Coupling TIAM and GEMINI-E3

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Aims of coupling

Enhance the description of world energy system by combining the strengths of the two models :

1. Detailed technological representation of the energy system of **ETSAP-TIAM** allowing the endogenous computation of (amongst others) energy flows and prices
2. General equilibrium effects of **GEMINI-E3** allowing the explicit representation of the main economy factors (labor, consumption, capital, etc.) and their interactions with the energy service demands

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GEMINI-E3

- General Equilibrium Model
- 24 countries/regions – 14 sectors
- CO_2 and other GHG
- Reference year 2001 – based on GTAP database
- Time period 2001- 2050
- *Website: http://gemini-e3.ordecsys2.com/*

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ETSAP-TIAM

- Technology rich, dynamic inter-temporal partial equilibrium
- Based on maximum total surplus (LP) with own price elastic service demands
- Driven by end-use demands.
  Eg. tons aluminium, km driven by cars, etc.
- 15 regions linked by 9 energy commodity trades + emission trades
- CO2 and other GHGs
- Reference year 2005 – IEA Energy Statistics
- Time horizon 2005-2100 (2005-2050 is used here)
- *Website: www.etsap.org/documentation*

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Connecting the models: regions, sectors and commodities

- Choose a common regional disaggregation

TIAM

Name	Countries
USA	USA
CAN	Canada
MEX	Mexico
CSA	Rest of america
WEU	Western Europe
EEU	Eastern Europe
FSU	Former USSR
AFR	Africa
AUS	Australia + New Zealand
IND	India
SKO	South Corea
CHI	China
JPN	Japan
MEA	Middle-East
ODA	Rest of Asia

GEMINI-E3

Name	Countries
EUR	European Union (25)
XEU	Other European Countries
FSU	Former Soviet Union (except Baltic States)
USA	United States of America
CAN	Canada
AUZ	Australia and New Zealand
JAP	Japan
MEX	Mexico
CHI	China
IND	India
ASI	Rest of Asia
LAT	Central and Latin America
MID	Middle East
AFR	Africa

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Connecting the models: regions, sectors and commodities

- Create connections between the two activity classifications
  (not easy because the two models are based on two different data sets)

Table 7.2: Processes aggregation by output

Coupling	TIAM nomenclature
AGRI	AGR000
MINE	INF000 (Non-Ferrous), INM000 (Non-Metals),
CHEM	ICH000 (Chemical)
META	IIS000 (Iron & Steel)
PAPE	ILP (Pulp & Paper)
TRAN	TRB*, TRC*, TRE*, TRH*, TRL*, TRM*, TTF000, TTP000
SEAT	TWD000, TWI000
AIRT	TAD000, TAI000
CONS	IOI000 (Other Industries), ONO000
SERV	CC*,CH*,CLA*,COE*,COT*,CRF*
HOUS	RC*, RDW, REA, RH*, RK*, RL*, ROT, RRF, TRT, TRW
ELEC	E*, CHP*

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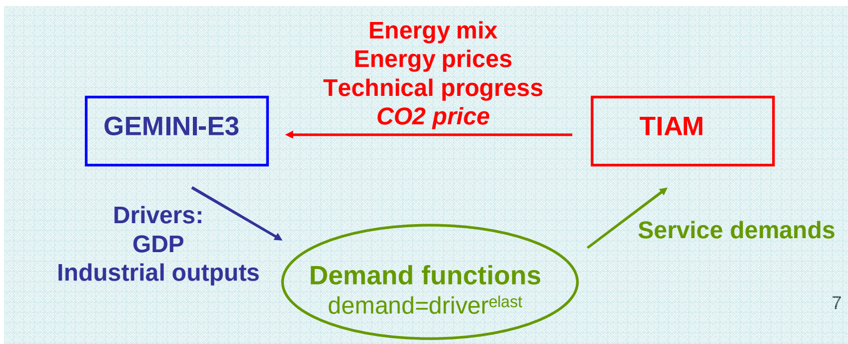
Coupling Framework

- ***Harmonisation*** of the two models (POP, GDP, energy prices, some energy constraints) – applied for the base case
- ***Coupling*** of the two models – applied to analyze the case with an environmental constraint

C O U P L I N G



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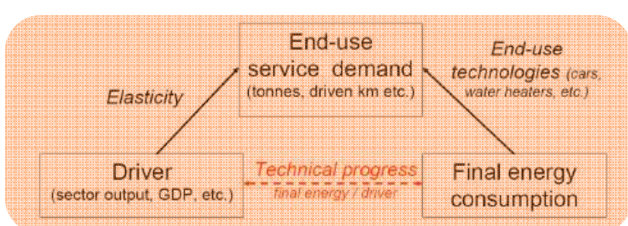
Technical progress

The final energy consumed in TIAM to satisfy the service 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 demands to these drivers;

– The energy and technology choices made by the model when optimizing the energy system.



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Coupling Algorithm

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1. Set first demands D_0
   Set $k = 0$
2. Run TIAM with demands D_k
   Get fuel mixes F_k, energy prices P_k and technical progress θ_k
3. Run GEMINI-E3 with F_k, P_k and θ_k
   Get GDP and industrial outputs
   Compute candidate demands vector D_{k+1}
4. Compute criteria $\gamma = \|D_{k+1} - D_k\|$
5. Increment k
6. **If** $\gamma \geq \epsilon$ **then** go to 2.

Starting point: harmonized models (GDP, POP, energy prices)

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Case study

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- Limit radiative forcing to 3.0 W/m^2 in 2100
- World full cooperation:
  - All sectors
  - All countries (no *cap&trade* system)
  - $\Rightarrow$ Only one carbon price for each time period, equivalent to a tax applied to all sectors and all countries

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Convergence

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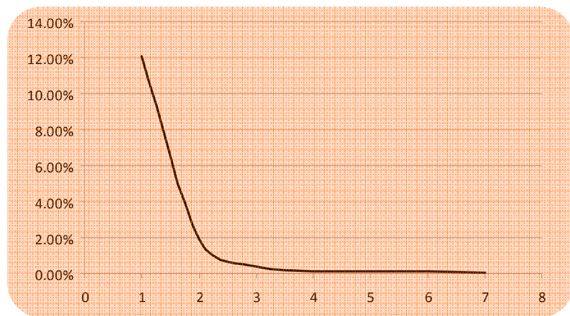
Convergence criteria



Achieved at iteration 6

- ➔ We now compare iteration 6 (TIAM - GEMINI-E3 coupled) versus iteration 0 (TIAM alone *without elastic demands*)
- ➔ To understand the consequences and the added value of the coupling

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CO_2 price and oil price

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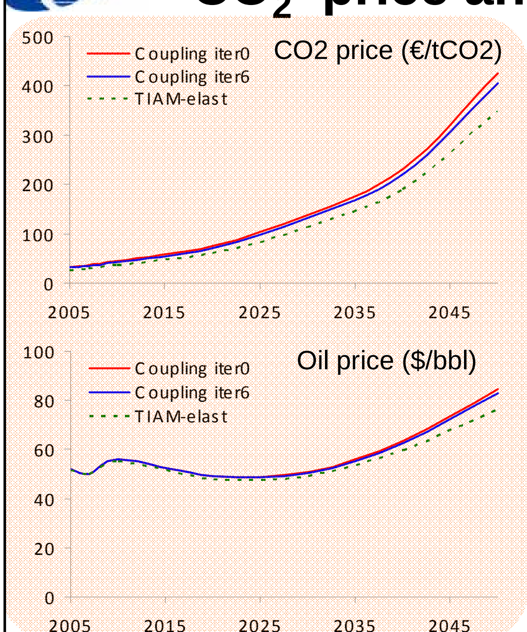

- ➔ The coupling helps reducing the CO2 and oil prices thanks to the reduction of service demands (there is no reduction of demands in iter0)
- ➔ This is of course an expected result, also observed when TIAM is used alone with elastic end-use demands

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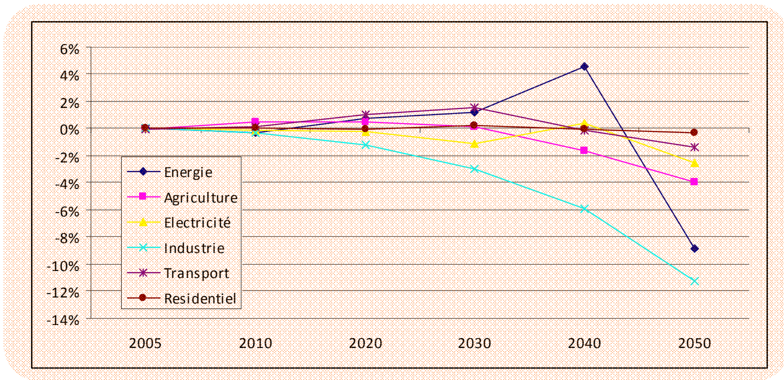
Total energy consumption

Variations between iter6 and iter0



- ➔ Higher decrease in the industry sector, explained by the decrease of the service demands – next slide
- ➔ (not shown) Alcohols and renewables penetrate less in the coupled scenario, given the contribution of the reduction of the service demands to the climate mitigation

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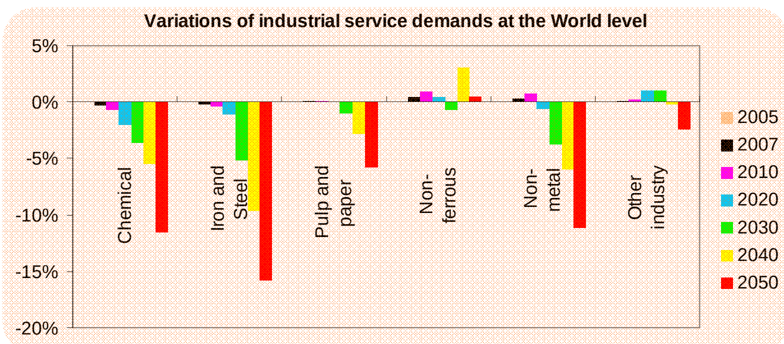
Industrial sectors



- ➔ Energy-intensive industrial sectors reduce their activity under the carbon constraint: transformation of the economy towards less energy intensive sectors

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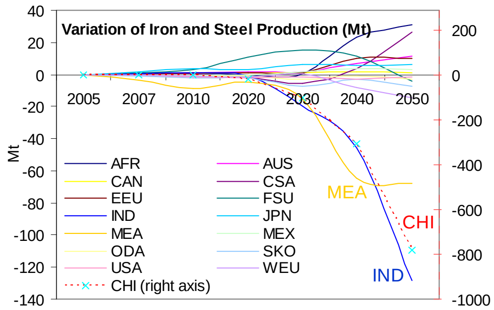
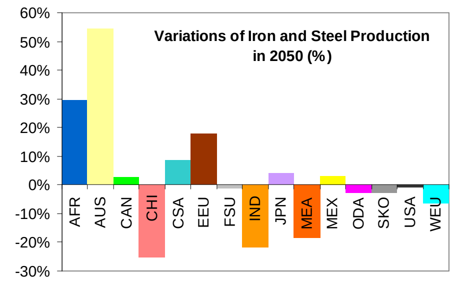
Example: the Iron&Steel sector





- The variations of the Iron&Steel production are not the same in all regions: strong decreases in China, India, Middle-East, while the production slightly increases in some other regions
- Why such differences?
Let’s look at the imports/exports/domestic demands, and the energy balance of the Iron&Steel sub-sector

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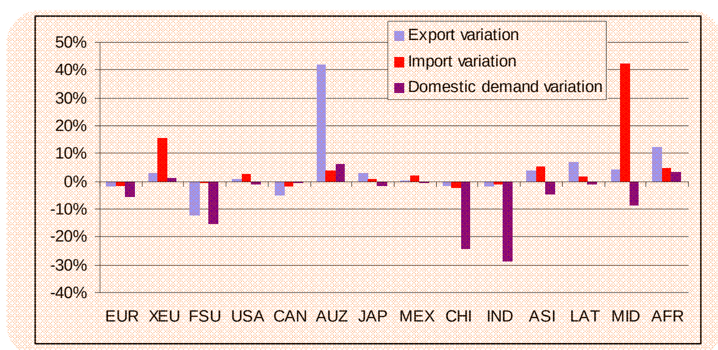
Domestic consumption and international trade of Iron&Steel



Domestic production (GEMINI-E3) =

Domestic consumption
+ Exports
- Imports

Decision factors

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Technology and energy

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- **World**
  - Substitution of fossil fuels by biomass and heat, the latter being itself mainly produced from biomass
- **Middle-East**
  - Limited availability of biomass
    ⇒ small fossil/biomass substitution potential
  - Electricity up to 90% free of CO2 but shared with several other demands
    ⇒ "limited" potential for fossil/elect. substitution in Iron&Steel subsector
  - No potential for the sequestration by forestry

Hence the only possibility to either increase the imports of Iron&Steel from countries able to produce it in a low emitting mode, or decrease the production (both domestic production and exports) in order to reduce the total emissions. The latter appears more cost-efficient.

Technology and energy

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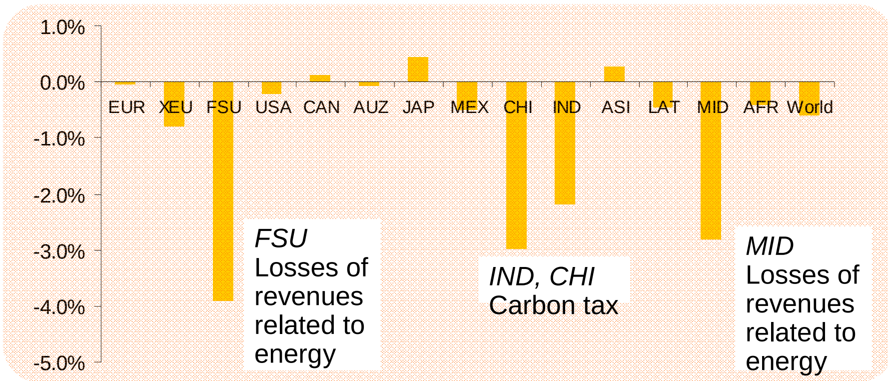
- In **China and India**, the decrease of the production is motivated by different reasons:
  - High contribution of these countries to the global emissions
    ⇒ any (or almost any) solution helping for the reduction of their emissions is considered: electricity with capture, biomass, mix of natural gas and hydrogen produced with capture, and also, decrease of the domestic demands
- **Africa and Australia** (increase of the exports)
  - Capacity of these regions to use biomass (directly, or indirectly via heat) in the production of Iron&Steel

➔ This illustrates the complementary information provided by the two models used in a coupled manner

Some macro-economic effects: GDP



Comparison with TIAM-Elastic

- The use of service demands elastic to their own price (in TIAM) captures some interactions between the energy system and the economy
- Several of the effects observed in the Coupled Framework are also observed in TIAM-Elastic. Eg. smaller carbon price
- However, no so strong reductions of industry production
- Reason: aviation
  - Strong decrease of service demand observed in TIAM-Elastic, as well as in GEMINI-E3, but not in the Coupled Framework
  - Aviation depends on GDP in TIAM and GDP does not vary so much according to GEMINI-E3
  - ⇒ Aviation does not vary a lot in TIAM under the Coupled Framework
  - ⇒ Important impact on the emissions and the need for other mitigation options, such as the reduction of industry production

At this stage, difficult to go deeper in the comparison

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Conclusion

- Fine technology and energy analysis (mix, prices, technical progress) provided by TIAM
- Fine macro-economic analysis (GDP, sectoral outputs) provided by GEMINI-E3
- Difficult to compare with TIAM-Elastic so far (need for adjustment of some drivers such as the ones used to compute aviation service demands)
- However, GEMINI-E3 allows a finer representation of the changes of the demands, as well as the possible delocalisations of the production
- Crucial (and not easy): Need to connect the two models
- To improve:
  - Some connections. Eg. commodity “other”, hydrogen
  - Some elasticities of the service demands of TIAM. Eg. Aviation
  - Technical progress for some sectors

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Coupling BU and TD models: existing experiences

1. ***Calibrating TD model with BU model***
   - Electricity sector: Pizer et al. (2003)
   - Transport sector: Schäfer and Jacoby (2005, 2006)
2. ***Integrating BU specifications in a TD model***
   - MARKAL-MACRO: Manne and Wene (1992)
   - MERGE: Manne et al. (1995)
   - Electricity sector: Wing (2006)
3. ***Coupling TD & BU models***
   - US models: Hoffman (1977)
   - Housing sector: Drouet et al. (2005)
   - Decomposition: Böhringer and Rutherford (2006)

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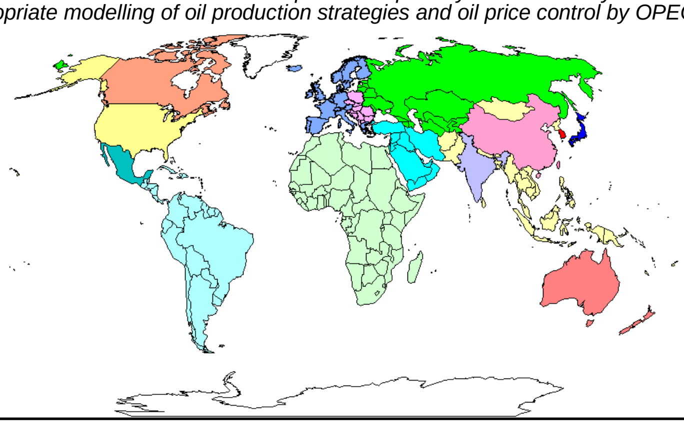
Regions of TIAM

Africa*
Australia-New Zealand
Canada
Central and South America*
China

Eastern Europe
Former Soviet Union
India
Japan
Mexico

Middle-East*
Other Developing Asia*
South Korea
United States
Western Europe

* *OPEC and Non-OPEC countries are separated in primary and secondary sectors*
⇒ appropriate modelling of oil production strategies and oil price control by OPEC countries



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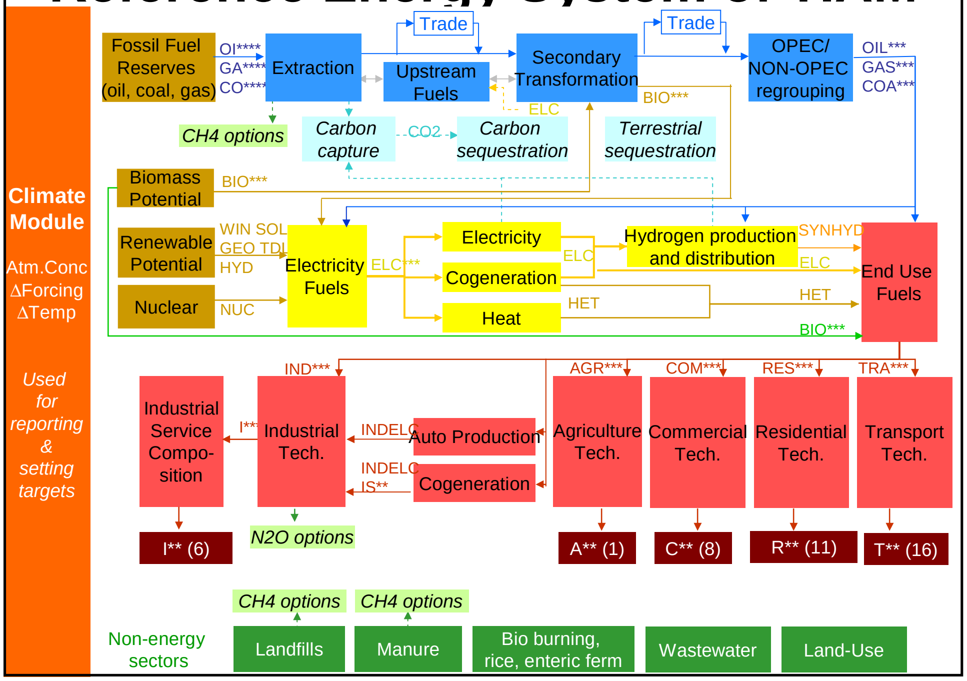
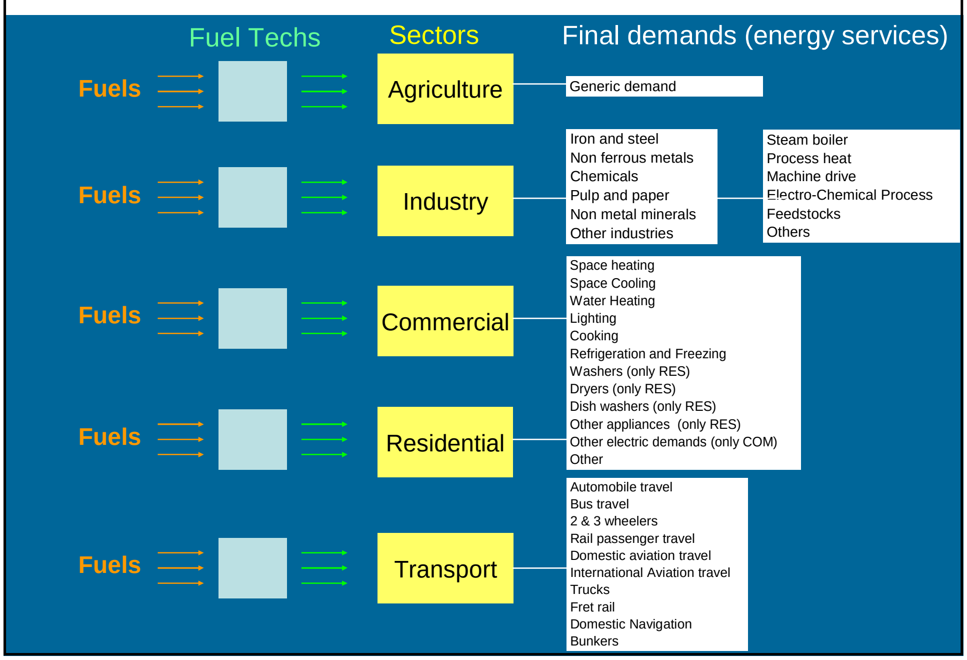
Reference Energy System of TIAM



Service demands of TIAM



Connections

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Table 5.3: GEMINI-E3 sectors

#	Designation
1	Coal
2	Oil
3	Gas
4	Petroleum Products
5	Electricity
6	Agriculture
7	Forestry
8	Mineral Products
9	Chemical, rubber, Plastic
10	Metal and Metal products
11	Paper products publishing
12	Transport nec
13	Sea Transport
14	Air Transport
15	Consuming goods
16	Equipment goods
17	Services
18	Dwellings
19	Household

Table 5.5: Connections between TIAM useful demands and GEMINI-E3 sectors

TIAM useful demands	Code(s)	Unit	#
Transportation segments (15)			
Autos	TRT	Billion vehicle-km/year	19
Buses	TRB	Billion vehicle-km/year	12
Light trucks	TRL	Billion vehicle-km/year	12
Commercial trucks	TRC	Billion vehicle-km/year	12
Medium trucks	TRM	Billion vehicle-km/year	12
Heavy trucks	TRH	Billion vehicle-km/year	12
Two wheelers	TRW	Billion vehicle-km/year	19
Three wheelers	TRE	Billion vehicle-km/year	12
International aviation	TAI	PJ/year	14
Domestic aviation	TAD	PJ/year	14
Freight rail transportation	TTF	PJ/year	12
Passengers rail transportation	TTP	PJ/year	12
Internal navigation	TWD	PJ/year	13
International navigation (bunkers)	PJ/year	TWI	13
Non-energy uses in transport	NEU	PJ/year	12
Residential segments (11)			
Space heating	RH1, RH2, RH3, RH4	PJ/year	19
Space cooling	RC1, RC2, RC3, RC4	PJ/year	19
Hot water heating	RWH	PJ/year	19
Lighting	RL1, RL2, RL3, RL4	PJ/year	19
Cooking	RK1, RK2, RK3, RK4	PJ/year	19
Refrigerators and freezers	RRF	PJ/year	19
Cloth washers	RCW	PJ/year	19
Cloth dryers	RCD	PJ/year	19
Dish washers	RDW	PJ/year	19
Miscellaneous electric energy	PJ/year	REA	19
Other energy uses	ROT	PJ/year	19

Connections

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Commercial segments(8)			
Space heating	CH1, CH2, CH3, CH4	PJ/year	17
Space cooling	CC1, CC2, CC3, CC4	PJ/year	17
Hot water heating	CHW	PJ/year	17
Lighting	CLA	PJ/year	17
Cooking	CCK	PJ/year	17
Refrigerators and freezers	PJ/year	CRF	17
Electric equipments	COE	PJ/year	17
Other energy uses	COT	PJ/year	17
Agriculture segment (1)			
Agriculture	AGR	PJ/year	6,7
Industrial segments (6)			
Iron and steel	IIS	Millions tonnes/year	10
Non ferrous metals	INF	Millions tonnes/year	10
Chemicals	ICH	PJ/year	9
Pulp and paper	ILP	Millions tonnes/year	11
Non metal minerals	INM	PJ/year	8
Other industries	IOI	PJ/year	15,16
Other segment (1)			
Other non specified energy consumption	ONO	15,16	

Connections

Table 7.1: Consumed commodities aggregation

Description	Coupling	TIAM nomenclature
Coal	COAL	*COA, INDCOG, INDCOK
Crude oil	COIL	INDCRD
Gas	CGAS	*NGA, INDNGL
Petroleum products	CPET	*DST,*GSL,*HFO,*KER,*LPG, ELCCGO, ELCGOI, INDOIL, INDETH, INDNAP, INDPTC, TRAAVG, TRAETH, TRAJTK, TRAMET
Electricity	CELE	*ELC, INDSTM
Uranium	CURA	ELCNUC, INDNUC
Hydraulic	CHYD	ELCHYD, INDHYD
Others	COTH	*BIO,*GEO,*HET, *SOL, ELCBGS, ELCBMU, ELCCRP, ELCSLD, ELCTDL, ELCWIN, INDBFG, INDOXY, INDTDL, INDWIN

Connections

Table 7.2: Processes aggregation by output

Coupling	TIAM nomenclature
AGRI	AGR000
MINE	INF000 (Non-Ferrous), INM000 (Non-Metals),
CHEM	ICH000 (Chemical)
META	IIS000 (Iron & Steel)
PAPE	ILP (Pulp & Paper)
TRAN	TRB*, TRC*, TRE*, TRH*, TRL*, TRM*, TTF000, TTP000
SEAT	TWD000, TWI000
AIRT	TAD000, TAI000
CONS	IOI000 (Other Industries), ONO000
SERV	CC*,CH*,CLA*,COE*,COT*,CRF*
HOUS	RC*, RDW, REA, RH*, RK*, RL*, ROT, RRF, TRT, TRW
ELEC	E*, CHP*

Connections

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Table 7.3: Processes aggregation by input

Coupling	TIAM nomenclature
AGRI	AGR000
MINE	IENF*, IMNF*, IONF*, IPNF*, ISNF* (Non-Ferrous), IENM*, IMNM*, IONM*, IPNM*, ISNM* (Non-Metals)
CHEM	IECH*, IMCH*, IOCH*, IPCH*, ISCH* (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*, TTF000, TTP000
SEAT	TWD000, TWI000
AIRT	TAD000, TAI000
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, TRT, TRW
ELEC	E*, CHP*

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Connections

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Table 7.4: Relation between useful demands and economy drivers

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

* For a selection of countries only

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CO_2 price and oil price

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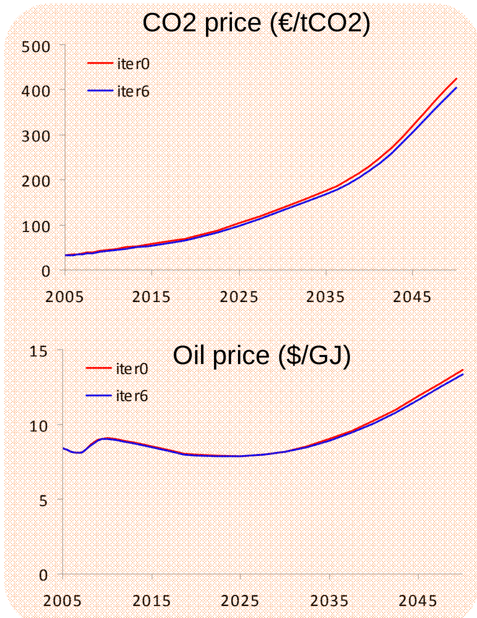

- ➔ The coupling helps reducing the CO2 and oil prices thanks to the reduction of service demands (there is no reduction of demands in iter0)
- ➔ This is of course an expected result, also observed when TIAM is used alone with elastic end-use demands

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