The coupled bottom-up and top-down models

Introduction to models coupling

This chapter presents the oracle based optimization technique used to couple the GEMINI-E3 model and the TIAM model. An oracle is a program that gives back information to a master program for a given situation. The optimization technique will reduce the “distance” between the two models through a characteristic function. We present the algorithm that performs the optimization. The oracle “TIAM” accepts as an input the variable:

- D : useful demands

Let the variables obtained from the oracle “TIAM” which are also the inputs of the oracle “GEMINI-E3”:

- P : energy prices
- F : fuel mixes
- Fe : fuel mixes for the electricity sector
- ϑ : technical progress
- ϑ_e : technical progress for the electricity sector
- *VARACT* : level of activity
- *COSTINV* : the cost of investment

Let the variables obtained from the oracle “GEMINI-E3”:

- *gdp* : GDP growth.
- *prod* : monetary value of the production sectors.

Even if they are not detailed, the variables are indexed by periods, regions, sectors or commodities when needed.

The oracle based optimization follows a Gauss-Seidel method which looks after a fixed point for the useful demands through an iterative procedure. First, we call the oracle “TIAM” at given useful demand D_0 that result from the calibration phase of the two models, and we obtain the values listed before. Right after, we call the oracle “GEMINI-E3” at these values, and we get its outputs.

The new useful demands D_1 are generated through demand functions based on the values given by the oracle “GEMINI-E3”. At this point, the iteration is finished and we compute the convergence criteria. If it does not meet a stopping threshold, we run a new iteration. The convergence of the process is helped by the computation of a candidate demands D_{k+1} as

$$D_{k+1} = \frac{2}{(k+2)(k+3)} \sum_{i=0}^{k+1} (i+1) D_i.$$

The convergence criteria is :

$$\zeta k = \frac{\sqrt{\sum_p (D_{p,k} - D_{p,k-1})^2}}{\sqrt{\sum_p D_{p,k}^2}},$$

where p is the period.

Figure and Table present respectively the oracle based optimization technique framework and algorithm. Table contains the updated set of indexes used in the OBOT framework. It lists the regions, the commodities and the economic sectors.

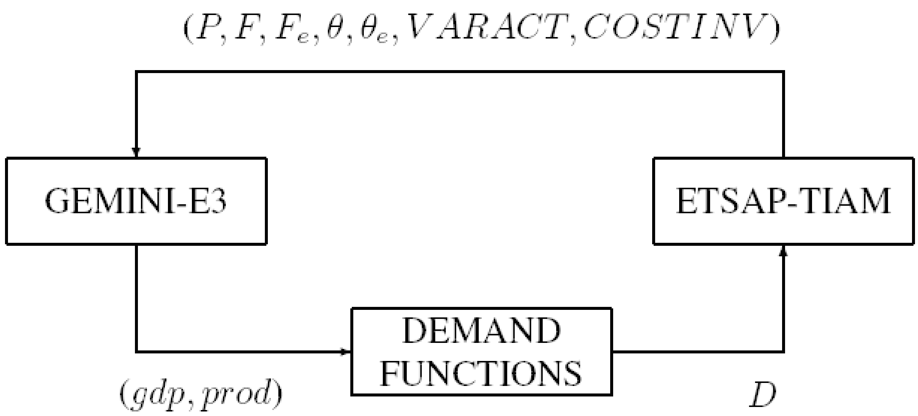

Figure-1: OBOT framework

Table-1: OBOT Algorithm

1.	Set first demands D_0 Set $k = 0$
2.	Call oracle "TIAM" at D_k Get $(P, F, F_e, \theta, \theta_e, VARACT, COSTINV)$ from the oracle
3.	Run GEMINI-E3 at $(P, F, F_e, \theta, \theta_e, VARACT, COSTINV)$ Get $(gdp, prod)$ from the oracle Compute candidate demands vector D_{k+1}
4.	Compute convergence criteria ζ_k
5.	Increment k
6.	**If** $\zeta_k \geq \epsilon$ **then** go to **2.**

Table-2: OBOT regions, commodities and economic sectors

Regions	Commodities	
USA	COAL	Coal
Canada	COIL	Crude Oil
Mexico	CGAS	Gas
Rest of america	CPET	Refined Petroleum Products
Western Europe	CELE	Electricity
Eastern Europe	COTH	Other energy sources
Former USSR	CBIO	Biomass
Africa	CHHD	Hydogen
Australia + New Zealand		
India	**Economy sectors**	
South Corea	AGRI	Agriculture and forestry
China	MINE	Mineral Products
Japan	CHEM	Chemical, rubber, Plastic
Middle-East	META	Metal and Metal products
Rest of Asia	PAPE	Paper products publishing
	TRAN	Transport nec
	SEAT	Sea Transport
	AIRT	Air Transport
	CONS	Consuming & Equipment goods
	SERV	Services
	HOUS	Household

The oracle GEMINI-E3

The oracle GEMINI-E3 consists in the model GEMINI-E3 with some modifications to allow the communication with the master program.

Domestic production in the standard version

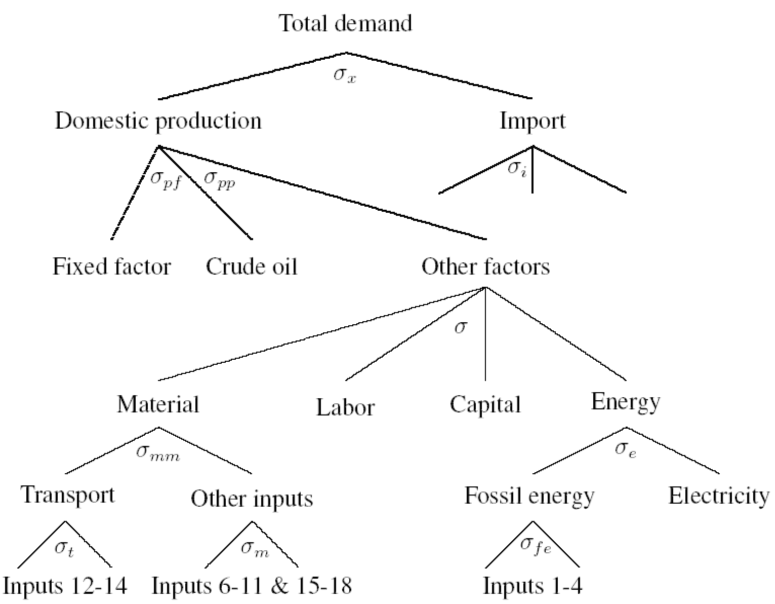

Figure-0: Structure of the Production Sector in GEMINI-E3

Figure-2 represents the structure of the production sector in GEMINI-E3. Production technologies are described through nested CES functions.

Aggregated inputs

X_{ir} is realized with four aggregated inputs : capital (K_{ir}), labor (L_{ir}), energy (E_{ir}), and material (MA_{ir}) Demand for these factors are then equal to:

$$K_{ir} \cdot \theta_{ir}^{k\ t} = X_{ir} \cdot \lambda_{ir} \cdot \alpha_{ir}^{k} \cdot \left[\frac{PD_{ir}}{PK_{ir} \cdot \lambda_{ir} \cdot \theta_{ir}^{k\ -t}}\right]^{\sigma_{ir}}$$

$$L_{ir} \cdot \theta_{ir}^{l\ t} = X_{ir} \cdot \lambda_{ir} \cdot \alpha_{ir}^{l} \cdot \left[\frac{PD_{ir}}{PL_{ir} \cdot \lambda_{ir} \cdot \theta_{ir}^{l\ -t}}\right]^{\sigma_{ir}}$$

$$E_{ir} \cdot \theta_{ir}^{e\ t} = X_{ir} \cdot \lambda_{ir} \cdot \alpha_{ir}^{e} \cdot \left[\frac{PD_{ir}}{PE_{ir} \cdot \lambda_{ir} \cdot \theta_{ir}^{e\ -t}}\right]^{\sigma_{ir}}$$

$$MA_{ir} \cdot \theta_{ir}^{mt} = X_{ir} \cdot \lambda_{ir} \cdot (1 - \alpha_{ir}^{k} - \alpha_{ir}^{l} - \alpha_{ir}^{e}) \cdot \left[\frac{PD_{ir}}{PM_{ir} \cdot \lambda_{ir} \cdot \theta_{ir}^{m-t}}\right]^{\sigma_{ir}}$$

Where θ_{ir}^{k}, θ_{ir}^{l}, θ_{ir}^{e} and θ_{ir}^{m} represent the technical progress incorporated respectively in capital, labor, energy and material.

Energy consumption by sectors

Demand for energy (E_{ir}) is allocated between aggregate fossil fuel consumption (EF_{ir}) and electricity (IC_{5ir}):

$$EF_{ir} = E_{ir} \cdot \lambda_{ir}^{e} \cdot \alpha_{ir}^{ee} \cdot \left[\frac{PE_{ir}}{\lambda_{ir}^{e} \cdot PEF_{ir}}\right]^{\sigma_{ir}^{e}}$$

$$IC_{5ir} = E_{ir} \cdot \lambda_{ir}^{e} \cdot (1 - \alpha_{ir}^{ee}) \cdot \left[\frac{PE_{ir}}{\lambda_{ir}^{e} \cdot PIC_{5ir}}\right]^{\sigma_{ir}^{e}}$$

and demand for each fuel through another CES function:

$$IC_{kir} = EF_{ir} \cdot \lambda_{ir}^{ef} \cdot \alpha_{kir}^{ef} \cdot \left[\frac{PEF_{ir}}{\lambda_{ir}^{ef} \cdot PIC_{kir}}\right]^{\sigma_{ir}^{ef}} \quad \forall k = 1, 2, 3, 4$$

Integration of fuel-mix coming from TIAM in the non fossil fuel sector

Rewriting CES functions

We assume that the elasticities σ_{ir}^{e} and σ_{ir}^{ef} are equal to zero. The CES functions become then Leontieff functions with fixed coefficients, where α_{ir}^{ee} is the share of fossil fuel energy in energy consumption, and α_{kir}^{ef} are the shares of each fossil fuel energy. These shares are determined by the model TIAM.

Introducing the fuel mix

We use the parameters ψ_{kir} which link energy consumption in monetary units (*IC_{kir}*) to energy consumption in ton oil equivalent (*$IOENER_{kir}$*). These parameters are computed on the reference year (2001) and are equal to:

$$\psi_{kir} = \frac{IOENER_{kir}}{IC_{kir}} \;\; \forall k = 1, 2, 3, 4, 5$$

We compute the parameters α_{ir}^{ee} and α_{kir}^{ef} on the basis of the fuel mix *$F_{kir.}$* in petajoule, coming from TIAM:

$$\alpha_{ir}^{ee} = 1 - \frac{\frac{F_{5ir}}{\psi_{5ir}}}{\sum_k \frac{F_{kir}}{\psi_{kir}}}$$

$$\alpha_{kir}^{ef} = \frac{\frac{F_{kir}}{\psi_{kir}}}{\sum_l \frac{F_{lir}}{\psi_{lir}}} \;\; \forall k = 1, 2, 3, 4,$$

Introducing hydrogen

GEMINI-E3 does not take into account hydrogen energy in contrary to TIAM. We do not add a new sector describing explicitly the hydrogen production but we take into account the energy inputs used to produce hydrogen and we allocate these energy inputs directly to the sector using hydrogen. Consequently we modify the variable *$F_{kir.}$* of each sector on the basis of hydrogen consumption:

$$F_{kir} = F_{kir} + \frac{Fuel_{kr}^{hydrogen}}{\sum_k Fuel_{kr}^{hydrogen}} \forall k = coal..cbio$$

We also take into account the fact that a part of this hydrogen is produced with fossil fuel associated with capture and sequestration technology, therefore we modify the coefficient emission parameters of the GEMINI-E3 model. We compute the "corrected share" of energy consumption which takes into account the penetration of renewable and nuclear on the basis of the evolution of $\alpha_{ir}^{\text{coth}}$

$$\alpha_{ir}^{e,t} = \alpha_{ir}^{e,2001} \cdot \left(1 + \frac{-\alpha_{ir}^{coth,t} + \alpha_{ir}^{coth,2005}}{1 - \alpha_{ir}^{coth,2005}}\right)$$

Part of the variation of α^e is due to biomass and is equal to:

$$\alpha_{ir}^{bio} = \frac{F_{cbio,ir}}{F_{cbio,ir} + F_{coth,ir}} \cdot \alpha^e \cdot \left[\frac{\alpha_{ir}^{e,t}}{\alpha_{ir}^{e,t-1}} - 1\right]$$

We suppose that the other part of variation coming from the energy consumption of renewable and nuclear is mainly done through capital consumption and we adjust the share of capital consumption :

$$\Delta\alpha_{ir}^{k,t} = \frac{F_{coth,ir}}{F_{cbio,ir} + F_{coth,ir}} \cdot \alpha^e \cdot \left[\frac{\alpha_{ir}^{e,t}}{\alpha_{ir}^{e,t-1}} - 1\right]$$

Introducing other energy sources

GEMINI-E3 describes explicitly only consumption of fossil fuel energy and electricity, other energy sources like renewable and nuclear are represented by consumption of capital and other materials. It is necessary to correct the coefficients of the nested CES in order to take into account the penetration of renewable and nuclear in the energy consumption especially when we implement greenhouse gases mitigation. We decide to modify the coefficient α_{ir}^{e} on the basis of the penetration of renewable and nuclear. We compute the share of renewable energy and nuclear in the energy consumption on the basis of TIAM output:

$$\alpha_{ir}^{coth} = \frac{F_{coth,ir} + F_{cbio,ir}}{\sum_{k=1,..,5} F_{kir} + F_{coth,ir} + F_{cbio,ir}}$$

We compute the "corrected share" of energy consumption which take into account the penetration of renewable and nuclear on the basis of the evolution of $\alpha_{ir}^{\mathrm{coth}}$:

$$\alpha_{ir}^{e,t} = \alpha_{ir}^{e,2001} \cdot \left(1 + \frac{-\alpha_{ir}^{coth,t} + \alpha_{ir}^{coth,2005}}{1 - \alpha_{ir}^{coth,2005}}\right)$$

one part of the variation of _e is due to biomass and is equal to:

$$\alpha_{ir}^{bio} = \frac{F_{cbio,ir}}{F_{cbio,ir} + F_{coth,ir}} \cdot \alpha^e \cdot \left[\frac{\alpha_{ir}^{e,t}}{\alpha_{ir}^{e,t-1}} - 1\right]$$

we suppose that the other part of variation coming from the energy consumption f renewable and nuclear is mainly done through capital consumption and e adjust the share of capital consumption :

$$\Delta\alpha_{ir}^{k,t} = \frac{F_{coth,ir}}{F_{cbio,ir} + F_{coth,ir}} \cdot \alpha^{e} \cdot \left[\frac{\alpha_{ir}^{e,t}}{\alpha_{ir}^{e,t-1}} - 1\right]$$

Introducing biomass

In the standard version of GEMINI-E3 we do not take into account explicitly biomass, in contrary to TIAM. We introduce in the coupled model the energy consumption coming from biomass. We suppose that all biomass energy is produced by the sector 6 in GEMINI-E3 which corresponds to the agriculture sector. The biomass consumption is computed on the basis of the coefficient α_{bio} and is equal to:

$$IC_{bio,r} = X_{ir} \cdot \lambda_{ir} \cdot \alpha_{ir}^{bio} \cdot \left[\frac{PD_{ir}}{PIC_{6r} \cdot \lambda_{ir}}\right]^{\sigma_{ir}}$$

Introducing technical progress on energy

The next step is to modify the technical progress associated to the energy goods, which determine the amount of energy needed for the production activity. This is done by computing the parameter θ_{ir}^{e} on the basis of TIAM runs. In TIAM, the end-use service demands (the useful demands) are built from socio-economic hypotheses. Thus, each useful demand depends on a specific river such as population, number of households, GDP, GDP per capita, etc. (see Table 3). The useful demands *DM* are computed as follows:

$$DM(d,r,t) = DR(d,r,t)^{elas(d,r,t)}$$

where *DM(d; r; t)* is the useful demands for the energy service *d*, for the region *r* and the period *t*, *DR* is the economic driver and *elas* is the elasticity of the demand to the driver. The elasticities of the service demands to their drivers can be understood as decoupling factor between the demands and the drivers, which accounts for phenomena such as saturation and changes in consumption patterns (for example, the private car demand is related to income, but with some saturation effect when income reaches a certain level), industrial structural changes, etc. and are in part empirically based. Therefore, the final energy consumed in TIAM to satisfy the useful demands results from several factors:

- The trajectories of the future end-use service demands themselves, driven by the macro-economic drivers and the elasticities of the service demands to these drivers;
- The energy and technology choices made by the model when optimizing the energy system.

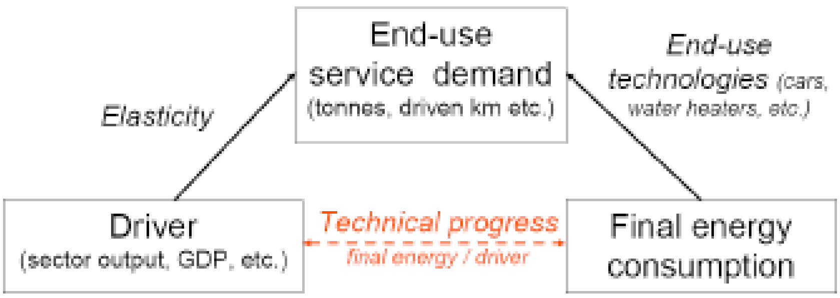

Figure-3: General approach to compute the technical progress in TIAM (to be applied to each end-use service demand)

In order to properly include the energy changes induced by the elasticities of the end-use demands to their drivers, we define the technical progress on energy computed with TIAM as the ratio of the final energy consumption to satisfy the demand d_i to the driver of the demand d_i to its driver (see Figure-3).

The technical progress computed for all the useful demands of TIAM that depend on GDP or sector outputs can be directly used in GEMINI-E3 since GDP and sector outputs of TIAM and GEMINI-E3 are the same. This applies to: all the industry sub-sectors, agriculture, the commercial sector as well as some transport demands (see Table-3).

Integration of investment expenses

In TIAM the decrease of carbon emissions comes non only from carbon free energy (like solar, biomass, nuclear) but also from new technologies allowing to emit less carbon emission with the same energy service. This is case for example of carbon capture and sequestration in the electricity sector where the main part of the cost comes from the use of more capitalistic technology (i.e more costly investment). For taking into account this mechanism we modify the technical progress incorporated in capital represented by the parameter θ_{ir}^{k} in GEMINIE3. We use the variation of capital intensity between the reference simulation and the scenario in TIAM and modify the technical progress of capital.

$$\theta_{ir}^{k} = (1-\beta_{ir}) \cdot \overline{\theta_{ir}^{k}} + \beta_{ir} \cdot \frac{\dfrac{COSTINV_{ir}^{scen}}{VARACT_{ir}^{scen}}}{\dfrac{COSTINV_{ir}^{ref}}{VARACT_{ir}^{ref}}}$$

where $\overline{\theta}_{ir}^{k}$ is the technical progress incorporated in capital in the standard version of GEMINI-E3 (i.e. without coupling), $COSTINV_{ir}^{ref}$ is the investment cost in TIAM, $VARSCT_{ir}^{ref}$ is the level of activity in TIAM and β_{ir}^{k} is the share of capital linked to energy consumption. *ref* refers to the reference baseline and *scen* to the scenario. Note that we modify the parameter θ_{ir}^{k} only when we perform climate change constraint scenarios.

Table-1: The energy service demands of TIAM and their drivers

DEMAND	DRIVER	
Transportation	All regions	
Automobile travel	GDP/capita	
Bus travel	POP	
2 & 3 wheelers	POP	
Rail passenger travel	POP	
Domestic aviation travel	GDP	
International Aviation travel	GDP	
Trucks	GDP	
Fret rail	GDP	
Domestic Navigation	GDP	
Bunkers	GDP	
Residential	All regions after 2050 + Non-OECD before 2050	OECD regions before 2050
Space heating	HOU	HOU
Space Cooling	HOU	GDPP
Water Heating	POP	POP
Lighting	GDPP	GDPP
Cooking	POP	POP
Refrigeration and Freezing	HOU	GDPP
Washers	HOU	GDPP
Dryers	HOU	GDPP
Dish washers	HOU	GDPP
Other appliances	GDPP	GDPP
Other	HOU	GDPP
Commercial	All regions	
Space heating	SPROD-Services	
Space Cooling	SPROD-Services	
Water Heating	SPROD-Services	
Lighting	SPROD-Services	
Cooking	SPROD-Services	
Refrigeration and Freezing	SPROD-Services	
Other electric demands	SPROD-Services	
Other	SPROD-Services	
Agriculture	SPROD-Agriculture	
Industry	All regions	
Iron and steel	SPROD-I	
Non ferrous metals	SPROD-I	
Chemicals	SPROD-I	
Pulp and paper	SPROD-O	
Non metal minerals	SPROD-O	
Other industries	SPROD-O	

HOU: number of households GDPP: GDP per capita
POP: population SPROD-X: production of sector
GDP: gross domestic product

Rewriting Household consumption

In the standard version of GEMINI-E3, the household consumption is represented by a Linear Expenditure System, this formulation is not enough flexible and it was decided to replace this formulation by a nested CES function. The
Figure represents the nested CES architecture retained. Total consumption is divided into three aggregated consumptions: housing, transportation and other consumption. Housing is again splited between energy and equipment. This energy nest excludes purchases of transport fuel included in the transportation nest. Equipment represents household consumption for housing minus energy consumption. Concerning transportation consumption we distinguish own-supplied transport and purchased transport (water travel, air travel and land travel). Own-supplied transport are provided using energy and equipment (mainly purchases of

vehicles). Finally, the others consumptions are described through a CES function between the 10 non energy goods (agriculture, forestry, mineral, ...).

Integration of fuel-mix coming from TIAM in the household consumption

We apply the same procedure described for the production sector to the energy consumption of households.

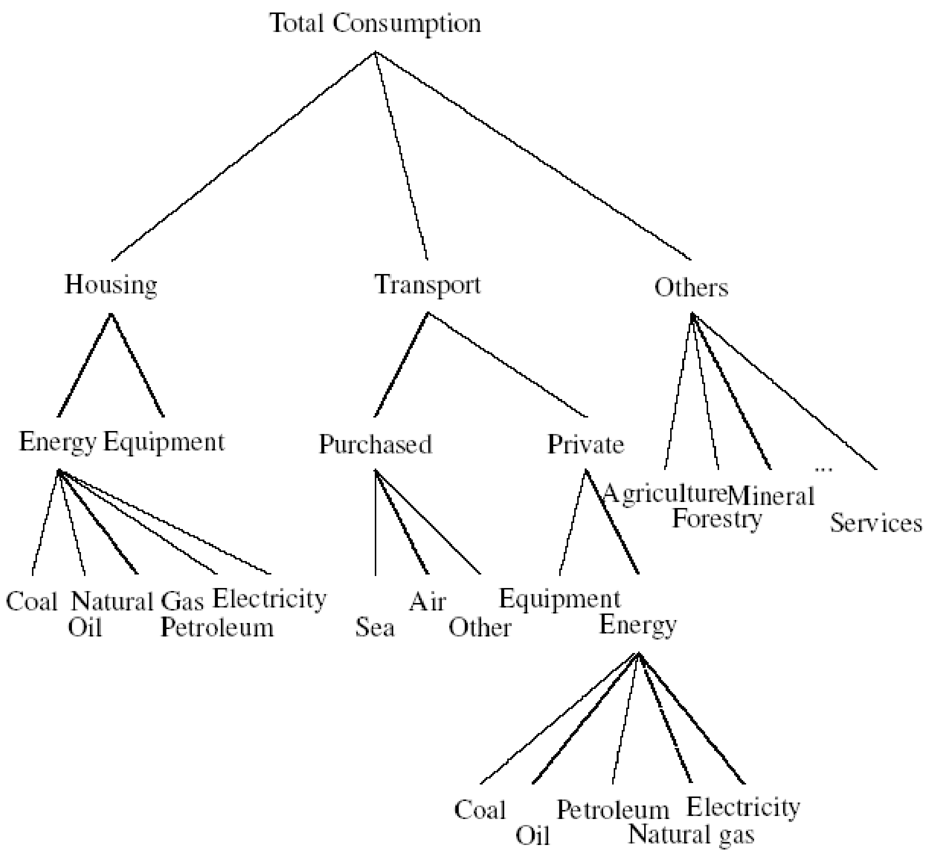

Figure-4: Structure of the Household Sector in GEMINI-E3

The oracle TIAM

The oracle TIAM consists in the model ETSAP-TIAM with some modifications to allow the communication with the master program.

Extracting sectoral technical progress and fuel mixes

TIAM outputs are very disaggregated, so the extraction essentially consists in summing up values following the connections established between the two models and the energy classifications of The International Energy Agency at http://www.iea.org/Textbase/stats/defs/defs.htm. The consumed commodities are aggregated into coupling commodities as shown in Table-2. Table-3 shows the processes which produce a commodity. Table-4 shows the processes which consume commodities by sector.

Table-2: Consumed commodities aggregation

Description	Coupling	TIAM nomenclature
Coal	COAL	*COA, INDCOG, INDCOK, COABCO, COAHCO, COAOVC, COAGSC
Crude oil	COIL	—
Gas	CGAS	*NGA, INDNGL, ELCGOI
Petroleum products	CPET	*DST,*GSL,*HFO,*KER,*LPG,*OIL ELCCGO, ELCGOI, INDOIL, INDETH, INDNAP, INDPTC, TRAAVG, TRAETH, TRAJTK, TRAMET OILLUB, OILASP, OILNSP, OILPTC, OILWAX, OILWSP
Electricity	CELE	*ELC
Uranium	CURA	ELCNUC, INDNUC
Hydrogen	CHHD	SYNHYD, TRAHH2
Biomass	CBIO	*BIO, TRAETH
Hydraulic	CHYD	ELCHYD, INDHYD
Others	COTH	*GEO,*HET, *SOL, ELCBGS, ELCBMU, ELCCRP, ELCSLD, ELCTDL, ELCWIN, INDBFG, INDOXY, INDTDL, INDWIN

* stands for the prefixes "AGR", "COM", "ELC", "IND", "RES" and "TRA".

Table-3: Processes aggregation by output

Coupling	TIAM nomenclature
AGRI	AGR*
MINE	INF (Non-Ferrous), INM (Non-Metals),
CHEM	ICH000 (Chemical)
META	IIS000 (Iron & Steel)
PAPE	ILP (Pulp & Paper)
TRAN	TRB*, TRC*, TRE*, TRH*, TRL*, TRM*, TTF*, TTP*
SEAT	TWD*, TWI*
AIRT	TAD*, TAI*
CONS	IOI000 (Other Industries), ONO000
SERV	CC*,CH*,CLA*,COE*,COT*,CRF*,
HOUS	RC*, RDW, REA, RH*, RK*, RL*, ROT, RRF,
CARS	TRT, TRW
ELEC	E*, CHP*

Table-4: Processes aggregation by input

Coupling	TIAM nomenclature
AGRI	AGR*
MINE	IENF*, IMNF*, IONF*, IPNF*, ISNF* (Non-Ferrous), IENM*, IMNM*, IONM*, IPNM*, ISNM* (Non-Metals)
CHEM	IECH*, IMCH*, IOCH*, IPCH*, ISCH*, NEO000 (Chemical)
META	IEIS*, IFIS*, IMIS*, IOIS*, IPIS*, ISIS* (Iron & Steel)
PAPE	IELP*, IMLP*, IOLP*, IPLP*, ISLP* (Pulp & Paper)
TRAN	TRB*, TRC*, TRE*, TRH*, TRL*, TRM*, TTF*, TTP*, NEU000
SEAT	TWD*, TWI*
AIRT	TAD*, TAI*
CONS	IEOI*, IMOI*, IOOI*, IPOI*, ISOI* (Other Industries), ONO000
SERV	CC*,CH*,CLA*,COE*,COT*,CRF*
HOUS	RC*, RDW, REA, RH*, RK*, RL*, ROT, RRF
CARS	TRT, TRW
ELEC	E*, CHP*

Output variables

Let be the following extracted data:

- *conso_com(r; s; c; p):* consumption of the commodity *c* of the sector *s* for region *r* in period *p*.
- *conso(r; s; p)*: total consumption of the sector *s* for region *r* in period *p*.
- *prod(r; s; p)*: total production of the sector *s* for region *r* in period *p*.
- *eff(r; s; p)*: efficiency of the sector *s* at period *p* for region *r*.

The fuel mix share is obtained by sector in value (PJ) with this expression:

$$F(r,s,c,p) = \frac{\mathbf{conso\_com}(r,s,c,p)}{\mathbf{conso}(r,s,p)},$$

Economy sector efficiency is obtained by :

$$\mathbf{eff}(r,s,p) = \frac{\mathbf{prod}(r,s,p)}{\mathbf{conso}(r,s,p)}.$$

Technical progress is the ratio of the sector efficiency at period p over the base year sector efficiency (2005).

$$\theta(r,s,p) = \frac{\mathbf{eff}(r,s,p)}{\mathbf{eff}(r,s,2005)}.$$

Demands generation at each iteration

The computation of the energy service demands of TIAM is described in another document. The macro-economic drivers used in TIAM are based on the GEMINIE3 results. In the implementation of OBOT, the demands elasticities of TIAM are always set to 0. GEMINI-E3 sectors and TIAM sectors are not exactly the same, the equivalences used to compute the TIAM useful demands from the coupling sectorial outputs are shown in Table-5.

Table-5: Relation between useful demands and economy drivers

Useful demands	Coupling sector/Driver
NEO, NEU, ONO	GDP
TRL, TTP, TRC, TRH, TRM, TRB, TTF	TRAN
TRW,TRT, TRE RL1, RL2, RL3, RL4, RCW, ROT, RRF	HOUS
AGR	AGRI
TAI,TAD	AIRT
ICH	CHEM
IIS	META
INF, INM	MINE
ILP	PAPE
TWI, TWD	SEAT
IOI	CONS
CC1,CC2,CC3,CC4 CCK, CH1, CH2, CH3, CH4 CHW, CLA, COE, COT, CRF	SERV

GEMINI-E3 computes the GDP and the sectorial economy outputs at each iteration k of the coupling. The macro-economic parameters obtained with GEMINI-E3 are used to compute again the energy service demands of TIAM, according to the correspondence provided by Table 7. In other words: when TIAM is run with climate constraint in a stand-alone manner, the energy service demands depend on their own price; when TIAM and GEMINI-E3 are run in a coupled manner, the energy service demands depend on the macroeconomic drivers computed by GEMINI-E3. Some energy service demands are not included in Table 7. (eg. RL*). In TIAM, these demands depend on the population growth and not on macro-economic parameters, and they have been considered as constant in the coupled methodology. The results will show how the coupled methodology can be compared (or not) with the elastic TIAM. At each iteration k of the coupling, new useful demands are computed as follows: