Supplementary material for GTAP-based model development with RunDynam including Energy and Power extensions

by Valeria Costantini and Elena Paglialunga

Contents

All files related to GTAP databases, GEMPACK codes and simulation of macro projections are covered by license No. RDM-0616 (CREA ENEA Centro Rossi Doria Universita RomaTre SEEDS). Financial support from Directorate General for Trade (European Commission) within the project "Trade and Climate Change: an Energy-Economic Modelling Approach", Contract No SI2.819836 DGTRADE-CRES is gratefully acknowledged.

1. Model building procedure

1.1 Software installation

The preliminary step for building and running the GTAP model here developed is the installation of three software: GFortran, GEMPACK and RunDynam.

GFortran is the free and open-source GNU Fortran compiler supported by the source-code versions of GEMPACK that can be used on Windows PCs. The GFortran compiler can be downloaded from http://www.copsmodels.com/gpgfort.htm. The choice about which install package to be used depends on: the operating system (both 32-bit and 64-bit install packages are available); the GEMPACK version (the GFortran package to be used needs to be compatible with the GEMPACK version). In what follows, we refer to the 64-bit GFortran package "**mingw-w64-gcc-6.4.0-setup.exe**" compatible with the GEMPACK releases 11.2. While following the standard software installation procedure, it is recommended to use the default directory: "C:\MinGW-w64". Additional recommendations: if upgrading, it is recommended to first uninstall the older GFortran; you might need to reboot the PC (GFortran might compile very slowly the first time it is used and the problem seems to disappear after rebooting).

Before installing GEMPACK, it is also recommended to test the correct installation of GFortran as follows: save the program hello.for (can be downloaded from http://www.copsmodels.com/gpgfort.htm) into a temporary folder "C:\test"; access the terminal command prompt and type the following commands:

```
cd\test
C:\test>gfortvars intel64
C:\test>gfortran hello.for -o hello.exe
C:\test>hello
```

The first command changes the directory to the "C:\test" folder containing hello.for; the second command sets up the environment for the compiler; the third command compiles the program "hello.exe"; the fourth command runs the "hello.exe" program. If the GFortran compiler has been correctly installed (thus it is correctly working), the "hello.exe" program will write "Hello World" to the terminal.

Differently from the GFortran compiler, both the GEMPACK and RunDynam software require licences.

The second software to install is the General Equilibrium Modelling PACKage, namely GEMPACK, that is the suite of economic modelling software. In what follows, we refer to the GEMPACK releases 12.1 made available in December 2019 (see https://www.copsmodels.com/gp121.htm for further details). The standard software installation procedure can be launched by running the file **"gpsc-12.0.001-install.exe"**. As remarked above, it requires a valid GEMPACK licence file ("licen.gem") that is requested during the installation procedure. In some cases, the licence requires activation to ensure the software continues to work, in which case an additional further software ("gpactivate.exe") is required.[1]

The GTAP model here developed is a multi-period CGE models, in which results are computed one-period-at-a-time, hence the third required software is RunDynam. RunDynam, a Windows interface that provides an environment tailored for carrying out forecasts and policy deviations with recursive-dynamic models. Similarly to what has been described for the GEMPACK installation, the standard software installation procedure can be launched by running the file **"rundynam-install-381.exe"** and, also in this case, a valid RunDynam licence file ("licen.rdn") is requested during the installation procedure.

1.2 Building aggregation with FlexAgg mode

FlexAgg is a command-line aggregation program that uses a batch file to run a series of GEMPACK execuTable Sfiles to aggregate data bases from the fully disaggregated GTAP Data Base. The data required to run the model here described results from merging different GTAP databases with 2014 reference year (further enriched with additional information for better representing trade, energy and climate dynamics). The GTAP databases used are: GTAP10, GDyn, GTAP-Power and GTAP-E. Please refer to the following section (2. Model database) for a detailed description of each database. In what follows, it is described the general method to map the fully disaggregated GTAP Data Base into the desired number of regional, sectoral and endowment grouping.

Each GTAP database is associated to: a FlexAgg utility folder and a text file describing the aggregation of the model, i.e., commodity, regions and endowment aggregation mapping (please refer to section 3 for the detailed description of the aggregation used to set up the model here described).

[1] A general description of the issue can be found here https://www.copsmodels.com/gpactivation.htm and refer to https://www.copsmodels.com/pdf/activation.pdf for technical details.

The general procedure consists of the following steps (to be repeated for each of the databases). The first step is the definition of the aggregation mapping in the text file (e.g., "agg_DGTRADE.txt"). This file needs to be located in the corresponding FlexAgg folder (e.g., "flexagg10"), which in turns needs to be in C (hence the path to access the aggregation text file should be: "C:\flexagg10\agg_DGTRADE.txt"). The second step involves the creation of a folder containing all data, set and parameters in accordance with the aggregation defined. In order to perform this step, it is required to access the terminal command prompt and type the following commands:

```
C:\ cd flexagg10
data-agg agg_DGTRADE
```

The first command changes the directory to the targeted FlexAgg folder; the second command run the FlexAgg program and automatically creates a folder (named "agg_DGTRADE" that will be located in C) with data, set and parameters coherent with the aggregation scheme in the text file (notice that among the files created, the ones required for running the final model are: gdset.har, gddat.har, gdpar.har and gdpextra.har). Table S1 reports the specific command to run for each GTAP database to be aggregated.

Table S1 – Commands to run for specific GTAP database

Model database	Change directory path	Run FlexAgg aggregation
GTAP10 database	cd\flexagg10Y14	data-agg agg_DGTRADE_dyn14_new
GDyn	cd\GDYNflexagg10A_Y14	data-agg agg_DGTRADE_dyn14_new
GTAP-E	cd\flexagg10E14	data-agg agg_DGTRADE_ene_new
GTAP-Power	cd\flexagg10Power14	data-agg agg_DGTRADE_power_new

Two further details need to be noticed. First, while the fully disaggregated GTAP10, GDyn and GTAP-E databases share the same number of regions and sectors (141 countries/regions and 65 sectors, among which only one electricity sector), GTAP-Power is an electricity-detailed extension that splits the electricity sectors in 12 sub-sectors (i.e., transmission and distribution, seven base load technologies and four peak load technologies) resulting in 141 countries/regions and 76 sectors. Hence, based on the GTAP-Power database, the reference aggregated sector mapping distinguishes between electricity from fossil fuels and from renewable energy. Accordingly, the final model uses the aggregated version of the GTAP-Power database as reference, integrated with data and parameters from the other versions that have been adapted to match the exact sectoral dimension as detailed in the next sections.

As second and related issue, a change in the FlexAgg command for GTAP-Power has been introduced in order to integrate in the model also the non-CO2 emissions. Specifically, in the FlexAgg tab file we defined the command for computing emissions on the basis of the traded commodities set (trad_comm) instead of the set of the commodities subject to carbon tax (ctax_comm). By running the modified GTAP-Power FlexAgg program on the basis of a har emission file that includes also non-CO2 emissions (i.e., "gsdemiss2.har", see section 2.5 GTAP-NCO2 for technical details), we directly obtain the aggregated emissions in har file compatible with the GDynE version that also includes the emissions associated to the chemical sector without changing the definition commodities subject to carbon tax (i.e., coal, oil, gas and oil products). The model aggregation including non-CO2 emissions then relies on the same gdset.har and gdpextra.har as the version without non-CO2 emissions, while it requires different har files for data and standard parameters (i.e., gddat1.har and gdpar1.har).

1.3 Composition of the dat file

The file containing the required base data for running the model (i.e., gddat.har and gddat1.har for the version including non-CO2 emissions) is based on the dat file produced by the GTAP-Power aggregation procedure, integrated as follows.

The following headers defined over the regional set need to be imported from the gddat.har file obtained from the aggregation of the GDyn version as in Table S2:

Table S2 – Header to be imported in gddat.har from the GDyn version

Header	Dimension	Coeff	Name
KHAT	REG	CKHAT	Normal growth rate of Capital
YHAT	REG	CYHAT	Normal growth rate of Income

RRGE	REG	CRRGE	Expected Gross Rate of return
RRGT	REG	CRRGT	Target Gross Rate of Return
YQHT	REG	CYQHT	Income earned on household equity located in the trust
YQTF	REG	CYQTF	Income earned on equity owned by the trust in Domestic firms
YQHF	REG	CYQHF	Income earned on household equity located in domestic firms

In addition to the har files described above, the aggregation of the GTAP-Power version also generates a file containing CO2 emissions associated to use and consumption of fossil fuels expressed in Mt CO2 ("gsdgemiss.har"). Hence, all headers from the file "gsdgemiss.har" have been imported in the dat file. CO2 emissions are associated only to coal, oil, gas and oil products, but the sectoral aggregation of trad_comm already includes the electricity sector divided between fossil and renewable. Since the headers names are different from the ones in the tablo file used for the simulation, these have to be renamed according to Table S3.

Table S3 – Name changes to headers related to CO2 emission for the GDynE version

Old Header	New Header	Dimension	Coeff	Name
	FC	4 length 12		Set FUEL_COMM
MDF	CODF	TRAD_COMM*PROD_COMM *REG	CCODF	Emissions from intermediate usage of domestic product
MIF	COIF	TRAD_COMM*PROD_COMM *REG	CCOIF	Emissions from intermediate usage of imports
MDG	CODG	TRAD_COMM*REG	CCODG	Emissions from government consumption of domestic product
MIG	COIG	TRAD_COMM*REG	CCOIG	Emissions from government consumption of imports
MDP	CODP	TRAD_COMM*REG	CCODP	Emissions from private consumption of domestic product
MIP	COIP	TRAD_COMM*REG	CCOIP	Emissions from private consumption of imports

The exe files in FlexAgg for GTAP-Power have been changed in order to run over the specification TRAD_COMM and PROD_COMM instead of EGY_COMM and PROD_COMM in order to obtain the headers for emissions that are compatible with the structure of GDynE. The FlexAgg module also contains a correction for an error in modelling the average value of emissions that had a ge 0 check range that was giving back an error.

Similarly, we import the following headers from a further har file generated by the aggregation of the GTAP-Power version ("gsdvole.har") that contains information about the volume of energy purchases by sector and region expressed in Mtoe. In addition, we include two further variables: CVOL, as the sum of EDF, EIF, EDP, EIP, EDG and EIG by energy commodity and region (fossil fuels and the two electricity sectors); CVOC, equivalent to CVOL but defined over the traded commodities set instead of the energy commodities set (thus for all non-energy commodities the volume is equal to zero).

Table S4 – Name changes to headers related to energy volumes for the GDynE version

New Header	Dimension	Coeff	Name
EDF	EGY_COMM*PROD_COMM*REG	CEDF	Volume of domestic purchases by firms
EIF	EGY_COMM*PROD_COMM*REG	CEIF	Volume of import purchases by firms
EDP	EGY_COMM*REG	CEDP	Volume of domestic purchases by households
EIP	EGY_COMM*REG	CEIP	Volume of import purchases by households
EDG	EGY_COMM*REG	CEDG	Volume of domestic purchases by government
EIG	EGY_COMM*REG	CEIG	Volume of import purchases by government
EXI	EGY_COMM*REG*REG	CEXI	Volume of bilateral trade
CVOL	EGY_COMM*REG	CCVOL	Total Volume
CVOC	TRAD_COMM*REG	CVOLC	CVOL for all trade comm

Further, the following headers related to purchases and imports net of carbon tax are obtained by cloning existing headers within the gddat.har of the GTAP-Power version, renaming according to the Table Sbelow

and adjusting the values according to the value obtained from the GTAP-E version. Since GTAP-E has a different sectoral aggregation (the renewable electricity sector is not included), after the headers have been cloned, to ensure that the original value provided by GTAP-E is associated to the correct sector, it is recommended to copy the GTAP-E value on a temporary excel file, add a row corresponding to the renewable electricity sector (according to the order in the GTAP-Power version) and then paste it in the corresponding header in the dat file. Notice that all values associated to energy commodities are equal to zero.

Table S5 – Cloning headers for the GDynE version

Cloned Header	New Header	Dimension	Coeff	Name
VDGA	DGNC	TRAD_COMM*REG	CDGN	Government - Domestic Purchases at Agents' Prices - Net Carbon Tax
VIGA	IGNC	TRAD_COMM*REG	CIGNC	Government - Imports at Agents' Prices- Net Carbon Tax
VDPA	DPNC	TRAD_COMM*REG	CDPNC	Private Households - Domestic Purchases at Agents' Prices- Net Carbon Tax
VIPA	IPNC	TRAD_COMM*REG	CIPNC	Private Households - Imports at Agents' Prices- Net Carbon Tax
VDFA	DFNC	TRAD_COMM*PROD_COMM*REG	CDFNC	Intermediates - Firms' Domestic Purchases at Agents' Prices- Net Carbon Tax
VIFA	IFNC	TRAD_COMM*PROD_COMM*REG	CIFNC	Intermediates - Firms' Imports at Agents' Prices- Net Carbon Tax

Finally, all headers from past model versions need to be included as in Table S6, coherently with the tablo file used for running the model.

Table S6 – Headers to be imported in dat from old versions to be compatible with the tablo in GDynE

Header	Dimension	Coeff	Name
RFLX	REG	RFLX	Coefficient for changing rigidity of firms
LKT	REG	LKHAT	Coefficient for changing speed of adjustment normal rate of growth
LROR	REG	LROR	Coefficient for changing speed of adjustment normal rate of return
RGF	REG	RGF	Coefficient for changing rigidity of firms
RGH	REG	RGH	Coefficient for changing rigidity of households
Endogenous technical change in clean energy technologies			
GFM	1	GFM	Share to be shocked for world carbon fund quota to mitigation costs
GFA	1	GFA	Share to be shocked for world carbon fund quota to adaptation costs
SHA	FIRM_COM*PROD_COMM*REG	SHA	Parameter to change share of world carbon fund to factor augmenting technical change
SHAS	REG	SHARS	Parameter to change share of world carbon fund to RD in renewables
SHF	REG	SHF	Parameter to change share of contribution from world carbon fund
SHT	REG	SHT	Parameter to change share of contribution to world carbon fund
SHR	REG	SHR	Parameter to change share of contribution from world carbon fund to RD
SHWS	PROD_COMM*REG	SHAWS	Parameter to change elasticity of substitution in capital-energy re
EFL	PROD_COMM*REG	EFL	Parameter to change elasticity of substitution in energy nest
EFM	PROD_COMM*REG	EFM	Parameter to change elasticity of substitution in capital-energy
SHAH	REG	SHARH	Parameter to change share of contribution from CWTRFD to EE in building
HASH	ENY_PCOMM*REG	SHAFSH	Parameter to change elasticity of technical change to EE in household
ELF	PROD_COMM*REG	ELF	Parameter to change elasticity of substitution in electricity sub-nest

Dynamic energy version corrected with climate damage			
WHCT	1	InitGCF	Initial value of GCF independent from financing mech
STCO	1	StockofCO2	Stock of CO2 in Mton equivalent to PPM
CCM	1	CCM	Average climate change cost, world level MlnUSD per MtonCO2 Stock
VULN	REG	VULN	Parameter to calculate vulnerability to climate change
CCR	REG	CCR	Value of cost of climate change at regional level
Additional header included in the development of the present model version			
COIH	TRAD_COMM*REG	COIH	Coefficient to shock COIH for change in carbon intensity households
COI	TRAD_COMM*PROD_COMM*REG	COI	Coefficient to shock COIN for change in carbon intensity of firms

In the following Table Swe report all headers that have been derived from (or whose valued have been updated with) past model versions, i.e., a dynamic energy version corrected with climate damage (Costantini et al., 2018) and with endogenous technical change in clean energy technologies (Corradini et al., 2018).

1.4 Composition of the par file

The variables in the gdpar.har file contains the behavioural parameters. As for the base data, also in this case the original file obtained from the aggregation of the GTAP-Power version needs to be integrated with additional headers from the other GTAP versions as in Table S7. Firstly, from the GTAP-E aggregation the following coefficient regulating the substitution possibilities in the energy nests need to be imported.[2] The parameters defined over the regional set, assume the same value for all regions. The parameters defined over the regional and prod_comm sets need to be adapted according to the sectoral aggregation of the GTAP-Power version that includes the additional sector of electricity produced from renewable (it is recommend to follow the same procedure described for the headers related to purchases and imports net of carbon tax). In these cases, the value for the renewable electricity is set equal to the fossil electricity sector, with the only exception of the coefficient ELFKEN (equal to 0.38 for fossil electricity and 0.80 for renewable electricity sector). The CDE parameters (regulating the private household demands according to constant difference of elasticities functional form specification) SUBP and INCP are equivalent to SUB1 and INC1 from the GTAP-Power par file, but are defined over the up_comm set (see section 1.6 for further details). The coefficients TRBL and MAPB are required to define regions subject to carbon pricing and to distinguish between domestic carbon tax and international emission trading.

Table S7 – Headers to be imported in par from old versions to be compatible with the tablo in GDynE

Header	Dimension	Coeff	Name
EGEN	REG	ELGENY	Elasticity of substitution in gov. energy sub-consumption
EGNN	REG	ELGNENY	Elasticity of substitution in gov. non-energy sub-consumption
EGUG	REG	ELGUG	Elasticity of substitution in the top of Government consumption nest
EPEN	REG	ELPENY	Elasticity of substitution in household's energy sub-consumption
EFEN	PROD_COMM*REG	ELFENY	Elasticity of substitution in energy sub-production
EFKE	PROD_COMM*REG	ELFKEN	Elasticity of substitution in capital-energy sub-production
EFNC	PROD_COMM*REG	ELFNCOAL	Elasticity of substitution in non-coal energy sub-production
EFNL	PROD_COMM*REG	ELFNELY	Elasticity of substitution in non-electricity energy sub-production
EFVE	PROD_COMM*REG	ELFVAEN	Elasticity of substitution in value-added- energy sub-production
SUBP	UP_COMM*REG	SUBPAR	CDE substitution parameter
INCP	UP_COMM*REG	INCPAR	CDE expansion parameter
TRBL	33 length 12		Set TR_BLOCK emissions trading blocs
MAPB	33 length 12		Mapping REGTOBLOC from REG to TRBL

[2] Since some of the parameters need to be redefined according to the aggregation of the GTAP-Power version, it is recommended to import the sets over which the parameters are defined from the gdset.har file described in section 1.6.

As for the base data, all parameters from past model versions have included, coherently with the tablo file used for running the model and are reported in Table S8.
There are three additional parameters that have been included while developing the present model version, with the purpose of distributing the effect of calibration of emissions on firms and households in the baseline. Finally, values for the ESUBD and ESUBM parameters have been updated according to CEPII, while ESBT, ESBM and ESUBVA according to previous version of the model.

Table S8 – Region aggregation

Header	Dimension	Coeff	Name
EFEL	PROD_COMM*REG	ELFELY	Elasticity of substitution in electricity energy sub-production
SHAW	PROD_COMM*REG	SHAW	Changes elasticity of substitution in capital-energy renewables
DIF	REG*PROD_COMM	DIFF	Productivity differential (factor productivity growth differential among energy commodities)
DIFF	FIRM_COM*PROD_COMM*REG	DIFF1	Productivity differential for endowment (non-accumulable endowment productivity growth differential)
DF2C	FIRM_COM*PROD_COMM*REG	DIFFc	Productivity for energy commodities in quantity (QF)
Endogenous technical change in clean energy technologies			
SHCT	REG	SHCT	Share of contribution to world carbon fund
SHCF	REG	SHCF	Share of contribution from world carbon fund
SHAR	REG	SHAR	Share of world carbon fund to RD in renewables
SHRD	REG	SHRD	Share of world carbon fund not to RD (e.g., to EE)
SHAF	FIRM_COM*PROD_COMM*REG	SHAF	Elasticity for factor augmenting technical change from world carbon fund
HARH	REG	SHARSH	Parameter to change share of contribution from CWTRFD to EE in building
SHHH	ENY_PCOMM*REG	SHAFH	Parameter to change elasticity of technical change EE in household
CONC	TRAD_COMM*REG	CONC	Consumption quota differential
New parameters to distribute efficiency between firms and households for emission calibration in baseline case			
CVOC	TRAD_COMM*REG	CVOLc	Parameter to calibrate effirm in BAU
COIP	TRAD_COMM*REG	COIP	Parameter to change COIP in carbon intensity of households
COIN	TRAD_COMM*PROD_COMM*REG	COIN	Parameter to change carbon intensity for firms

1.5 Composition of the parextra file

The variables in the gdpextra.har file contains the special parameters regulating the dynamic features of the model. They are all generated in the aggregation of the GDyn model version and the parextra file just needs to be copied in the final folder of the model together with the rest of the har files. The values of these dynamic parameters have been updated according to past model versions and in accordance with the GTAP community suggestions obtained in several years of scientific exchanges. This is strongly recommended whel working on the last tablo version 3.6 of GDyn as closures are changed and the original dynamic parameters bring to optimization errors very likely.

1.6 Composition of the set file

The gdset.har file contains all mapping information required to run the model according to the equations in the tablo file. Besides the sets automatically generated from the GTAP-Power aggregation procedure, the sets in Table S9 need to be added.

Table S9 – Region aggregation

Header	Dimension	Name	Sectors
FC	4 length 12	Set FUEL_COMM	Coil, oil, gas, oil products
ENY	6 length 8	Set ENY_PCOMM Energy commodities households	FUEL_COMM + ely_rw +ely_f
EGY	6 length 8	Set EGY_COMM Energy commodities	FUEL_COMM + ely_rw +ely_f

HF	47 length 8	Set FIRM_COM	Endowments + trad_comm + vaen+ ken + eny+ ely+ nely + ncoal
H10	37 length 8	Set PROD_COMM	TRAD_COMM + CGDS
ELY	2 length 6	Set ELY_COMM Electricity commodities	ely_rw +ely_f
SUP	31 length 8	Set UP_COMM	TRAD_COMM with ENY_PCOMM aggregated in one sector (eny)

2. Model database

The original databases used for building a GDyn version that includes combustion-based CO2 emissions, non-CO2 emissions and renewable sources for the production of electricity are: GTAP10 for all base information of input-output elements of a GTAP-based model in FlexAgg mode; GDyn database for all inputs required to transform the model from a static to a dynamic version; GTAP-E for all information on the linkages between the energy sector and the related combustion-based CO2 emissions associated to the use of fossil fuels for energy purposes; GTAP-Power for information about renewable energy sources in electricity production; GTAP-NCO2 for GHG emissions different from CO2 associated to the use of energy commodities and additional emissions associated to the production process including agriculture and livestock activities. All input files are included in the folder "Model database" while commands for aggregation are in the folder "Aggregation".

2.1 GTAP10

The GTAP Data Base is a consistent representation of the world economy for a pre-determined reference year. Underlying the data base there are several data sources, including among others: national input-output (I-O) tables, trade, macroeconomic, energy and protection data. The underlying input-output tables are heterogeneous in sources, methodology, base years, and sectoral detail, thus for achieving consistency, substantial efforts are made to make the disparate sources comparable. For these reasons, the objective of the GTAP Data Base is not to provide I-O tables, but to facilitate the operation of economic simulation models ensuring users a consistent set of economic facts. Some users interested in particular Social Accounting Matrices (SAMs) use utilities written by researchers in the network to extract them. Users building I-O tables based on this information do that under their own risk, and are assumed to understand the limitations imposed by the process of data base construction. The data in the GTAP Data Base accurately depicts the magnitudes of economic variables, but they are presented in terms of the aggregates that serve CompuTable SGeneral Equilibrium (CGE) modelling. The total number of countries and regions is 141 and the number of sectors is 65, with a substantial increase in the disaggregation of the service sector. For a complete description of all features in GTAP10 refer to Aguiar et al. (2019).
The name of the folder with GTAP10 database shaped in FlexAgg utility is "flexagg10Y14" and the text file for aggregation of the model for DGTRADE is "agg_DGTRADE_dyn14_new".

2.2 GDyn

The GDyn Model builds on the GTAP Data Base augmented with foreign income data and allows dynamic analysis to be undertaken without imposing severe limitations on the model size. The data aggregated by this program is based on the GTAP10 supplemented with additional data on income payments and convergence parameters.
The total number of countries and regions is 141 and the number of sectors is 65, with a substantial increase in the disaggregation of the service sector. For a complete description of all features in GDyn database refer to Ianchovichina and Walmsley (2012).
The name of the folder with GDyn database shaped in FlexAgg utility is "GDYNflexagg10A_Y14" and the text file for aggregation of the model for DGTRADE is "agg_DGTRADE_dyn14_new".
The version on which the tablo is built is GDyn v3.6 that includes corrections to avoid zero divide issues.

2.3 GTAP-E

The GTAP-E Data Base provides carbon dioxide (CO2) emissions data distinguished by fuel and by user for each of the 141 countries/regions and the 65 sectors in the GTAP10 Data Base. GTAP-E data is based on: GTAP 10 and extended energy balances compiled by the International Energy Agency (IEA). A FlexAgg distribution and GTAPAgg2 packages for each of the reference years are available.
For a complete description of all features in GTAP-E database refer to McDougall and Golub (2009).

The name of the folder with GTAP-E database associated to the GTAP10 shaped in FlexAgg utility is "flexagg10E14" and the text file for aggregation of the model for DGTRADE is "agg_DGTRADE_ene_new". The version on which the tablo is built is GDyn v3.6 that includes corrections to avoid zero divide issues plus the energy version corrected with climate damage (Costantini et al., 2018) and endogenous technical change in clean energy technologies (Corradini et al., 2018).

2.4 GTAP-Power

Electricity-detailed extension ('ely' sector in GTAP disaggregated into: transmission and distribution, seven base load technologies (nuclear, coal, gas, hydroelectric, oil, wind and other power technologies), and four peak load technologies (gas, oil, hydroelectric, and solar) for 2014 is detailed in GTAP-Power database. This is an electricity-detailed extension of the GTAP Data Base. These new sectors are combined with the original GTAP sectors resulting in a data base with 76 sectors and 141 regions. The original description of GTAP-Power is provided in Peters (2016).

More recently, Chepeliev (2020) provided an updated version of the methodology. Changes introduced to the GTAP-Power database construction process consist in a different way with which output of the electricity and heat generation sector has been split using electricity generation data together with heat generation volumes to provide a more representative sectoral split and better concordance with GTAP sectoral definitions. Second, data on country and year-specific shares of transformation and distribution costs in electricity tariff for 80 countries are introduced.

The name of the folder with GTAP-Power database associated to the GTAP10 shaped in FlexAgg utility is "flexagg10Power14" and the text file for aggregation of the model for DGTRADE is "agg_DGTRADE_power_new".

2.5 GTAP-NCO2

The GTAP-NCO2_V10a database compatible with the GTAP10 database version is based on the methodology developed by Irfanoglu and van der Mensbrugghe (2016). The database provides emissions for 24 non-CO2 emissions categories with 119 unique emissions subcategories for 244 countries. Emissions by region and economic sector, as well as emissions driver, for three major non-CO2 gases (or groups of gases) are provided, CH4, N2O, and the group of fluorinated gases (F-gases), including CF4, HFCs, and SF6. Emissions come from three emissions drivers: consumption (by consumers and firms), endowment use (land and capital), and output. With respect to the emissions associated to consumption by firms and households the original har file has been transformed in order to be compatible with the structure of CO2 emissions used in GTAP-Power with 76 sectors. With the excel file "GHG_transformation.xlsx" we have first computed the share of emissions associated to imported and domestic inputs according to the shares obtained by imported and domestic CO2 emissions for coal, oil, gas, p_c and gdt sectors. For the chm sector, we have computed the share of VIFM and VDFM on total intermediate use of chm input and the associated the share to the value of emissions. For non-CO2 emissions associated to the "ely" sector in the original database, we have associated the related non-CO2 emissions based on the share of emissions for the ely sector in Power for combustion-based CO2 emissions.

The new "gsdemiss2.har" file contains the sum of combustion-based CO2 emissions and non-CO2 emissions associated to the use of energy inputs plus the chemical sector. Thanks to the changes in flexagg command for GTAP-Power, by computing emissions on the basis of trad_comm instead of ctax_comm it is possible to add the emissions associated to the chm sector without changing the definition of ctax_comm and at the same time obtaining emissions in har file compatible with the GDynE version. When making the model version with aggregation, it is necessary to substitute in the flexagg folder the "gsdemiss.har" file with the new "gsdemiss2.har" file by changing its name into "gsdemiss.har".

3. Aggregation

The aggregation into regions and sectors has been coordinated with the Commission in order to express as much as detailed the regional trade preferential agreements and the most representative sectors in both climate and trade policy for the EU as in Table S10-11-12. The latest information on which the aggregation for GSP preferences is available from the pdf file in the folder Aggregation from official EU source. The aggregation is available in a compact excel format in the file agg_DGTRADE and in txt format for three different versions of flexagg database: agg_DGTRADE_dyn14_new.txt is valid for GTAP10 and the dynamic version; agg_DGTRADE_ene_new is valid for GTAP-E, agg_DGTRADE_power_new is valid for GTAP-Power.

Table S10 – Region aggregation

No	Model code	Description	GTAP code region
1	AFDC	Africa developing countries	cmr, zwe, bwa, nam
2	AFEX	Africa energy exporters	egy, xnf
3	AFNorth	Africa North	mar, tun
4	AS1	Rest of East Asia	aze, geo, isr, jor, xws
5	AS2	Asian countries (rest of)	twn, xea, brn, khm, sgp, tha
6	ASEX	MiddleEast & Asian energy exp.	kaz, bhr, irn, kwt, omn, qat, sau, are
7	Australia	Australia	aus
8	Brazil	Brazil	bra
9	Canada	Canada	can
10	ColPeru	Colombia and Peru	col, per
11	China	China plus Hong Kong	chn, hkg
12	EBA	Everything but arms countries	lao, xse, bgd, npl, xsa, ben, bfa, gin, sen, tgo, xwf, xac, eth, mdg, mwi, moz, rwa, tza, uga, zmb, xec, xsc
13	EFTA	EFTA countries	xna, che, nor, xef
14	EU27	European Union members	aut, bel, bgr, hrv, cyp, cze, dnk, est, fin, fra, deu, grc, hun, irl, ita, lva, l tu, lux, mlt, nld, pol, prt, rou, svk, svn, esp, swe
15	GSP	GSP countries	xoc, vnm, tjk, xsu, civ, gha, nga, xcf, ken, mus
16	GSPplus	GSP plus countries	mng, pak, lka, bol, kgz, arm
17	India	India	ind
18	Indonesia	Indonesia	idn
19	Japan	Japan	jpn
20	Korea	South Korea	kor
21	Malaysia	Malaysia	mys
22	Mexico	Mexico	mex
23	NewZealand	New Zealand	nzl
24	Philippines	Philippines	phl
25	RestAndean	Rest of Andean countries	chl, ecu, ven, xtw
26	RestEurope	Rest of Europe	alb, blr, ukr, xee, xer
27	RestLatAmer	Rest of Latin America	xsm, cri, gtm, hnd, nic, pan, slv, xca, dom, jam, pri, tto, xcb
28	RestMercosur	Rest of Mercosur	arg, pry, ury
29	Russia	Russian Federation	rus
30	SouthAfrica	South Africa	zaf
31	Turkey	Turkey	tur
32	UK	UK	gbr
33	USA	USA	usa

Table S11 – Sector aggregation

No.	Model code	Description	GTAP sector code
1	rice	Rice	pdr, pcr
2	cer	Cereal grains	wht, gro
3	o_prim	Other primary	osd, pfb, ocr, wol
4	veg	VegeTable Sand fruit	v_f
5	liv	Livestock	ctl, oap
6	r_meat	Rumin meat	cmt
7	o_meat	Other meat	omt
8	fish	Fishery	fsh
9	dai	Dairy	rmk, mil
10	bev_t	Beverages and tobacco	b_t
11	food	Processed food	vol, ofd
12	sug	Sugar	c_b, sgr
13	tex	Textile	tex, wap, lea
14	pap	Paper and publishing	ppp
15	wood	Wood	frs, lum
16	chem	Chemical	chm, rpp
17	phar	Pharmaceutics	bph
18	min	Mineral	nmm, oxt
19	mot	Motor vehicles	mvh
20	tr_eq	Transport equipment	otn
21	elect	Electronics and electronic equipment	ele, eeq
22	metal	Metal product	fmp
23	mach	Machinery	ome
24	fer	Ferrous metal	i_s, nfm
25	o_man	Other manufacturing	omf
26	coal	Coal	coa
27	oil	Oil crude	oil
28	gas	Natural gas and LNG	gas, gdt
29	ely_f	Electricity from fossil fuels	NuclearBL, CoalBL, GasBL, OilBL, OilP, GasP
30	ely_rw	Electricity from renewables	HydroBL, HydroP, OtherBL, SolarP, WindBL
31	oil_p	Oil products	p_c
32	r_transp	Road and railway transport	otp
33	a_transp	Air transport	atp
34	w_transp	Water transport	wtp
35	serv1	Service private	TnD, ofi, ins, rsa, obs, whs, cmn, trd, cns, afs
36	serv2	Service public	ros, osg, hht, edu, wtr, dwe

Table S12 – Endowment aggregation

No.	Model code	Description	GTAP endowment code
1	Land	Land	Land
2	SkLab	Skilled labour force	tech_aspros, off_mgr_pros
3	UnSkLab	Unskilled labour force	service_shop
4	Capital	Capital	Capital
5	NatRes	Natural resources	NatlRes

4. Building scenarios and shocks

The first step consists in the computation of shocks for main variables to be used in the baseline and in policy scenarios for all 141 countries/regions available in GTAP10 version database. The second step consists in computing from the scenarios available for all 141 countries/regions the aggregation and the related shocks. Both steps are routinised with STATA MP16 and all datasets and command do files are provided in dedicated folders.

4.1 Scenarios

All commands and files for the first step are included in the folder "Scenarios 141 GTAP regions". The commands file is a do file for STATA MP16 version named "GTAPshock_141regions".

The final database is an excel file including the following variables: GDP at constant 2015USD, total population starting from GTAP10 2014 data, skilled and unskilled labour force as aggregated in Table S3, combustion-based CO2 emissions starting from GTAP-E 2014 data, non-CO2 emissions divided into total non-CO2 GHG emissions derived from GTAP-NCO2V10a data for 2014 in Mton CO2-eq, energy input related non-CO2 emissions that are based on the sum of header NCQF and NCQP associated to intermediate use and households consumption, production of electricity from renewable sources to calibrate the baseline with respect to the JRC low-carbon reference case with the electricity sector.

The source on which scenarios are based are divided between the current period 2014-2020 and projections for the time span 2025-2050.

For the reference period data on population for 2014 is taken by GTAP10 while for updates 2014-2020, data comes from Eurostat and World Development Indicators (WDI) from the World Bank.

For the reference period data on combustion-based CO2 emissions for 2014 is taken by GTAP-E while for updates 2014-2020, data comes from Eurostat, IEA CO2 emissions highlights and WDI.

Data for GDP in 2014-2020 are based on WDI.

Data for non-CO2 emissions in 2014 are based on GTAP-NCO2V10a updated with change in 2014-2020 based on Eurostat and IEA energy balances.

Data for skilled and unskilled labour force in 2014 are calculated as share of total labour force from CEPII information applied to GTAP population data and the period 2014-2020 is calibrated with ILO information on labour force and CEPII statistics.

Data for RES (renewables in electricity production) are taken from GTAP Power 2014 and projected according to growth rate of electricity production with RES in GECO reference + EUREF for EU countries.

Data for electricity production by using fossil fuels (ELEF) are taken from GTAP Power 2014 and projected according to growth rate of electricity production with FF in GECO reference + EUREF for EU countries.

For the projections in the time span 2025-2050 there is a baseline case computed on the basis of the combination of data from GECO reference case (Keramidas et al., 2020), the European Commission reference case for single EU members (European Commission, 2016), CEPII for labour forces.

The policy scenarios are of two types. The first type is the replication of GECO policies with the two cases with 2C° and 1.5C° according to the Paris Agreement. The second type is based on the Shared Socio-Economic Pathways (SSPs) available from IIASA. A folder named "Original files for scenarios" includes all original data sources and pdf files with references.

The final outcome of the first step is an excel file named "GTAP_DATA_2014-2050_141regions" with several sheets in which the information for all 141 countries/regions are available for the years 2014-2015-2020-2025-2030-2035-2040-2045-2050. The variables available the file are: GDP at 2015 USD constant values, Population, Labour force divided into Skilled and Unskilled expressed in thousand people, CO2 emissions, non-CO2 emissions, Renewable sources in the electricity sector (in GWH), Electricity from fossil fuel sources (in GWH). Table S13 provides a summary of the content.

Table S13 – Content of GTAP_DATA_2014-2050_141regions xlsx file

Sheet	Unit	Source
CO2_BAU	Mton CO2	GECO reference + EUREF for EU countries
CO2_15C	Mton CO2	GECO 1.5C policy
CO2_2C	Mton CO2	GECO 2C policy
CO2_SSP1	Mton CO2	SSP1 IIASA database
CO2_SSP2	Mton CO2	SSP2 IIASA database
CO2_SSP3	Mton CO2	SSP3 IIASA database

CO2_SSP4	Mton CO2	SSP4 IIASA database
CO2_SSP5	Mton CO2	SSP5 IIASA database
NOCO2FF_BAU	Mton CO2-eq	GECO reference + EUREF for EU countries
NOCO2FF_15C	Mton CO2-eq	GECO 1.5C policy
NOCO2FF_2C	Mton CO2-eq	GECO 2C policy
NOCO2_BAU	Mton CO2-eq	GECO reference + EUREF for EU countries
NOCO2_15C	Mton CO2-eq	GECO 1.5C policy
NOCO2_2C	Mton CO2-eq	GECO 2C policy
NOCO2_SSP1	Mton CO2-eq	SSP1 IIASA database
NOCO2_SSP2	Mton CO2-eq	SSP2 IIASA database
NOCO2_SSP3	Mton CO2-eq	SSP3 IIASA database
NOCO2_SSP4	Mton CO2-eq	SSP4 IIASA database
NOCO2_SSP5	Mton CO2-eq	SSP5 IIASA database
GDP_BAU	Bn USD 2015	GECO reference + EUREF for EU countries
GDP_SSP1	Bn USD 2015	SSP1 IIASA database
GDP_SSP2	Bn USD 2015	SSP2 IIASA database
GDP_SSP3	Bn USD 2015	SSP3 IIASA database
GDP_SSP4	Bn USD 2015	SSP4 IIASA database
GDP_SSP5	Bn USD 2015	SSP5 IIASA database
POP_BAU	Million	GECO reference + EUREF for EU countries
POP_SSP1	Million	SSP1 IIASA database
POP_SSP2	Million	SSP2 IIASA database
POP_SSP3	Million	SSP3 IIASA database
POP_SSP4	Million	SSP4 IIASA database
POP_SSP5	Million	SSP5 IIASA database
SKLAB_BAU	Thousand	GECO ref + EUREF for EU + CEPII on skilled and unskilled share
SKLAB_SSP1	Thousand	SSP1 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
SKLAB_SSP2	Thousand	SSP2 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
SKLAB_SSP3	Thousand	SSP3 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
SKLAB_SSP4	Thousand	SSP4 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
SKLAB_SSP5	Thousand	SSP5 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
UNSKLAB_BAU	Thousand	GECO reference + EUREF for EU countries + CEPII on skilled and unskilled share
UNSKLAB_SSP1	Thousand	SSP1 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
UNSKLAB_SSP2	Thousand	SSP2 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
UNSKLAB_SSP3	Thousand	SSP3 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
UNSKLAB_SSP4	Thousand	SSP4 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
UNSKLAB_SSP5	Thousand	SSP5 IIASA database on LF (active population 15-64 years) + CEPII on skilled and unskilled share
RES_BAU	GWH	GECO reference + EUREF for EU countries: Electricity produced by RES
RES_15C	GWH	GECO 15C scenario from 2025: Electricity produced by RES
RES_2C	GWH	GECO 2C scenario from 2025: Electricity produced by RES
ELEF_BAU	GWH	GECO reference + EUREF for EU countries: Electricity produced by FF
ELEF_15C	GWH	GECO 15C scenario from 2025: Electricity produced by FF
ELEF_2C	GWH	GECO 2C scenario from 2025: Electricity produced by FF

4.2 Shocks

The procedure for computing the shocks associated to the aggregation with respect to countries and regions is fully replicable for whatever aggregation by simply changing the name of the countries in ISO code forming the regional aggregates in the STATA do file "RM3_AGG-shock.do" available in the folder "Shocks for DGTRADE aggregation".

The commands start with the lines for generating shock values for GTAP aggregate scenario based on GECO BAU, 1.5C, 2C and EUREF for the variables to be shocked in the baseline, namely GDP, Population, Skilled and Unskilled labour force, combustion-based CO2 emissions, emissions including also non-CO2 emissions associated to the use of energy intermediates, the production of electricity by RES and FF.

After computing the shocks for the baseline is then possible to compute the policy shocks in the form of tshock in psh file for 1.5C GECO combustion-based CO2 and for 2C GECO combustion-based CO2. GDP and population are not shocked in policy scenarios for these two emissions pathways because the GECO and EUREF scenarios do not provide changes on GDP and population but only for emissions and energy-related variables.

The commands for building policy shocks (tshock in psh file) for 15C and 2C GECO for all type of emissions and also for RES and ELEF are provided.

After commands referring to GECO-EUREF scenarios, there are commands lines to build scenarios for the baseline and the policy shocks associate to the five SSPs.

5. Calibration procedure

The shocks computed with the STATA do file are saved as dta in the same folder "Shocks for DGTRADE aggregation" and then it is necessary to pass from the dta format to an xlsx file for passing the shocks into the har file containing all shocks to be included in folder of the GTAP model version. The har file with macro shocks named "macro_RM3" is in the general model folder "RM3_dyn". The figures included in the har file are not perfectly coincident with the shocks derived from the STATA computation because they needed some adjustments during the calibration procedure. It is worth mentioning that in both policy scenarios 1.%C° and 2C° the emission pathway is different from GECO-EUREF in terms of reduction targets because in the GTAP model there are emissions absorption reductions due to LULUCF, carbon sinks and carbon capture and storage (CCS) technologies that are typically modelled in technology-based modelling approaches. Accordingly, the final target is calibrated with the relative share of emission reduction as in GECO and EUREF arriving at a 2050 scenario with a a cut of -90% of emissions with respect to BAU while the reduction in gross emissions (including LULUCF and CCS) in GECO is -99%. As a way forward for result interpretation, we are assuming that the remaining 10% not abated directly will be indirectly removed with other policies and/or technologies that are not included in GTAP.

5.1 Baseline

The baseline is calibrated with shocks associated to GDP, population, skilled and unskilled labour force and CO2 emissions that are considered as exogenous and are calibrated with the increase in production and consumption efficiency. This is a requirement for the GTAP modelling exercise because otherwise CO2 emissions have no cap and they proportionally follow the GDP and population trends without any assumptions on technological improvements that will reduce carbon intensity of economic dynamics.

The variable to be shocked as exogenous in the baseline file "basb.cls" is "gco2q" that is swapped with "effirm". The headers in the parameter file that help the system reducing emissions by technological change in emitting sectors are CVOLc for households and DF2C. Depending on the type of emissions included in the model the parameter file changes.

Regarding the calibration of the production of electricity produced by RES and FF into the electricity sub-domain we have swapped the variable "qo" with "aoall" only for the commodities "ely_f" and "ely_rw" thus obtaining at the end of 2050 a share of RES on total electricity for the EU compatible with GECO-EUREF baseline case. The shocks in baseline for ELEF and RES are based on the evolution over time in the reference case of the production of electricity by the two sources expressed in GHW, where the starting point in 2014 if the value of electricity production provided in the GTAP-Power database in GWH. Accordingly, the evolution over time is not fully aligned with the GECO-EUREF value in absolute terms, since the alignment has been made on the basis of growth rates (starting from different base-year values in GTAP-Power wrt to GECO-EUREF). The calibration has been also carried by comparing the composition of the energy mix on the

consumption side (the CVOL header in baseline results) with respect to GECO-EUREF information on total primary consumption volumes expressed in Mtoe.
It is worth mentioning that in order to make clear all steps formulated in the tablo, we have included short comments in the tablo file for single changes made.

5.2 Shocks

The shocks are applied first to CO2 emissions by the variable "gco2q" according to the closure file "eutax.cls" in which there is no emission trading and the EU is the only region implementing a mitigation policy unilaterally. If an emission trading is required for applying reduction targets also to other countries it is necessary to select the har file "gdparet.har" in model details and change the name of the countries in header TRBL and BLOC. In the current version included in the folder the emission trading is modelled at the global level with all regions trading permits with no cap.
The calibration of the policy shocks for each year is made by ensuring that the share of RES on the total electricity in the CVOL variable obtained in the results is compatible with the related GECO scenario, resulting in around a 72% share in the case of 2°C scenario and in around a 82% share in the case of the 1.5C° scenario approximatively. Energy intensity measures are not comparable with those available in GECO-EUREF since the total energy consumption as the sum of CVOL components has been calibrated with the relative values in GECP but the GDP as exogenously given in such scenarios is not compatible with the closure to be adopted in RunDynam where GDP is exogenous in the baseline case and endogenous after the policy shocks. Accordingly, while the numerator of the energy intensive measure CVOL/GDP can be calibrated also in the policy shock, the GDP measure is completely different.

5.3 Simulation details

We have programmed four different policy scenarios associated to two different emissions types and two alternative targets. We list here the name of the ds1 file containing simulation details and the corresponding description in Table S14.

Table S14 – Content of GTAP_DATA_2014-2050_141regions xlsx file

File simulation detail	File tab and sti	File dat and par	Description
EU2CB.ds1	geco_co2ff.tab geco_co2ff.sti	gddat.har gdpar.har	Emission target for the EU obtained with a Pigouvian carbon tax and with RES production according to the GECO 2C° policy scenario applied to combustion-based CO2 emissions
EU15CB.ds1	geco_co2ff.tab geco_co2ff.sti	gddat.har gdpar.har	Emission target for the EU obtained with a Pigouvian carbon tax and with RES production according to the GECO 1.5C° policy scenario applied to combustion-based CO2 emissions
EU2C_NCB.ds1	geco_nco2ff.tab geco_nco2ff.sti	gddat1.har gdpar1.har	Emission target for the EU obtained with a Pigouvian carbon tax and with RES production according to the GECO 2C° policy scenario applied to energy-based CO2 emissions
EU15C_NCB.ds1	geco_nco2ff.tab geco_nco2ff.sti	gddat1.har gdpar1.har	Emission target for the EU obtained with a Pigouvian carbon tax and with RES production according to the GECO 1.5C° policy scenario applied to energy-based CO2 emissions

It is worth mentioning that by 2030 both scenarios respect the European Green Deal target of 50% of electricity produced by RES and CO2 emissions reduced by 30% wrt 1990 levels. From 2035 the two scenarios differ in mitigation targets, where the 1.5C° scenario coincides with a Paris Agreement with a 10% carbon reduction via carbon sinks and LULUCF.

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