances owned	2	2	3	4	3	3	3
Homes	Appliance use	2	2	3	4	3	3	3
Diet	Calories consumed	2	2	3	3	4	3	3
Diet	Type of diet	2	2	3	3	4	3	3
Consumption	Use of paper and packaging	4	2	3	3	3	4	3
Consumption	Product substitution rate	4	2	3	3	3	4	3
Consumption	Food waste at consumption level	4	2	3	3	3	4	3
Consumption	Freight distance	4	2	3	3	3	4	3
Transport	Passenger efficiency	2	2	4	3	3	3	3
Transport	Passenger technology	2	2	4	3	3	3	3
Transport	Freight efficiency	2	2	4	3	3	3	3
Transport	Freight technology share	2	2	4	3	3	3	3
Transport	Freight mode	2	2	4	3	3	3	3
Transport	Freight utilization rate	2	2	4	3	3	3	3
Transport	Fuel mix	2	2	4	3	3	3	3
Buildings	Building envelope	2	2	3	4	3	3	3
Buildings	District heating share	2	2	3	4	3	3	3
Buildings	Technology and fuel share	2	2	3	4	3	3	3
Buildings	Heating and cooling efficiency	2	2	3	4	3	3	3
Buildings	Appliances efficiency	2	2	3	4	3	3	3
Manufacturing	Material efficiency	4	2	3	3	3	4	3
Manufacturing	Material switch	4	2	3	3	3	4	3
Manufacturing	Technology efficiency	4	2	3	3	3	4	3
Manufacturing	Energy efficiency	4	2	3	3	3	4	3
Manufacturing	Fuel mix	4	2	3	3	3	4	3
Manufacturing	Carbon Capture in manufacturing	1	1	1	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	1	1	1	1	1	1
Power	Coal phase out	2	4	3	3	3	3	4
Power	Carbon Capture ratio in power	1	1	1	1	1	1	1
Power	Nuclear	2	4	3	3	3	3	4
Power	Wind	2	4	3	3	3	3	4
Power	Solar	2	4	3	3	3	3	4
Power	Hydro, geo & tidal	2	4	3	3	3	3	4
Power	Balancing strategies	2	4	3	3	3	3	4
Power	Charging profiles	2	4	3	3	3	3	4
Land and food	Climate smart crop production	2	2	3	3	4	3	3
Land and food	Climate smart livestock	2	2	3	3	4	3	3
Land and food	Bioenergy capacity	2	2	3	3	4	3	3
Land and food	Alternative protein source	2	2	3	3	4	3	3
Land and food	Forestry practices	2	2	3	3	4	3	3
Land and food	Land management	2	2	3	3	4	3	3
Land and food	Hierarchy for biomass end-uses	2	2	3	3	4	3	3
Water and biodiversity	Biodiversity	2	2	3	3	3	3	3
Water and biodiversity	Land prioritization	1	1	1	1	1	1	1
Demographics & long-term	Population	2	2	2	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2	2	2	2
Demographics & long-term	EU emissions after 2050	x	x	x	x	x	x	x
Domestic production	Domestic food production	2	2	2	2	2	2	2
Domestic production	Domestic product output	2	2	2	2	2	2	2
Domestic production	Domestic material production	2	2	2	2	2	2	2
Constraints	Global mitigation effort	1	1	1	1	1	1	1
Constraints	Discount factor	x	x	x	x	x	x	x

Table 10.5 - Lever settings for pathways EUREF, LTS Combo, LTS 1.5 Lifestyle, LTS 1.5 Technology

Group	Lever	EUREF	COMBO	15LFE	15TECH
Travel	Passenger distance	1	1.2	2	1.5
Travel	Mode of transport	1	2.9	3.4	2.1
Travel	Occupancy	1	2.8	3.7	2.4
Travel	Car own or hire	1	3	3.5	2
Homes	Living space per person	1	1.5	2	1.5
Homes	Percentage of cooled living space	2	2	2	2
Homes	Space cooling & heating	2	2	2	2
Homes	Appliances owned	1.5	1.8	1.8	1.8
Homes	Appliance use	1.5	1.8	1.8	1.8
Diet	Calories consumed	2.1	2	2	2
Diet	Type of diet	1	1	2	1
Consumption	Use of paper and packaging	1	2	2	2
Consumption	Product substitution rate	2	1	1	1
Consumption	Food waste at consumption level	1	3	3	3
Consumption	Freight distance	1	2.8	3.6	1.9
Transport	Passenger efficiency	2	3	2.8	3.8
Transport	Passenger technology	2	3.2	3.1	3.5
Transport	Freight efficiency	2	3	2.6	3.4
Transport	Freight technology share	1	3.3	2.9	3.7
Transport	Freight mode	2	2.8	3.3	2.3
Transport	Freight utilization rate	1	2.9	3.1	2.6
Transport	Fuel mix	1	2.7	3.5	2
Buildings	Building envelope	1.5	3	3	3
Buildings	District heating share	1.5	2	2	2
Buildings	Technology and fuel share	1.5	2.5	3	3
Buildings	Heating and cooling efficiency	1.5	3	3	3
Buildings	Appliances efficiency	1.5	3	3	3
Manufacturing	Material efficiency	1.5	2.7	4	2.8
Manufacturing	Material switch	1.5	2.6	3.5	2.9
Manufacturing	Technology efficiency	1.5	2.5	4	2.9
Manufacturing	Energy efficiency	1.5	2.7	4	2.9
Manufacturing	Fuel mix	1.5	2.5	3.6	2.9
Manufacturing	Carbon Capture in manufacturing	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	1	1	1
Power	Coal phase out	1	3	4	4
Power	Carbon Capture ratio in power	1	1	1	1
Power	Nuclear	4	4	4	4
Power	Wind	1	1.8	1.8	1.9
Power	Solar	1	2.6	2.4	3.1
Power	Hydro, geo & tidal	1	2	1.9	2
Power	Balancing strategies	1	1	2	3
Power	Charging profiles	1	3	3	4
Land and food	Climate smart crop production	2	2	2.5	2
Land and food	Climate smart livestock	2	2	2.5	2
Land and food	Bioenergy capacity	1	3	2	3
Land and food	Alternative protein source	1	1	1	1
Land and food	Forestry practices	1	1	1	1
Land and food	Land management	1	1	1	1
Land and food	Hierarchy for biomass end-uses	2	3	2	3
Water and biodiversity	Biodiversity	1	1	1	1
Water and biodiversity	Land prioritization	1	1	1	1
Demographics & long-term	Population	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2
Demographics & long-term	EU emissions after 2050	1	1	1	1
Domestic production	Domestic food production	2	2	2	2
Domestic production	Domestic product output	2	2	2	2
Domestic production	Domestic material production	2	2	2	2
Constraints	Global mitigation effort	1	1	1	1
Constraints	Discount factor	2	2	2	2

Table 10.6 – Lever settings for additional pathways simulated in GTAP-EUCalc (1)

Group	Lever	behav	behalandfood	techfuels	techlandfood
Travel	Passenger distance	4	4	1	1
Travel	Mode of transport	4	4	1.3	1.3
Travel	Occupancy	4	4	1.3	1.3
Travel	Car own or hire	4	4	1.3	1.3
Homes	Living space per person	4	4	1.5	1.5
Homes	Percentage of cooled living space	4	4	2	2
Homes	Space cooling & heating	4	4	1	1
Homes	Appliances owned	4	4	1.8	1.8
Homes	Appliance use	4	4	1.8	1.8
Diet	Calories consumed	4	4	2	2
Diet	Type of diet	4	4	1	1
Consumption	Use of paper and packaging	4	4	2	2
Consumption	Product substitution rate	4	4	1	1
Consumption	Food waste at consumption level	4	4	3	3
Consumption	Freight distance	4	4	1.1	1.1
Transport	Passenger efficiency	1.3	1.3	4	4
Transport	Passenger technology	1.1	1.1	4	4
Transport	Freight efficiency	1.1	1.1	4	4
Transport	Freight technology share	1.1	1.1	4	4
Transport	Freight mode	1.3	1.3	4	4
Transport	Freight utilization rate	1.3	1.3	4	4
Transport	Fuel mix	1.3	1.3	4	4
Buildings	Building envelope	1.5	1.5	4	4
Buildings	District heating share	1.5	1.5	4	4
Buildings	Technology and fuel share	1.5	1.5	4	4
Buildings	Heating and cooling efficiency	1.5	1.5	4	4
Buildings	Appliances efficiency	1.5	1.5	4	4
Manufacturing	Material efficiency	1.5	1.5	4	4
Manufacturing	Material switch	1.5	1.5	4	4
Manufacturing	Technology efficiency	1.5	1.5	4	4
Manufacturing	Energy efficiency	1.5	1.5	4	4
Manufacturing	Fuel mix	1.5	1.5	4	4
Manufacturing	Carbon Capture in manufacturing	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	1	4	1
Power	Coal phase out	1	1	4	4
Power	Carbon Capture ratio in power	1	1	1	1
Power	Nuclear	4	4	4	4
Power	Wind	1	1	4	4
Power	Solar	1	1	4	4
Power	Hydro, geo & tidal	1	1	4	4
Power	Balancing strategies	1	1	4	4
Power	Charging profiles	1	1	4	4
Land and food	Climate smart crop production	2	4	2	4
Land and food	Climate smart livestock	1	4	1	4
Land and food	Bioenergy capacity	1	4	1	4
Land and food	Alternative protein source	1	4	1	4
Land and food	Forestry practices	1	4	1	4
Land and food	Land management	1	4	1	4
Land and food	Hierarchy for biomass end-uses	2	4	2	4
Water and biodiversity	Biodiversity	1	1	1	1
Water and biodiversity	Land prioritization	1	1	1	1
Demographics & long-term	Population	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2
Demographics & long-term	EU emissions after 2050	1	1	1	1
Domestic production	Domestic food production	2	2	2	2
Domestic production	Domestic product output	2	2	2	2
Domestic production	Domestic material production	2	2	2	2
Constraints	Global mitigation effort	1	1	1	1
Constraints	Discount factor	2	2	2	2

Table 10.7 - Lever settings for additional pathways simulated in GTAP-EUCalc (2)

Group	Lever	pasttrends	middleroad	ambitious	base
Travel	Passenger distance	1	2.5	4	1
Travel	Mode of transport	1	2.5	4	1.3
Travel	Occupancy	1	2.5	4	1.3
Travel	Car own or hire	1	2.5	4	1.3
Homes	Living space per person	1	2.5	4	1
Homes	Percentage of cooled living space	1	2.5	4	2
Homes	Space cooling & heating	1	2.5	4	2
Homes	Appliances owned	1	2.5	4	1.5
Homes	Appliance use	1	2.5	4	1.5
Diet	Calories consumed	1	2.5	4	2.1
Diet	Type of diet	1	2.5	4	1
Consumption	Use of paper and packaging	1	2.5	4	1
Consumption	Product substitution rate	1	2.5	4	2
Consumption	Food waste at consumption level	1	2.5	4	1
Consumption	Freight distance	1	2.5	4	1.1
Transport	Passenger efficiency	1	2.5	4	1.3
Transport	Passenger technology	1	2.5	4	1.1
Transport	Freight efficiency	1	2.5	4	1.1
Transport	Freight technology share	1	2.5	4	1.1
Transport	Freight mode	1	2.5	4	1.3
Transport	Freight utilization rate	1	2.5	4	1.3
Transport	Fuel mix	1	2.5	4	1.3
Buildings	Building envelope	1	2.5	4	1.5
Buildings	District heating share	1	2.5	4	1.5
Buildings	Technology and fuel share	1	2.5	4	1.5
Buildings	Heating and cooling efficiency	1	2.5	4	1.5
Buildings	Appliances efficiency	1	2.5	4	1.5
Manufacturing	Material efficiency	1	2.5	4	1.5
Manufacturing	Material switch	1	2.5	4	1.5
Manufacturing	Technology efficiency	1	2.5	4	1.5
Manufacturing	Energy efficiency	1	2.5	4	1.5
Manufacturing	Fuel mix	1	2.5	4	1.5
Manufacturing	Carbon Capture in manufacturing	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	2.5	4	1
Power	Coal phase out	1	2.5	4	1
Power	Carbon Capture ratio in power	1	1	1	1
Power	Nuclear	4	2.5	4	4
Power	Wind	1	2.5	4	1
Power	Solar	1	2.5	4	1
Power	Hydro, geo & tidal	1	2.5	4	1
Power	Balancing strategies	1	2.5	4	1
Power	Charging profiles	1	2.5	4	1
Land and food	Climate smart crop production	2	2	2	2
Land and food	Climate smart livestock	2	2	2	2
Land and food	Bioenergy capacity	1	2.5	4	2
Land and food	Alternative protein source	1	2.5	4	2
Land and food	Forestry practices	1	2.5	4	1
Land and food	Land management	1	2.5	4	2
Land and food	Hierarchy for biomass end-uses	2	2.5	4	2
Water and biodiversity	Biodiversity	1	2.5	4	1
Water and biodiversity	Land prioritization	1	1	1	1
Demographics & long-term	Population	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2
Demographics & long-term	EU emissions after 2050	1	1	1	1
Domestic production	Domestic food production	2	2	2	2
Domestic production	Domestic product output	2	2	2	2
Domestic production	Domestic material production	2	2	2	2
Constraints	Global mitigation effort	1	1	1	1.5
Constraints	Discount factor	2	2	2	2

Table 10.8 - Lever settings for additional pathways simulated in GTAP-EUCalc (3)

Group	Lever	homebuild	travel_b	travel_t	TrvTrnspPwr
Travel	Passenger distance	1	4	1	4
Travel	Mode of transport	1.3	4	1.3	4
Travel	Occupancy	1.3	4	1.3	4
Travel	Car own or hire	1.3	1.3	1.3	4
Homes	Living space per person	4	1	1	1.5
Homes	Percentage of cooled living space	4	2	2	2
Homes	Space cooling & heating	4	2	2	1
Homes	Appliances owned	4	1.5	1.5	1.8
Homes	Appliance use	4	1.5	1.5	1.8
Diet	Calories consumed	2	2.1	2.1	2
Diet	Type of diet	1	1	1	1
Consumption	Use of paper and packaging	2	1	1	2
Consumption	Product substitution rate	1	2	2	1
Consumption	Food waste at consumption level	3	1	1	3
Consumption	Freight distance	1.1	1.1	1.1	4
Transport	Passenger efficiency	1.3	1.3	4	4
Transport	Passenger technology	1.1	1.1	4	4
Transport	Freight efficiency	1.1	1.1	1.1	4
Transport	Freight technology share	1.1	1.1	1.1	4
Transport	Freight mode	1.3	1.3	1.3	4
Transport	Freight utilization rate	1.3	1.3	1.3	4
Transport	Fuel mix	1.3	1.3	1.3	4
Buildings	Building envelope	4	1.5	1.5	1.5
Buildings	District heating share	4	1.5	1.5	1.5
Buildings	Technology and fuel share	4	1.5	1.5	1.5
Buildings	Heating and cooling efficiency	4	1.5	1.5	1.5
Buildings	Appliances efficiency	4	1.5	1.5	1.5
Manufacturing	Material efficiency	1.5	1.5	1.5	1.5
Manufacturing	Material switch	1.5	1.5	1.5	1.5
Manufacturing	Technology efficiency	1.5	1.5	1.5	1.5
Manufacturing	Energy efficiency	1.5	1.5	1.5	1.5
Manufacturing	Fuel mix	1.5	1.5	1.5	1.5
Manufacturing	Carbon Capture in manufacturing	1	1	1	1
Manufacturing	Carbon Capture to fuel	1	1	1	1
Power	Coal phase out	1	1	1	4
Power	Carbon Capture ratio in power	1	1	1	1
Power	Nuclear	4	4	4	4
Power	Wind	1	1	1	4
Power	Solar	1	1	1	4
Power	Hydro, geo & tidal	1	1	1	4
Power	Balancing strategies	1	1	1	4
Power	Charging profiles	1	1	1	4
Land and food	Climate smart crop production	2	2	2	2
Land and food	Climate smart livestock	2	2	2	2
Land and food	Bioenergy capacity	1	2	2	1
Land and food	Alternative protein source	1	2	2	1
Land and food	Forestry practices	1	1	1	1
Land and food	Land management	1	2	2	1
Land and food	Hierarchy for biomass end-uses	2	2	2	2
Water and biodiversity	Biodiversity	1	1	1	1
Water and biodiversity	Land prioritization	1	1	1	1
Demographics & long-term	Population	2	2	2	2
Demographics & long-term	Urban population	2	2	2	2
Demographics & long-term	EU emissions after 2050	1	1	1	1
Domestic production	Domestic food production	2	2	2	2
Domestic production	Domestic product output	2	2	2	2
Domestic production	Domestic material production	2	2	2	2
Constraints	Global mitigation effort	1	1.5	1.5	1
Constraints	Discount factor	2	2	2	2