To pdf - COFFEE-TEA

From IAMC-Documentation

Reference card - COFFEE-TEA

Contents

The reference card is a clearly defined description of model features. The numerous options have been organized into a limited amount of default and model specific (non default) options. In addition some features are described by a short clarifying text.

Legend:

- ☐ not implemented
- ☑ **implemented**
- ☑ **implemented (not default option)**

⚠ ***Note:*** *The documentation of COFFEE-TEA is 'under review' and is not yet 'published'!*

About

Name and version COFFEE-TEA v1

Institution and users	UFRJ (COPPE UFRJ), Brazil, http://www.ppe.ufrj.br/index.php/en. main users: Roberto Schaeffer; Alexandre Szklo; Andre F. P. Lucena; Angelo C. Gurgel; Pedro R. R. Rochedo; Mariana Imperio; Bruno S. L. Cunha; Rafael Garaffa
Documentation	COFFEE-TEA documentation consists of a referencecard and detailed model documentation

Model scope and methods

Model documentation: Model scope and methods - COFFEE-TEA

Objective	The models were developed at COPPE/UFRJ, Brazil, for assessing climate, land, energy and environmental policies, providing relevant information to experts and decision-makers about the possible development strategies and repercussions of long term climate scenarios.
Concept	The models can run scenarios as a stand-alone application or linked through a soft-link process.
Solution method	The COFFEE model is solved through Linear Programming (LP). The TEA model is formulated as a mixed complementary problem (MCP) and is solved through Mathematical Programming System for General Equilibrium -- MPSGE within GAMS using the PATH solver.
Temporal dimension	Base year:2011, time steps:5 year, horizon: 2100
Spatial dimension	Number of regions:18

1. AFR Africa
2. AUS Australia and New Zealand
3. BRA Brazil
4. CAM Central America
5. CAN Canada
6. CAS Caspian Region
7. CHN China
8. EEU Europe
9. IND India
10. JPN Japan
11. KOR South Korea
12. MEA Middle East
13. RAS Rest of Asia and Oceania
14. RUS Russia
15. SAF South Africa
16. SAM South America
17. USA United States
18. WEU Rest of Europe

Socio economic drivers

Model documentation: Socio-economic drivers - COFFEE-TEA

Exogenous drivers	☑ **Exogenous GDP** ☐ Total Factor Productivity ☐ Labour Productivity ☐ Capital Technical progress ☐ Energy Technical progress ☐ Materials Technical progress	☑ **GDP per capita** ☑ **Active Population** ☑ **Active population growth** ☑ **GDP per household** ☑ **Population**
Endogenous drivers	☑ **Carbon prices** ☑ **Fossil fuel prices**	☑ **Renewable price** ☑ **Total Factor Productivity**
Development	☑ **GDP per capita** ☐ Income distribution in a region ☐ Urbanisation rate	☐ Education level ☐ Labour participation rate

Macro economy

Model documentation: Macro-economy - COFFEE-TEA

Economic sectors	☑ **Agriculture** ☑ **Industry** ☑ **Energy** ☑ **Transport**	☑ **Services** ☑ **Manufactures** ☑ **other**
Cost measures	☑ **GDP loss** ☑ **Welfare loss** ☑ **Consumption loss**	☐ Area under MAC ☐ Energy system costs
Trade	☑ **Coal** ☑ **Oil** ☑ **Gas** ☐ Uranium ☑ **Electricity** ☑ **Bioenergy crops** ☑ **Food crops** ☐ Capital ☑ **Emissions permits** ☑ **Non-energy goods**	☑ **Bioenergy products** ☑ **Chemical Products** ☑ **Consumer Goods Industries** ☑ **Diesel** ☑ **Livestock products** ☑ **Manufactures** ☑ **Ferrous and non ferrous metals** ☑ **Refined Liquid Fuels** ☑ **Services**

Energy

Model documentation: Energy - COFFEE-TEA

Resource use	☑ **Coal** ☑ **Oil** ☑ **Gas**	☑ **Uranium** ☑ **Biomass**

Electricity technologies	☑ **Coal** ☑ **Gas** ☑ **Oil** ☑ **Nuclear** ☑ **Biomass** ☑ **Wind**	☑ **Solar PV** ☑ **CCS** ☑ **Geothermal** ☑ **Hydropower** ☑ **Solar CSP** ☑ **non-fossil**
Conversion technologies	☑ **CHP** ☑ **Heat pumps** ☐ Hydrogen	☐ Fuel to gas ☐ Fuel to liquid ☑ **Refined fuels**
Grid and infrastructure	☑ **Electricity** ☑ **Gas** ☐ Heat	☑ **CO2** ☐ H2
Energy technology substitution	☑ **Discrete technology choices** ☑ **Expansion and decline constraints**	☑ **System integration constraints**
Energy service sectors	☑ **Transportation** ☑ **Industry**	☑ **Residential and commercial** ☑ **Agriculture**

Land-use

Model documentation: Land-use - COFFEE-TEA; Non-climate sustainability dimension - COFFEE-TEA

Land-use	☑ **Cropland** ☑ **Forest**	☑ **Grassland** ☑ **Extensive Pastures**

Other resources

Model documentation: Non-climate sustainability dimension - COFFEE-TEA

Other resources	☐ Water ☑ **Metals**	☑ **Cement**

Emissions and climate

Model documentation: Emissions - COFFEE-TEA; Climate - COFFEE-TEA

Green house gasses	☑ **CO2** ☑ **CH4** ☑ **N2O**	☐ HFCs ☐ CFCs ☐ SF6
Pollutants	☐ NOx ☐ SOx ☐ BC	☐ OC ☐ Ozone

Climate indicators

- ☐ CO2e concentration (ppm)
- ☐ Radiative Forcing (W/m^2)
- ☐ Temperature change (°C)
- ☐ Climate damages $ or equivalent

Model Documentation - COFFEE-TEA

This wiki page provides detailled information on the COFFEE-TEA models. The COFFEE-TEA is an integrated assessment model framework that consists of two models -- the energy and land-use model COFFEE, and the Computable General Economic (CGE) model TEA. The models were developed at COPPE/UFRJ, Brazil, for assessing climate, land, energy and environmental policies, providing relevant information to experts and decision-makers about the possible development strategies and repercussions of long term climate scenarios. The models can run on a stand-alone basis or linked through a soft-link process, providing long-term (up to 2100) assessments of the interaction between the energy and land-use systems and the economy.

1) Model scope and methods - COFFEE-TEA

COFFEE (COmputable Framework For Energy and the Environment) is a multi-regional and multi-sectorial partium equilibrium (PE) model[1][2]. The model includes a rich technological representation of the energy and land-use systems in a completely integrated framework, providing the assessment of potential synergies/trade-offs in energy, environmental and climate policies. COFFEE can assess the evolution of fossil-fuel GHG emissions from combustion, from all sectors of the economy, including industrial processes, waste treatment and land-use related, including fugitive emissions.

The COFFEE model is based on the MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts), an optimization software in linear programming applied for most physical balances (mass, energy, exergy and land)[3][4]. MESSAGE suits the development of bottom-up models and partial equilibrium models, with perfect foresight, sovled through Linear Programming (LP).

TEA (Total Economy Assessment) is a multi-regional and multi-sectorial CGE model that tracks the production and distribution of goods in a dynamic recursive setup for the global economy. The model is based on the MIT EPPA model[5][6] and on GTAPinGAMS[7].

The model is formulated as mixed complementary problem (MCP) and is solved through Mathematical Programming System for General Equilibrium -- MPSGE[8] within GAMS (https://gams.com/) using the PATH solver[9]. It assumes total market clearance (through commodity price equilibrium), zero profit condition for producers (with constant-returns-to-scale) and perfect competition to reach general equilibrium.

The models have been developed at COPPE/UFRJ, Brazil, for assessing climate, land, energy and environmental policies, providing relevant information to experts and decision-makers about the possible development strategies and repercussions of long term climate scenarios. The model can run scenarios as a stand-alone application or linked through a soft-link process.

1.1) Model concept, solver and details - COFFEE-TEA

The COFFEE model is based on the MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts), an optimization software in linear programming applied for most physical balances (mass, energy, exergy and land)[3][4]. MESSAGE suits the development of bottom-up models and partial equilibrium models, with perfect foresight, sovled through Linear Programming (LP).

The TEA model is formulated as mixed complementary problem (MCP) and is solved through Mathematical Programming System for General Equilibrium -- MPSGE[8] within GAMS (https://gams.com/) using the PATH solver[9]. It assumes total market clearance (through commodity price equilibrium), zero profit condition for producers (with constant-returns-to-scale) and perfect competition to reach general equilibrium.

1.3) Temporal dimension - COFFEE-TEA

COFFEE and TEA are long-term global models suitable for policies and climate aspects evaluation. The temporal dimension of the models covers the 2010--2100 period. The base year is 2010 and the time step is five years. COFFEE is a perfect foresight model, while TEA is a recursive dynamic myopic model.

1.4) Spatial dimension - COFFEE-TEA

The spatial dimension of the COFFEE and TEA models covers 18 regions, as shown in Table 1.

Table 1: COFFEE-TEA spatial breakdown

Code	Country / Region	Code	Country / Region
AFR	Africa	JPN	Japan
AUS	Australia and New Zealand	KOR	South Korea
BRA	Brazil	MEA	Middle East
CAM	Central America	RAS	Rest of Asia and Oceania
CAN	Canada	RUS	Russia
CAS	Caspian Region	SAF	South Africa
CHN	China	SAM	South America
EEU	Europe	USA	United States
IND	India	WEU	Rest of Europe

In addition, the COFFEE models has a global region represented as the 19th region of the model.

3) Macro-economy - COFFEE-TEA

The TEA model provides demand projections for the COFFEE model. The main economic drivers for the TEA model are population and GDP growth, which are exogenous and currently derived from the SSP database. When run as a linked application, economic consistency of the COFFEE model is guaranteed by the information from the TEA model. When run as a stand-alone application, the macroeconomic consistency of the COFFEE model is guaranteed by the implementation of exogenous macroeconomic drivers that provide the demand growth over time, such as the SSP database.

3.1) Production system and representation of economic sectors - COFFEE-TEA

The production system in TEA model is based on nested Constant Elasticity of Substitution (CES) functions. Representative consumers maximize welfare subject to budget constraint in each region. Such choices are determined by the parameters of substitution and transformation elasticicities in the utility and production functions. The CES functions describe the substitution possibilities between factors of production and intermediate inputs in the productive process, in a least cost approach. The CES production function can be expressed by the following Equation 1:

where *Y* represents the output, *A* is a constant for productivity, is the share of input *i* and *X* is the factor of production (capital, labor, resources etc.). The elasticity of substitution is a positive constant . The CES production function leads to the linear production function as , to the Cobb - Douglas production function as , and to the production function with fixed proportions (Leontief) as .

Production functions follow a nested technological structure. For instance, the electricity production includes emission factors to account for the CO2 emissions, the fuel used to produce electricity, capital (K), labor (L) and other fixed factors, as shown in Figure 1.

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As a CGE model, all the economic activity is consistently represented in the TEA model. The economic system is represented by 16 sectors in the TEA model.

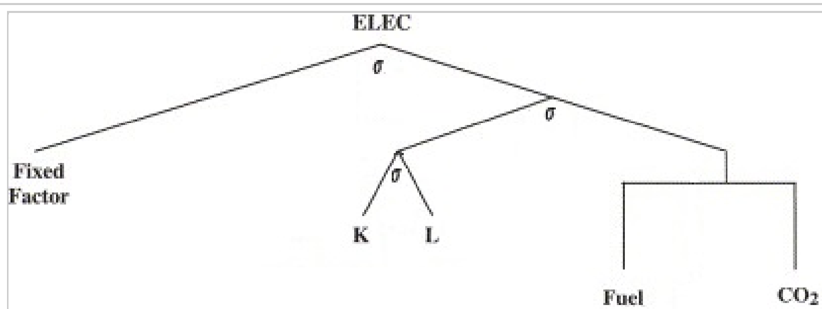

Figure 1: TEA Electricity generation technological structure -- fuel and emissions

Agriculture	Energy	Industry	Transport	Services
Agriculture crops and vegetables	Coal	Iron and Steel	Transport nec	Services
Livestock	Crude Oil	Chemical rubber and plastic	Water transport	Dwellings
	Electricity	Manufacture of non-metallic mineral products	Air transport	
	Natural Gas	Other manufacture		
	Petroleum products			

The production systems that are explicitely represented in the COFFEE model, as a partial equilibrium model, are the energy and land-use systems (described in the following sections). The economic sectors are exougenously represented through the demand projections from external sources.

3.2) Capital and labour markets - COFFEE-TEA

In the TEA model, the macroeconomic closure assumes full employment of the factors of production (capital and labour). Savings equals investment in the general equilibrium, but regionally the imbalances are closed by a surplus (or deficit) in the current account. An endogenous real exchange rate clears the current accounts and the capital account decreases exougenously in the long-run. Capital stock evolves at each period with the formation of new capital that depends on the investment level in that period and the capital depreciation rate, as described in Equation 1.

where: is the capital stock in region *r* and time *t*; is the investment in new capital goods in region *r* and time *t*; is the depreciation rate of capital in region *r*.

In the COFFEE model, capital and labour are represented throught technological parameters, such as capital expenditures (CAPEX) and operational and maintenance expenditures (OPEX).

3.3) Monetary instruments - COFFEE-TEA

Not applicable

3.4) Trade - COFFEE-TEA

In the TEA model, international trade follows an Armington's aggregation[10], in which a composite CES function differentiate consumer's preferences between imported and domestic goods.

In the COFFEE model, international trade of energy and agriculture commodities is explicitely represented. Partial equilibrium is reached in a minimun cost basis, whereas trade between regions is part of the solution.

3.5) Technological change - COFFEE-TEA

Technological change in COFFEE is described by cost, performance and conversion efficiencies parameters for each technology (...)

4) Energy - COFFEE-TEA

COFFEE is designed to meet the demand for energy services (exogenous whether run in a stand-alone basis or when linked to the TEA model), given the competition between technologies and energy sources, with the objective of minimizing the total cost of the system. In COFFEE, the energy sector includes the main elements such as resources and conversion technologies which are used and flow through the different levels of the energy system. Figure 14 shows the representation of the energy system in COFFEE.

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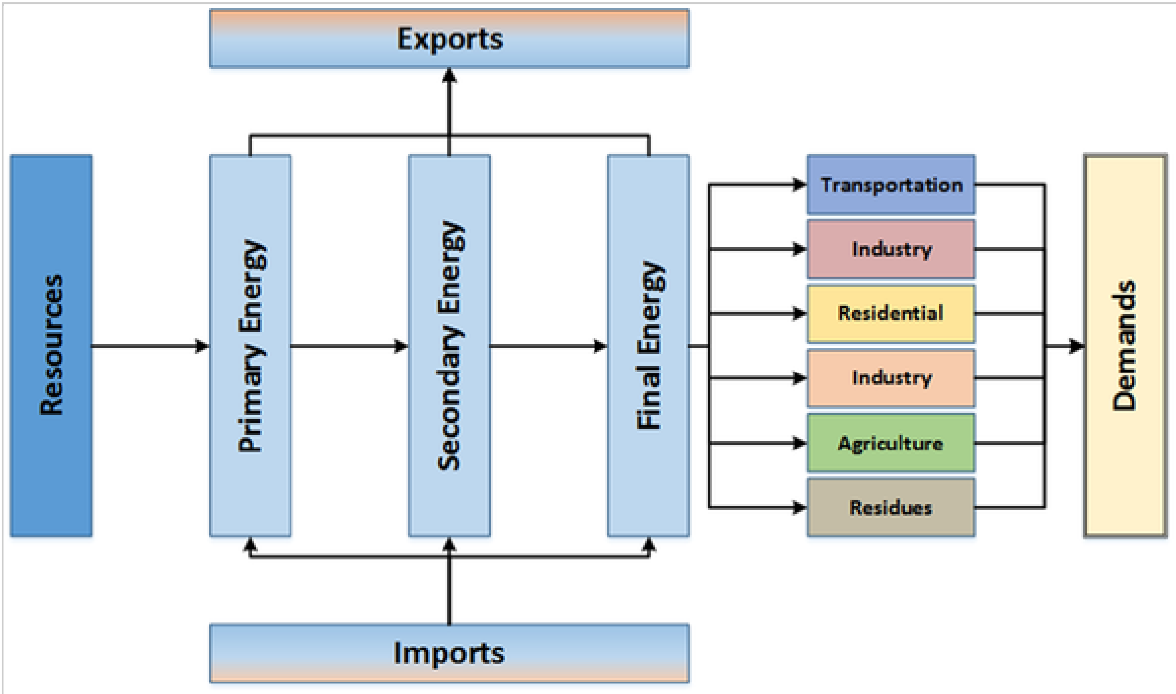

Figure 2: COFFEE Energy system

The representation of the energy sector in the TEA model is based on the COFFEE model. The soft-link with COFFEE improves energy system analysis, achieving a more comprehensive representation of the energy system. This feature is particularly interesting because COFFEE describes energy conversion technologies based on discrete techniques with pre-defined technological (size, lead time, efficiency, availability, etc.) and economic (overnight costs, fixed and variable O&M costs, contingency factors etc.) variables, thus capturing technological deployment over time in a least cost approach.

The linking procedure between the models relies on base year data harmonization that includes:

- energy production and consumption (fossil fuel used in electricity generation, fuel plants energy consumption and non-energy use);
- explicit technological representation of nuclear, hydro, wind, solar and biomass sources;
- implementation of autonomous energy efficiency improvement (AEEI);
- share of power generation and energy trends; and
- GHG emissions (CO_2, CH_4 and N_2O).

Data for electricity generation (in energy physical units) and the shares of production factors (capital, labor, services, resources, fuel and land) are inputted into TEA in order to explicitly represent nuclear, hydro, wind, solar and biomass technologies. The production functions of these technologies were changed from CES to typical Leontief structures in order to facilitate that results from COFFEE could be completely embedded by the TEA model. Thus, the substitution elasticity between the different energy inputs is set to equal zero so that there is no substitutability between factors. The power generation branch has fixed input proportions and the penetration of different technologies carriers is determined by the COFFEE model.

4.1) Energy resource endowments - COFFEE-TEA

Energy resource endowments in the COFFEE model influences the choices of how to supply the demand. The resource supply curve is used to define the accessible amount of resource and its costs. This information was developed for the following resources:

- Oil and associated gas resources
- Natural Gas and NGL resources
- Coal resources
- Uranium Resources
- Hydro Energy
- Solar and Wind Energy
- Carbon Transportation and Storage

In addition, agricultural crops and residues are increasingly seen as sources of feedstocks for energy to displace fossil fuels. A wide range of materials has been proposed for use, including grain, crop residue, cellulosic crops (e.g., switchgrass, sugarcane), and various tree species.

4.1.1) Fossil energy resources - COFFEE-TEA

The oil and natural gas supply curve in the COFFEE model were built based on several studies. The data was obtained from detailed resource assessments in the engineering literature, detailed technical and cost parameters (such as Enhanced Oil Recovery, or EOR, recovery rates and potential) are available in [11][12][13]. Data were gathered processed and compiled to determine the supply curve, as shown in Figure 3 and Figure 4.

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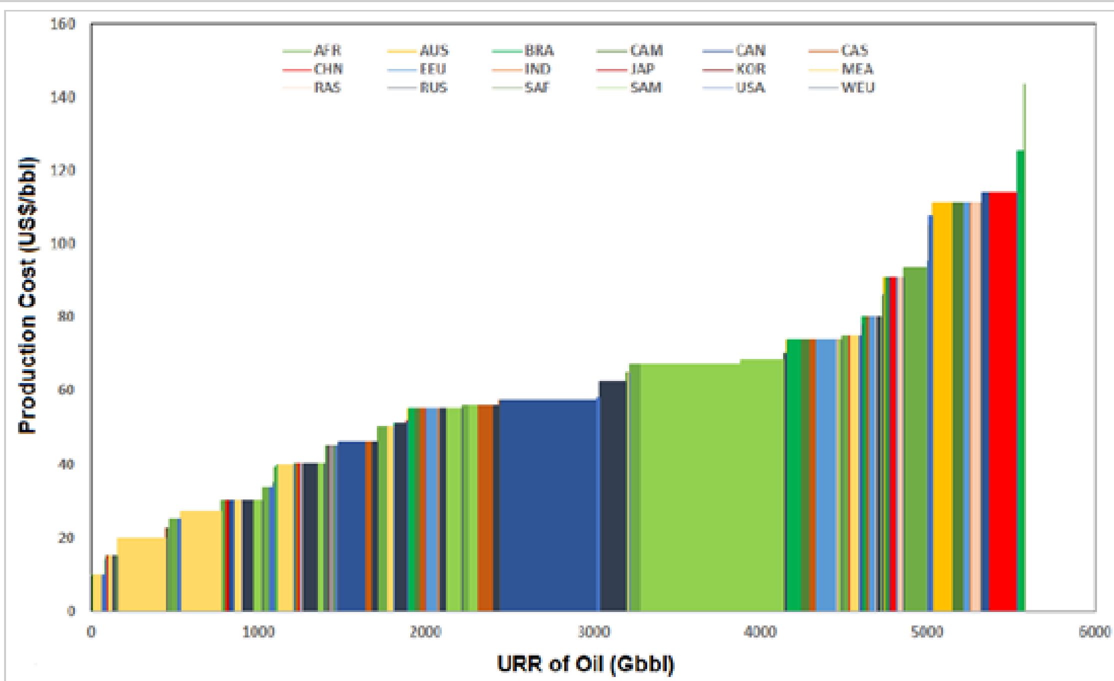

Figure 3: Oil supply curve detailing each oil category

A coal resource assessment profile was also developed to check this availability. In the model, the categories defined for coal are betuminous, sub-betuminous, and lignite, all of them split in surface or mining availability for each region. Main sources for developing a specific supply curve include [12] and other related literature that was used to the estimate the methane content for every coal resource category (Figure 5).

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4.1.2) Uranium and other fissile resources - COFFEE-TEA

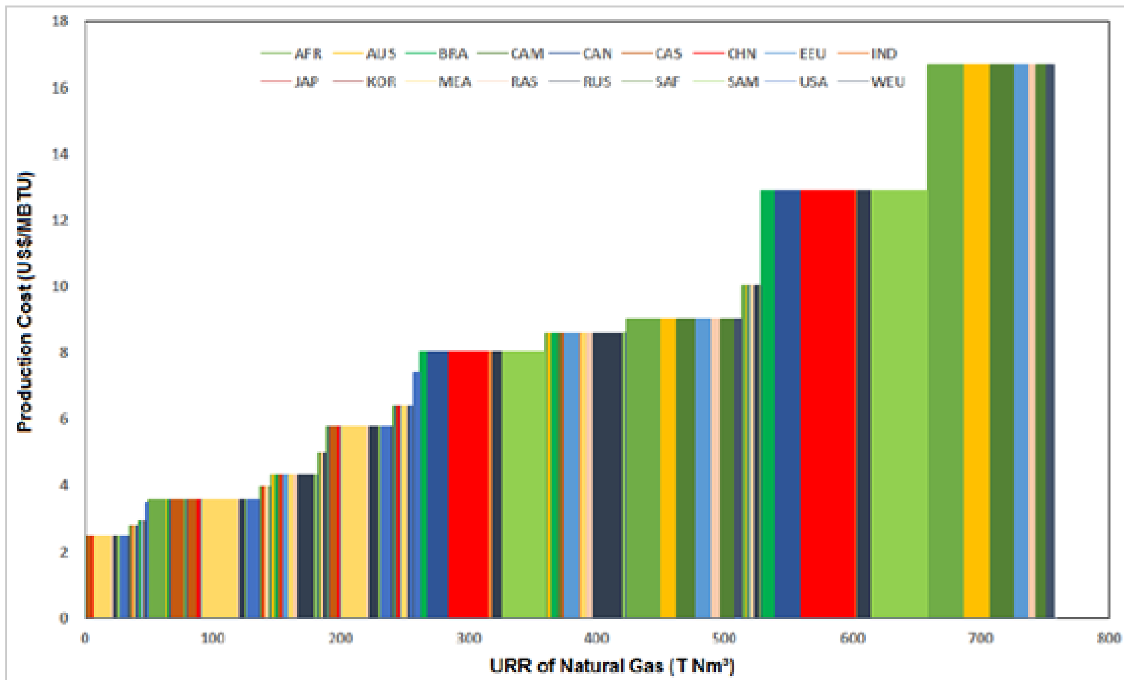

Figure 4: Natural gas supply curve detailing each regional resource

	Betuminous (m^3CH4/t)							Sub-Betuminous (m^3CH4/t)							Lignite (m^3CH4/t)				
	Reserve		Res. 2P Rec		Res 3P	URR 1P	URR 3P	Reserve		Res. 2P Rec		Res 3P	URR 1P	URR 3P	Reserve	Res. 2P Rec	Res 3P	URR 1P	URR 3P
	Surface	Mining	Surface	Mining	Mining	Mining	Mining	Surface	Mining	Surface	Mining	Mining	Mining	Mining	Surface	Surface	Mining	Mining	Mining
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
AFR	2.2	29.3	2.2	29.3	29.3	29.3	29.3	2.2	29.3	2.2	29.3	29.3	29.3	29.3	2.2	2.2	29.3	29.3	29.3
AUS	2.8	9.9	2.8	9.9	9.9	9.9	9.9	2.8	9.9	2.8	9.9	9.9	9.9	9.9	2.8	2.8	9.9	9.9	9.9
BRA	2.6	22.2	2.6	22.2	22.2	22.2	22.2	2.6	22.2	2.6	22.2	22.2	22.2	22.2	2.6	2.6	22.2	22.2	22.2
CAM	3.0	14.1	3.0	14.1	14.1	14.1	14.1	3.0	14.1	3.0	14.1	14.1	14.1	14.1	3.0	3.0	14.1	14.1	14.1
CAN	0.9	14.4	0.9	14.4	14.4	14.4	14.4	0.9	14.4	0.9	14.4	14.4	14.4	14.4	0.9	0.9	14.4	14.4	14.4
CAS	9.5	19.5	9.5	29.0	33.0	33.0	33.0	9.5	19.5	9.5	29.0	33.0	33.0	33.0	9.5	9.5	19.5	19.5	19.5
CHN	0.6	6.5	0.6	6.5	6.5	6.5	6.5	0.6	6.5	0.6	6.5	6.5	6.5	6.5	0.6	0.6	6.5	6.5	6.5
EEU	0.7	11.0	0.7	11.0	11.0	11.0	11.0	0.7	11.0	0.7	11.0	11.0	11.0	11.0	0.7	0.7	11.0	11.0	11.0
IND	0.3	21.5	0.3	21.5	21.5	21.5	21.5	0.3	21.5	0.3	21.5	21.5	21.5	21.5	0.3	0.3	21.5	21.5	21.5
JAP	10.9	27.0	10.9	27.0	27.0	27.0	27.0	10.9	27.0	10.9	27.0	27.0	27.0	27.0	10.9	10.9	27.0	27.0	27.0
KOR	10.9	27.0	10.9	27.0	27.0	27.0	27.0	10.9	27.0	10.9	27.0	27.0	27.0	27.0	10.9	10.9	27.0	27.0	27.0
MEA	1.4	6.9	1.4	6.9	6.9	6.9	6.9	1.4	6.9	1.4	6.9	6.9	6.9	6.9	1.4	1.4	6.9	6.9	6.9
RAS	0.3	7.1	0.3	7.1	7.1	7.1	7.1	0.3	7.1	0.3	7.1	7.1	7.1	7.1	0.3	0.3	7.1	7.1	7.1
RUS	7.6	15.0	7.6	15.0	15.0	15.0	15.0	7.6	15.0	7.6	15.0	15.0	15.0	15.0	7.6	7.6	15.0	15.0	15.0
SAF	0.5	3.7	0.5	3.7	3.7	3.7	3.7	0.5	3.7	0.5	3.7	3.7	3.7	3.7	0.5	0.5	3.7	3.7	3.7
SAM	6.0	14.1	6.0	14.1	14.1	14.1	14.1	6.0	14.1	6.0	14.1	14.1	14.1	14.1	6.0	6.0	14.1	14.1	14.1
USA	1.3	14.4	1.3	14.4	14.4	14.4	14.4	1.3	14.4	1.3	14.4	14.4	14.4	14.4	1.3	1.3	14.4	14.4	14.4
WEU	0.1	20.6	0.1	20.6	20.6	20.6	20.6	0.1	20.6	0.1	20.6	20.6	20.6	20.6	0.1	0.1	20.6	20.6	20.6

Figure 5: Methane content for every region and resource category

The estimates available in the literature for uranium resources are a lot more comprehensive and agreeable then that of oil and gas due to the national and international interest in mapping the location and accessibility of the nuclear resources, due to risk of exposure to natural radiation and potential proliferation of non-energetic nuclear technologies.

For instance, [14] and other related literature provide a summary of national reports, which includes resource assessment of natural uranium. All these studies used the IAEA classification for uranium resources [14]. The resources are divided into two aspects, extraction costs and resource nature, as shown in Figure 6.

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4.1.3) Bioenergy - COFFEE-TEA

The resources considered in COFFEE as biomass for bioenergy are the crop for energy, woody biomass, grassy biomass, that are exclusively for this purpose, and agriculture residues. The amount of resource available depends on the land use and agriculture activities.

4.1.4) Non-biomass renewables - COFFEE-TEA

Solar and Wind energy resources were estimated in the COFFEE model from [15] and other related engineering literature, especially for cost estimation. For solar resource the supply curve introduced in the model was based on solar radiance itself, instead of on electricity or power. Additionally, resources are split in four steps of increasing capacity factor.

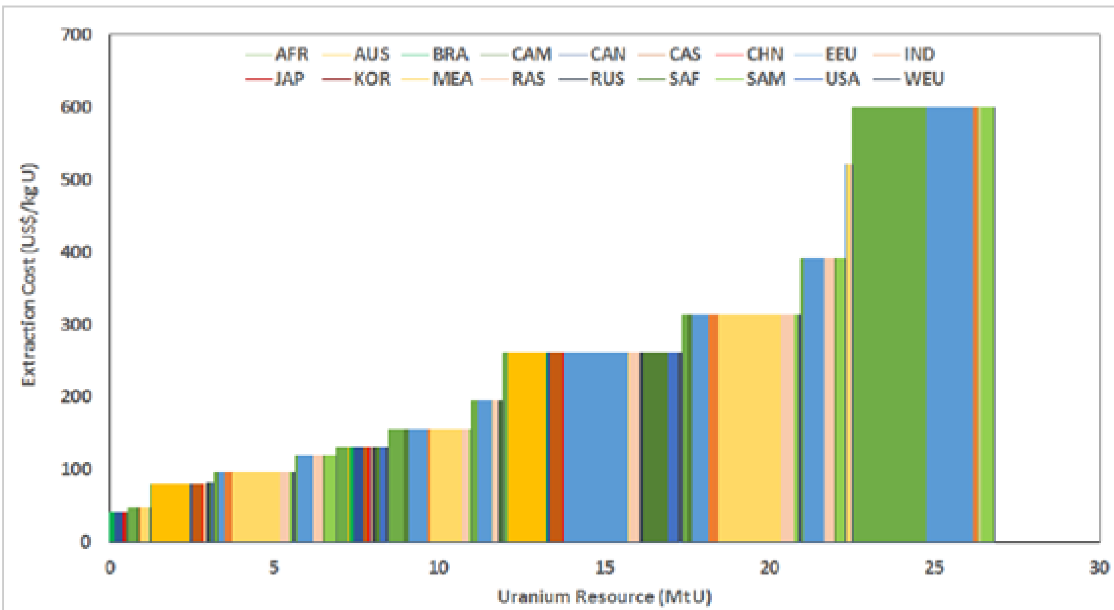

Figure 6: Global supply curve for uranium

For wind resources the capacity factor is split in offshore and onshore and the distance to major consumers and to the coastline are considered. This is important to generate better supply curves for energy resources, since the optimum decision from the model may be to use a lower capacity factor that is closer to the end consumer, depending on the costs associated. In the COFFEE model, wind resource was estimated considering 12 step curves for and 27 step discrete curves were created combining capacity factor, distance to shore and water depth for onshore and offshore, respectively. Figure 7 summarizes the wind and solar resource categories.

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In the COFFEE model, the quality of the hydro resources derives from two major components: capacity factors and resource availability. These aspects are directly associated with exploitation costs. Thus, the total resources can be separated in terms of costs in order to create a supply curve for Hydro power. [16] and other related literature provide regional profiles for hydro projects and was used to estimate the hydro resource availability for the 18 regions of the model.

Offshore Categories	
Water Depth	Distance
Shallow	100 km
Shallow	200 km
Shallow	1500 km
Transitional	100 km
Transitional	200 km
Transitional	1500 km
Deep	100 km
Deep	200 km
Deep	1500 km

Wind Average C.F.*	
Original	New Steps
18%	20%
20%	
24%	
28%	30%
32%	
36%	38%
40%	
44%	44%
46%	

Solar Average Radiation (KWh/m²/d)	
Original	New Steps
< 3	3.25
3.0 - 3.5	
3.5 - 4.0	4.5
4.0 - 4.5	
4.5 - 5.0	
5.0 - 6.25	6.25
6.25 - 7.25	
7.25 - 7.5	7.5
7.5 - 7.75	
> 7.75	

Onshore Caterogies
Distance
100 km
200 km
1500 km

*C.F.: Capacity factor categories for both onshore and offshore wind.

Figure 7: Wind and solar resource categories

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4.2) Energy conversion - COFFEE-TEA

Region	Installed Capacity	Total Potential	Large Hydro Potential					Small Hydro Potential				
			Categ. 1	Categ. 2	Categ. 3	Categ. 4	Categ. 5	Categ. 1	Categ. 2	Categ. 3	Categ. 4	Categ. 5
AFR	31	439	301	36	7	5	2	75	9	2	1	0
AUS	18	71	49	6	1	1	0	12	1	0	0	0
BRA	84	265	182	22	4	3	1	46	5	1	1	0
CAM	15	105	72	9	2	1	0	18	2	0	0	0
CAN	98	161	110	13	2	2	1	28	3	1	0	0
CAS	28	257	176	21	4	3	1	44	5	1	1	0
CHN	48	735	505	60	11	8	3	126	15	3	2	1
EEU	140	430	295	35	7	5	2	74	9	2	1	0
IND	78	217	149	18	3	2	1	37	4	1	1	0
JPN	32	51	35	4	1	1	0	9	1	0	0	0
KOR	7	7	5	1	0	0	0	1	0	0	0	0
MEA	18	457	314	38	7	5	2	78	9	2	1	0
RAS	30	437	300	36	7	5	2	75	9	2	1	0
RUS	92	461	316	38	7	5	2	79	9	2	1	0
SAF	3	12	8	1	0	0	0	2	0	0	0	0
SAM	52	350	240	29	5	4	1	60	7	1	1	0
USA	155	407	279	33	6	4	2	70	8	2	1	0
WEU	17	39	27	3	1	0	0	7	1	0	0	0

Figure 8: Estimated installed capacity, total potential and potential by category for the hydro resource (GW).

The transformation of energy forms, i.e., from primary energy to secondary and, eventually, final energy is detailly represented in the COFFEE model. The chosen technology to meet the energy service demand is subject to the many economical and technical features that characterize the energy conversion technologies, as listed below:

- All technologies considered
- All elements that characterize the technologies
- Investment costs
- Maintenance costs
- Variable operation costs
- Fixed costs
- Technical lifetime
- Efficiency
- Plant availability or maximum utilization time per year
- Consumption or production of certain materials
- Year of first commercial availability and last year of commercial availability of the technology.

4.2.1) Electricity - COFFEE-TEA

The electricity sector is another complex subsector within the Energy sector also assessed in COFFEE model. The transformation of primary energy and secondary energy sources into electricity includes several different options for every resource which provides the model a large number of possibilities and a better way to represent the power systems (Figure 9).

For most of the power technologies incorporated in the model, an estimation of the current installed capacity in all regions was performed. The main source of information was [17], except for nuclear power plants [14]. The COFFEE model takes a relative detailed approach for nuclear power technologies, differentiating reactor technology and, consequently, nuclear fuels. Thus, the type of nuclear fuel is depended on the nuclear reactor used. Then the costs to produce the nuclear fuels are considered and the costs relating to waste management as well. The production costs vary according to the level of enrichment (Figure 10).

4.2.2) Heat - COFFEE-TEA

4.2.3) Gaseous fuels - COFFEE-TEA

For gaseous fuels, the only options presented are related to hydrogen technologies. Synthetic natural gas technologies are not addressed in the COFFEE model. Despite that, they can be easily introduced into the modelling framework in future analysis if needed. The hydrogen technologies available and their parameters are presented in the Figure 11.

4.2.4) Liquid fuels - COFFEE-TEA

Betuminous	PP_BetCoal_IGCC
	PP_BetCoal_USC
	PP_BetCoal_SC
	PP_BetCoal_SubC
	PP_BetCoal_IGCC_CCS
	PP_BetCoal_USC_CCS
	PP_BetCoal_SC_CCS
Sub-betuminous	PP_BetCoal_SubC_CCS
	PP_SubbetCoal_USC
	PP_SubbetCoal_SC
	PP_SubbetCoal_SubC
	PP_SubbetCoal_USC_CCS
	PP_SubbetCoal_SC_CCS
	PP_SubbetCoal_SubC_CCS
Lignite	PP_LigCoal_SC
	PP_LigCoal_SubC
Natural Gas	PP_NG_GT
	PP_NG_NGCC
	PP_NG_NGCC_CCS
	PP_NG_SubC
Fuel Oil	PP_FO_SubC
	PP_FO_Engine
Diesel	PP_Diesel_SubC
	PP_Diesel_Engine
Pet. Coke	PP_Petcoke_IGCC
	PP_Petcoke_SubC
Biomass	PP_Bio_SubC
	PP_Bio_SubC_CCS
	PP_Bio_IGCC
	PP_Bio_IGCC_CCS
Nuclear	PP_Nuclear_PWR
	PP_Nuclear_BWR
	PP_Nuclear_APWR
	PP_Nuclear_GCR
	PP_Nuclear_PHWR
	PP_Nuclear_LWGR
	PP_Nuclear_FBR
	PP_Nuclear_HTGR
Solar	PP_Solar_PV
	PP_Solar_CSP
	PP_Solar_CSP_7h
	PP_Solar_CSP_12h

Hydro	PP_Hydro_Large_Existing
	PP_Hydro_Large_Categ1
	PP_Hydro_Large_Categ2
	PP_Hydro_Large_Categ3
	PP_Hydro_Large_Categ4
	PP_Hydro_Large_Categ5
	PP_Hydro_Small_Categ1
	PP_Hydro_Small_Categ2
	PP_Hydro_Small_Categ3
	PP_Hydro_Small_Categ4
	PP_Hydro_Small_Categ5
Wind Onshore	PP_WindOn_100km_C1
	PP_WindOn_100km_C2
	PP_WindOn_100km_C3
	PP_WindOn_100km_C4
	PP_WindOn_200km_C1
	PP_WindOn_200km_C2
	PP_WindOn_200km_C3
	PP_WindOn_200km_C4
	PP_WindOn_1500km_C1
	PP_WindOn_1500km_C2
	PP_WindOn_1500km_C3
	PP_WindOn_1500km_C4
Wind Offshore	PP_WindOff_100km_C1_shallow
	PP_WindOff_100km_C1_transitional
	PP_WindOff_100km_C1_deep
	PP_WindOff_100km_C2_shallow
	PP_WindOff_100km_C2_transitional
	PP_WindOff_100km_C2_deep
	PP_WindOff_100km_C3_shallow
	PP_WindOff_100km_C3_transitional
	PP_WindOff_100km_C3_deep
	PP_WindOff_200km_C1_shallow
	PP_WindOff_200km_C1_transitional
	PP_WindOff_200km_C1_deep
	PP_WindOff_200km_C2_shallow
	PP_WindOff_200km_C2_transitional
	PP_WindOff_200km_C2_deep
	PP_WindOff_200km_C3_shallow
	PP_WindOff_200km_C3_transitional
	PP_WindOff_200km_C3_deep
	PP_WindOff_1500km_C1_shallow
	PP_WindOff_1500km_C1_transitional
	PP_WindOff_1500km_C1_deep
	PP_WindOff_1500km_C2_shallow
	PP_WindOff_1500km_C2_transitional
	PP_WindOff_1500km_C2_deep
	PP_WindOff_1500km_C3_shallow
	PP_WindOff_1500km_C3_transitional
	PP_WindOff_1500km_C3_deep

Figure 9: Power technologies and energy sources considered in the COFFEE model

In general liquid fuels are produced by the processing of crude oils carried out in refineries. To evaluate the refining sector to evaluate such a complex sector, a detailed methodology was used, not commonly used in global IAMs. The capacities of all existing process units were compiled by [18] and a refining simulation tool called CAESER (Carbon and Energy Strategy Analysis for Refineries), described in [19]. With this tool, the oil products production profile and the utilities consumption for each region were estimated, albeit in a simplified form.

One major advantage of the approach used in this study, besides the detailing of energy products and consistent energy consumption associated, is that it allows estimating the CO2 emissions related to process emissions, such as those associated with Hydrogen Generation Unit (HGU) and Fluid Catalytic Cracking (FCC) units.

Enrichment	%	0.72%	0.85%	2.00%	3.50%	4.50%	8.00%	20.00%	3.50%	MOX
Input Type		Natural	Natural	Natural	Natural	Natural	Natural	Natural	Depleted	Depleted
Input	t U	0.995	0.995	0.995	0.995	0.995	0.995	0.995	1.000	1.000
Fuel	t U	0.964	0.736	0.238	0.127	0.096	0.053	0.021	0.195	1.059
Waste	t U	0.021	0.251	0.754	0.867	0.898	0.942	0.974	0.805	0.000
Cost	$/kg U	460.2	462.5	467.5	468.7	469.0	469.4	469.7	5.1	1247.0
SWU	SWU/t U	6.2	85.2	408.4	554.6	606.7	700.4	795.4	157.6	45.5

Figure 10: Material balance and production cost for nuclear fuel.

Aspect	Unit	NG Ref.	NG Ref. CCS	CTH	CTH CCS	BTH	BTH CCS	Electrolysis
Energy Input		Natural Gas	Natural Gas	Coal	Coal	Biomass	Biomass	Electricity
Efficiency (LHV)	% (LHV)	74	74	59	59	83	83	67
CO2 Emissions	t/GJ	0.076	0.021	0.160	0.009	0.000	0.000	0.000
CO2 Captured	t/GJ	0.000	0.052	0.000	0.151	0.000	-0.114	0.000

Figure 11: Material balance and production cost for nuclear fuel.

For future expansions, the approach was to provide two refinery configurations: a high naphtha yield greenfield refinery and a high diesel yield greenfield refinery. The proposed refinery schemes (presented in Figure 12) were optimized in CAESER to provide the highest yield possible for the desired main product.

Besides oil products, two alternative sources of liquid fuels are considered: synthetic fuels and biofuels. As for synthetic fuels, two main sources of fuel are considered, both with or without carbon capture: coal and biomass. The technical parameters and carbon balance for technologies considered are presented in the Figure 13.

Parameter		New Gasoline			New Diesel		
Type of Run		Naphtha	Diesel	Kerosene	Naphtha	Diesel	Kerosene
Output (%)	RefGas	1.9	1.9	1.9	1.6	1.6	1.5
	LPG	5.8	5.8	5.8	2.1	1.9	2.1
	Naphtha	34.9	32.7	31.1	20.8	19.1	17.3
	Gasoil	47.7	52.2	52.2	64.4	68.9	68.9
	Coke	1.3	1.3	1.3	3.0	3.0	3.0
	Heavy	4.9	4.9	4.9	3.9	3.9	3.9
Utilities (%)	H2	2.4	2.4	2.4	3.9	4.2	5.1
	Steam	0.7	0.7	0.7	0.6	0.6	0.7
	Heat	5.0	5.0	5.0	6.4	6.3	6.1
	FCC Coke	2.1	2.1	2.1	0.0	0.0	0.0
	Elect	0.3	0.3	0.3	0.4	0.4	0.4

Figure 12: New refinery output yield and utilities consumption estimated from CAESAR.

4.2.5) Solid fuels - COFFEE-TEA

4.2.6) Grid, pipelines and other infrastructure - COFFEE-TEA

4.3) Energy end-use - COFFEE-TEA

The energy end-use is defined as the energy demanded by the different sector to provide them services. COFFEE includes the transport, industrial, residential and commercial sectors. The demand for the service of these sectors is projected to the future which makes possible to estimate the energy demand over the considered time horizon (Figure 14).

Tech.	Fuel Input	CCS	Coal w/o CCS	Coal w/ CCS	Biomass w/o CCS	Biomass w/ CCS
Input	Coal	PJ/y	25.2	25.2		
	Biomass	PJ/y			21.4	21.4
Output	Elect	PJ/y	3.2	2.7	3	2.4
	Gasol	PJ/y	2	1.8	1.6	1.4
	Diesel	PJ/y	10.3	10.5	8.2	8.3
Carbon Balance	Emitted	kt C/y	376	42	360	33
	Product	kt C/y	217	217	174	173
	Stored	kt C/y		334		328

Figure 13: Gasification with Fischer-Tropsch technologies.

4.3.1) Transport - COFFEE-TEA

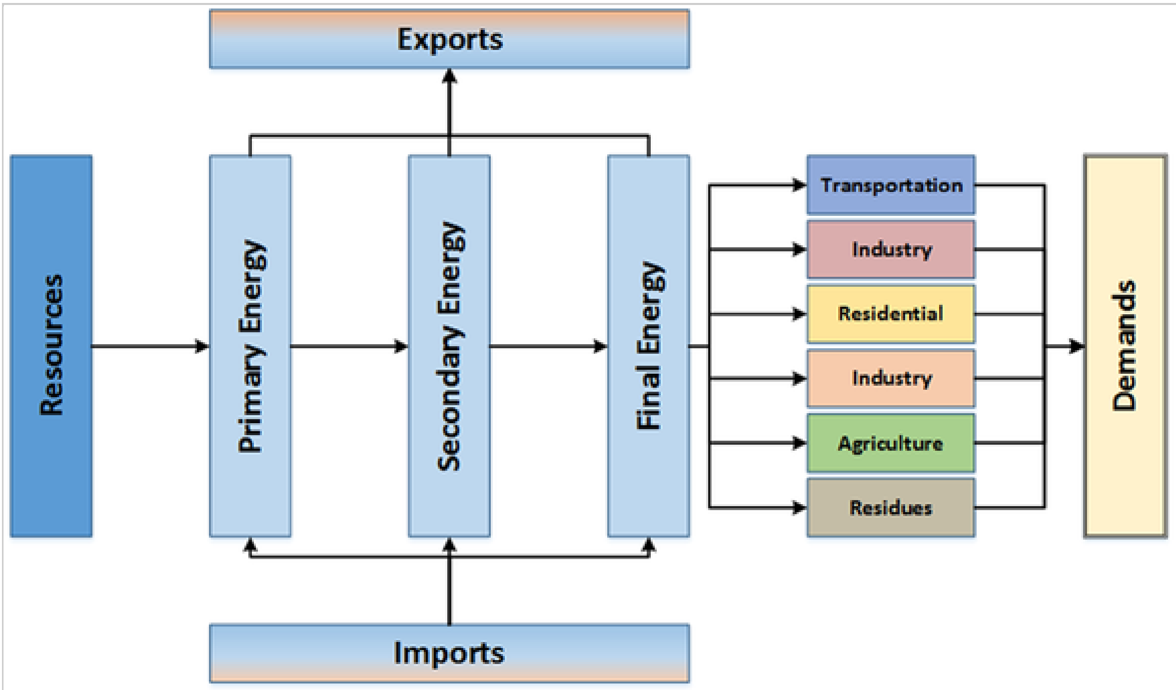

Figure 14: Energy demand

The activity of the transportation sector is usually separated into passenger and freight. The activity of the former is represented in passenger-km, or pkm, which is a measurement of the total distance required by the total number of passengers. As for freight, the unit used to represent the activity is tonne-km, or tkm. In this activity indicator, all goods and products are combined into the total weight beings transported by the total distance.

The energy consumed in this sector is used to achieve a necessary level of activity. In this sense, within the model, the exogenous demand will be expressed in pkm, for passengers, and tkm, for freight.

4.3.2) Residential and commercial sectors - COFFEE-TEA

The energy consumption is actually driven by the energy services required by the households. The IEA database [13] was used to estimate the energy consumption in the buildings (residential and commercial) sector. The energy services modelled are: Space Heating, Water Heating, Cooking, Lighting, Cooling (Ambient Conditioning) and Appliances. For these services the energy service intensity was calculated relative to the total estimated buildings as a first indicator of the energy demand estimation. Non-electricity-based technology participation for lighting, such as kerosene, biomass and candles was also estimated. For ambient heating and cooling the average HDD and CDD for every region were estimated.

4.3.3) Industrial sector - COFFEE-TEA

In global energy model, the assessment of the industrial sector is often simplified, because of the difficulty in assessing several industries, in detail, for many countries and regions of the world, where the detailed information needed are not easily available. Then a simplified approach for all 18 regions was used for the current model, considering only one industrial sector.

To estimate the energy demand for every region and the energy sources that provide this demand, the International Energy Agency (IEA) main energy datasets were used. Besides it is important to assess the energy services that are consuming energy. In industrial facilities the most common energy services are related to heating (direct or indirect) and drive of machineries, such as engines and turbines. The energy services modelled are: Heat, meaning direct heating; Steam, either for indirect heating or steam-driven engines; HVAC, or Heating, Ventilation and Air Conditioning of internal areas; Light; Motor, or the drive for electric motors; and other services.

Besides energy consumption, the industrial sector also presents a consumption of typically energy sources as non-energy inputs. This includes naphtha, from refineries, natural gas and even coal. Typically, these products are used as feedstock in industry processes, such as ammonia and petrochemical production. The non-energy consumption does not result in energy-related emissions, but it is an important part of the total consumption of energy products and they are also considered in this model.

4.3.4) Other end-use - COFFEE-TEA

Just like the tertiary sector, the residue sector provides a service to society and does not involve the production of an end product. However, since the environmental service provided by collecting and treating residues is not properly valued by society, the residues sector is less significant in the value added to the economy than other activities of the services sector.

Generally speaking, the residue sector is not a major source of GHG emissions. However, there are two reasons to address this sector in detail. First of all, there are a few abatement options, which can also provide further co-benefits to society, such as reduction of environmental damages. Other advantage is that some options of treatment can also provide alternative source of energy (waste-to-energy options).

The other reason is that the GHGs typically emitted by this sector are methane and nitrous oxide, which, even if emitted in low quantities, have a higher impact on the greenhouse gas effect. Hence, changes in consumption behaviour and the development of collecting and treatment options within all regions may prove to be an important source of GHG emissions.

There are a few sources of emissions within the residue sector, such as municipal solid waste (MSW), liquid effluents and agricultural residues. As for liquid effluents, there is very limited literature for assessing this topic worldwide it was not addressed in the current model.

4.4) Energy demand - COFFEE-TEA

The TEA model provides energy demand projections for the COFFEE model. The TEA model treats energy consumption in energy units. For the base year calibration, balanced benchmark data in monetary values is converted to exajoules (EJ) based on the compatibility with energy databases. For energy consumption, monetary values were transformed into energy units from the IEA-WEO global energy balance database (IEA, 2011).

The TEA model explicitly represents the primary energy extraction sectors (coal - COL; natural gas - GAS; crude oil - crude) as well as the secondary energy production sectors (petroleum products - OIL; electrical sector - ELE) and sectors of high final energy consumption in industry (iron and steel - I_S; chemical - CRP; non-metallic minerals - NMM; other manufactures - MAN) and in transportation (land - OTP; air - ATP, waterway - WTP).

4.5) Technological change in energy - COFFEE-TEA

5) Land-use - COFFEE-TEA

In the COFFEE model, a non- "spatial explicit" model was developed into the MESSAGE framework, with the object of optimizing land use in order to meet demand for food and bioenergy products. In order to create the land categories, or zones, several aspects were considered, such as land cover, yields, soil productivity and estimates for production costs.

The land cover categories considered in the COFFEE model were defined based on [20], which consist of spatial resolution of 300 m x 300 m land use information, split in the following types: cropland, crop-veg, forest, for-grass, grassland, flooded and not suited, which include regions that cannot be changed such as urban, desert and permanent ice regions.

The soil productivity was addressed by the Productivity Index (PI), an ordinal measure of the productivity of a soil. The PI uses family-level Soil Taxonomy information. The reason this index was used as a proxy for relative productivity is that it relies in very few additional information. However, the simplicity is exactly what creates the limitations of this analysis, since it disregards other aspects, such as water availability and climatic conditions which limit crop production.

The raster dataset of soil production index used in this study has a spatial resolution of 10 x 10 km. Information with regard to soil production was obtained from the "Derived Soil Properties" of the FAO-UNESCO Soil Map of the World which contains raster information on soil properties [21]. The soil production index considers the suitability of the best adapted crop to each soil's condition in an area and makes a weighted average for all soils present in a pixel.

The soil production Index ranges from 0% to 100% and was used as a proxy for productivity and relative yield. The average yields for every crop and region were taken from FAO (2015) and will be further discussed later. To better estimate the production cost of agricultural products the transportation cost of agricultural goods was incorporated in the evaluation. In this model the travel time was used as a proxy for distance, which, in turn, was used as a proxy for transportation costs.

Thence all these three land aspects, land-use, soil productivity and travel time, were aggregated based on production costs and the categories which could be related to production costs: soil productivity, which accounts for relative production costs at the field, and travel time, which accounts for relative costs of transportation. So, by combining all categories of Soil Productivity and Travel Time, a matrix of relative costs for 56 cells was designed and then the cells were aggregated in 7 new cost categories. Finally, for every one of the 18 regions a two-factor land system was created, considering 7 land cover types and 7 combined cost categories. However the category with highest cost was not considered viable for agriculture.

5.1) Agriculture - COFFEE-TEA

5.2) Forestry - COFFEE-TEA

5.3) Land-use change - COFFEE-TEA

5.4) Bioenergy land-use - COFFEE-TEA

5.5) Other land-use - COFFEE-TEA

5.6) Agricultural demand - COFFEE-TEA

5.7) Technological change in land-use - COFFEE-TEA

6) Emissions - COFFEE-TEA

In addition to the prices of traditional goods and services in the economic structure of the TEA model, consumers and producers are becoming aware of the cost (or price) of GHG emissions, particularly regarding climate scenarios. Much of the internalization of the negative externality of GHG emission is due to the identity between the carbon price (CO2) and the social cost of carbon (COASE, 1960), that is, the environmental damage to society from the emission additional unit of a carbon dioxide in the atmosphere.

The TEA model allows sectoral and international trading of emissions credits (or allowances) that are accounted for along with other trade flows. In climate scenarios, the carbon price of equilibrium is achieved subject to global emission constraints, also known as carbon budgets. Carbon pricing revenue returns to the representative agent (households and government), which is equivalent to a revenue recycling in the form of a lump sum transfer to society. Emissions of non-CO2 gases, such as CH4 and N2O emissions from agricultural sector, can be part of the pricing structure, not considering emission credits, but a differentiated tax policy focusing on the capital productive factor of each sector.

6.1) GHGs - COFFEE-TEA

COFFEE and TEA models simulate emissions from long-lived GHGs (CO2, CH4, N2O). CO2 emissions from fuel combustion are calculated based on energy sources. CO2 resulting from land-use changes is endogenously calculated as a consequence of the land use (taking difference of land use from previous year). Non-CO2 emissions, CH4, and N2O emissions are basically associated with each sector's activity level. GWP100 (AR5).

6.2) Pollutants and non-GHG forcing agents - COFFEE-TEA

6.3) Carbon dioxide removal (CDR) options - COFFEE-TEA

Storage is the last step of Carbon Capture and Storage (CCS), and involves finding a location or a way to store carbon dioxide, which was previously captured (separated and purified) from carbon sources. Several studies address the importance of CCS in achieving GHG emission reduction, Nonetheless, there is not a lot of literature on detailed assessment on the amount of reservoir capacity for carbon storage. The methodology used in this study differentiates between Enhanced Oil Recovery (EOR), Gas Fields and Saline Aquifers. For EOR, the potential was calculated from the amount of oil available for EOR with carbon storage coefficient from the literature. This coefficient varied between 0.27 to 0.32 tCO_2/bbl across regions, according to IEA-GHG (2009a).

As for gas fields, the procedure was basically the same as for EOR, but the gas fields were used. The coefficient for carbon storage was estimated from IEA-GHG (2009b), and varied from 2.3 to 2.9 tCO_2/kNm^3.

The last storage option, saline aquifers, has the highest storage potential, but there are many uncertainties regarding the extent to which the potential capacity can become usable storage (IEA-GHG, 2008). Another important stage of CCS, which can result in a considerable fraction of the cost associated with CO_2 storage is the transportation stage. Depending on the distance and the type of terrain where the CO_2 must pass, the costs associated with transportation can easily overcome the injection costs.

In order to estimate transportation costs, an analysis was made using a Geographic Information System (GIS) environment to estimate average distance between carbon storage reservoirs and main emissions sources. The location of major urban agglomerations was used as a proxy for emissions sources. As for the destination, the location of the main oil and gas fields around the world was used.

Also, to simplify the manipulation of data inside the model and simplify calculation time within the model, four standard steps for distance were used for all regions: 100 km; 500 km; 1,000km; and over 2,000 km.

7) Climate - COFFEE-TEA

Under development

7.1) Modelling of climate indicators - COFFEE-TEA

Under development

7.2) Climate damages, temperature changes - COFFEE-TEA

Under development

8) Non-climate sustainability dimension - COFFEE-TEA

Under development

8.1) Air pollution and health - COFFEE-TEA

Under development

8.2) Water - COFFEE-TEA

Under development

8.3) Other materials - COFFEE-TEA

Under development

8.4) Other sustainability dimensions - COFFEE-TEA

Under development

9) Appendices - COFFEE-TEA

9.1) Mathematical model description - COFFEE-TEA

9.2) Data - COFFEE-TEA

10) References - COFFEE-TEA

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