ETSAP Workshop and Training Course

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Energy technologies systems analysis: an introduction

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Content

A1 – Energy technologies

An energy technology is any device that produces, transforms, transmits, distributes or uses energy, such as refineries, power plants, pipelines, boilers, trucks, lamps, kilns, ovens, etc. Each one is characterized by different costs, efficiencies, emissions, ..

As for economic goods, some technologies are complementary: I cannot heat my apartment with natural gas if it is not extracted, purified, transported and distributed. If the transport technology becomes cheaper, more gas heating systems will be used.

Some technologies are substitutes: coal fired and nuclear power plants, a compact fluorescence and an incandescence lamp. If the first costs less, the latter has a smaller market.

A2 – Energy systems

No energy technology works in isolation, complementary technologies form chains, all substitute technologies and their chains form a system.

What is the efficiency of energy technology?

- From resources in place to primary energy, 10-90%
- From primary energy to final energy, 30-90%
- From final energy to useful energy, 40%
- From useful energy to energy services (change of unit)

What is the efficiency of the system? 10-25%

A3 – Energy system diagram: supply

Extraction Treatment	Gas Well	Coal Mine		Uranium Mine	Oil Well	Agroforesty
Primary Sources	Natural Gas	Coal	Sunlight/ Wind	Uranium	Oil	Biomass
Conversion/ Transport	Gas Pipeline/ LNG Tanker	Power Plant		Power Plant	Refinery	Ethanol Plant/ Biodiesel
Centralised Energy	Natural gas at the hub	High voltage electricity		High voltage electricity		
Distribution Technologies	Gas Grid	Electricity Grid	PV Cell/ Wind Farms	Electricity Grid	Truck	Truck
Final Energy	Gas	Low voltage Electricity	Low voltage Electricity	Low voltage Electricity	Kerosene	Ethanol/ Biodiesel

A4 – Energy system diagram: consumption

Final Energy	Gas	Low voltage Electricity	Low voltage Electricity	Low voltage Electricity	Kerosene	Ethanol/ Biodiesel
Energy end-use Devices	Furnace	Light Bulb	Heat Pump	Air conditioner	Motor Engine	Motor Engine
Useful Energy	Heat	Radiation	Heat	Cool	Work	Work
Non Energy end-use Devices	Reduced use of materials	Luminaire	Thermal insulation of the building	Thermal insulation of the building	The aircraft around the engine	The automobile around engine
						End Use
Energy Services	Non metallic minerals	Illumination	Feeling comfortably at home	Feeling comfortably at home	Long distance passenger transport	Urban passenger traffic

B1 – Systems analysis

Systems analysis "*applies systems principles to aid decision makers in problems of*

- *identifying,*
- *quantifying, and*
- *controlling*

a system" (quoted from Principia Cybernetica). "*While taking into account multiple objectives, constraints, resources, it aims to specify possible courses of action, together with their risks, costs and benefits.*"

B2 – Main dimensions of energy systems

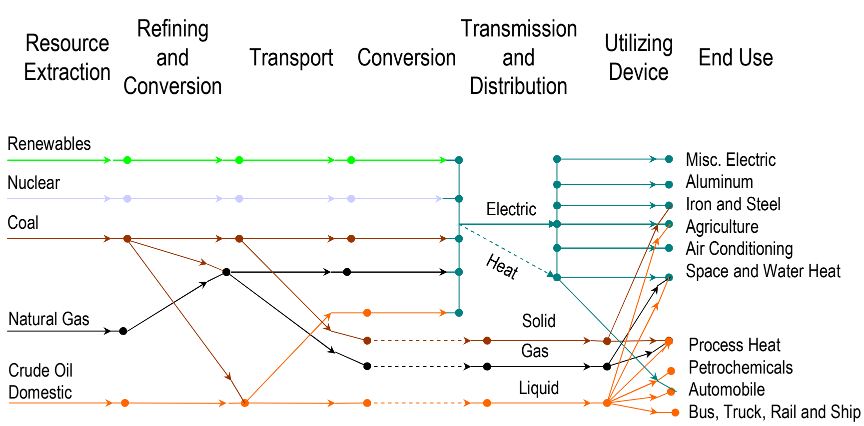
- Energy
- Engineering
- Environment
- Economy

Other important dimensions, such as political, administrative, risk and safety, social, etc. are studied by social sciences

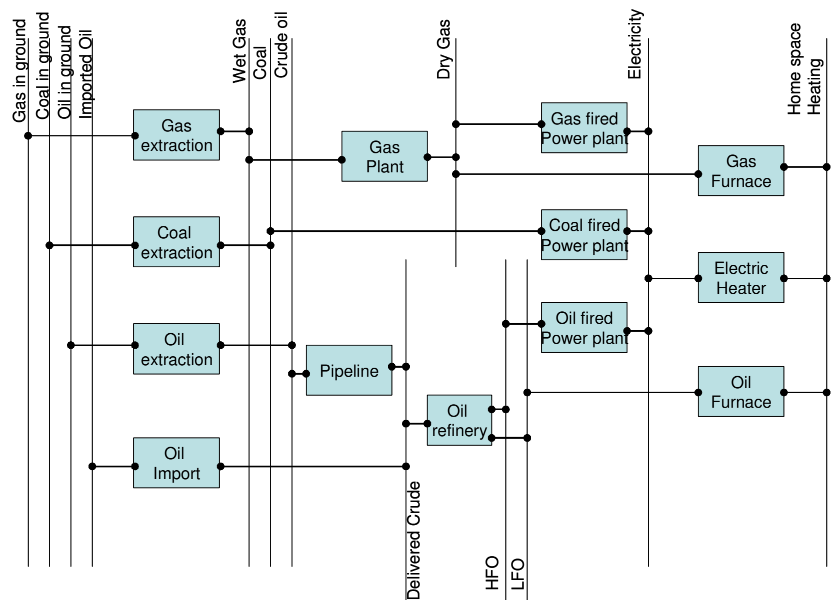
C1a – Identification of the system

a. Space boundaries: the globe, region, nation, province, town; single or multi-region;
b. Logical boundaries: from mining to the production of useful energy and energy services;
c. Time horizon (2020? 2050? 2100?), temporal details;
d. Components: energy commodity flows (natural gas, coke, gasoline, etc.), transformation technologies (power plants, refineries, etc.) and demand devices (car, fridge, etc.); and
e. Internal connections (the Reference Energy System) and external dependencies.

C1b – Reference Energy System (1)



C1c – Reference Energy System (2)



C2 – Quantification of the present system

The 4E main dimensions are quantified and integrated:

a. Energy commodity flows

b. Stock of existing transformation processes and end use devices, by category and vintage

c. Emissions by species

d. Prices and values of commodities, technologies, sub-systems and total system.

C2a – Quantification of energy flows

SUPPLY AND CONSUMPTION	Coal	Crude Oil	Petroleum Products	Gas	Nuclear	Hydro	Geotherm. Solar, *etc.*	Combust. Renew.	Electricity	Heat	Total
Thousand tonnes of oil equivalent											
Production	698779	164131	-	31365	4553	23859	-	215930	-	-	1138617
Imports	1369	60260	28315	-	-	-	-	-	155	-	90098
Exports	-67316	-7550	-11495	-	-	-	-	-	-876	-	-87238
Intl. Marine Bunkers	-	-	-3969	-	-	-	-	-	-	-	-3969
Stock Changes	4526	-1297	-1369	-	-	-	-	-	-	-	1860
TPES	**637358**	**215544**	**11481**	**31365**	**4553**	**23859**	**-**	**215930**	**-722**	**-**	**1139369**
Transfers	-	-	-	-	-	-	-	-	-	-	-
Statistical Differences	13753	-3824	-1989	-3988	-	-	-	-	-	-	3952
Electricity Plants	-290951	-816	-11103	-1344	-4553	-23859	-	-838	126563	-	-206903
Heat Plants	-35986	-123	-4096	-1697	-	-	-	-490	-	36585	-5807
Gas Works	-4670	-	-228	3827	-	-	-	-	-	-	-1072
Petroleum Refineries	-	-204068	201793	-	-	-	-	-	-	-	-2275
Coal Transformation	-45850	-	-	-	-	-	-	-	-	-	-45850
Own Use	-30016	-4422	-15046	-7822	-	-	-	-	-19240	-9335	-85882
Distribution Losses	-126	-	-17	-643	-	-	-	-	-8881	-430	-10097
TFC	**243511**	**2291**	**180795**	**19697**	**-**	**-**	**-**	**214602**	**97720**	**26820**	**785435**
Industry	165870	2092	51984	12449	-	-	-	-	61562	20110	314067
Transport	5280	-	69161	228	-	-	-	-	1307	-	75977
Agriculture	3688	-	16119	-	-	-	-	-	6676	57	32841
Comm. and Publ. Services	5400	-	16014	588	-	-	-	-	6439	450	28892
Residential	43981	-	13652	6431	-	-	-	214602	15817	5581	300064
Non-specified	4174	136	-	-	-	-	-	-	5917	622	10912
Non-energy use	8818	-	13865	-	-	-	-	-	-	-	22683
Electr. Generated - GWh	*1121973*	-	*47343*	*5474*	*17472*	*277432*	-	*1963*	-	-	*1471657*
Heat Generated - TJ	*1307224*	-	*147659*	*63965*	-	-	-	*13187*	-	-	*1532035*

Example: China, 2001 (Excluding Hong Kong)

C2b – Characterization of the existing stock of energy technologies and end-use devices

GENERAL	TECHNICAL	ECONOMIC	ENVIRONMENTAL	LABOUR & MAT.	REF.
technology	av. size	currency	GHG emissions	materials	title
techn. sector	existing capacity	costs	solid waste	- steel	autor
data quality	construction time	- investiment	liquid waste	- concrete	editor
technical availability	technical life	- fixed o&m	gaseous waste	- …	type
commercial availab.	max. availability	- variable o&m	acustic impact	- …	year
prototype	av. availability	- fuel	land use	labour	access
commercialization	energy input	- total ex. fuel		- construction	
market share	energy output	- total incl. fuel		- operation	
		- decommiss.			

C2c – Emissions by species and process

Emissions in kilotonnes, except CO2 in megatonnes

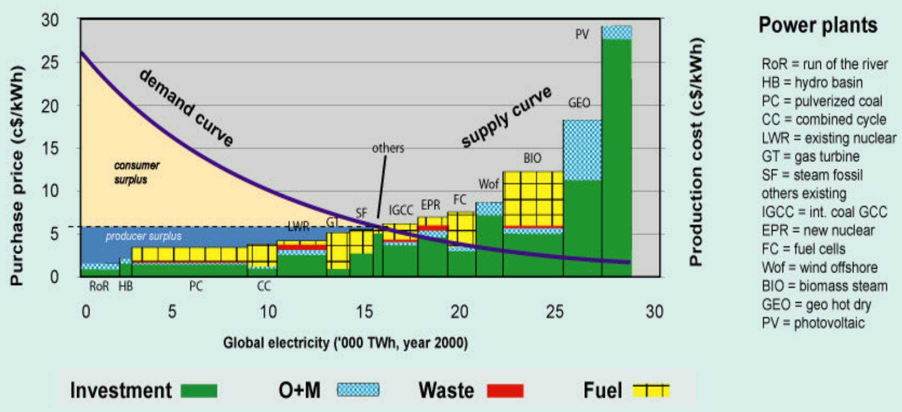
Snap90 Code	Description	SO_2	NO_X as NO_2	NMVOC	CH_4	CO	CO_2	N_2O	NH_3
GROUP 1	PUBLIC POWER, COGENERATION AND DISTRICT HEATING								
10100	Public power and cogeneration plants								
10101	Combustion plants > = 300 mw	13691	3316	41	33	650	1160	84	1
10102	Combustion plants > = 50 and < 300 mw	385	161	2	2	25	58	5	
10103	Combustion plants < 50 mw	110	29	1	1	8	19	2	
10104	Gas turbines	8	38			11	10		
10105	Stationary engines	25	28	1		6	1		
10200	District heating plants								
10201	Combustion plants > = 300 mw	129	46	1	1	6	19	2	
10202	Combustion plants > = 50 mw and < 300 mw	326	67	2	2	23	27	3	
10203	Combustion plants < 50 mw	272	69	5	4	80	36	2	
10204	Gas turbines		2			1	1		
10205	Stationary engines		2						

C2d1 – Energy commodity prices (IEA, $US2006)

	Heavy Fuel Oil for Industry[b] (tonne)	Light Fuel Oil for Households (1000 litres)	Automotive Diesel Oil[c] (litre)	Unleaded Premium[d] (litre)
South Africa	387.53 L	..	0.780 L	0.822 L
Slovak Republic	305.38	..	1.157	1.369
Spain	372.15	725.63	1.005	1.248
Sweden	914.91	1 327.54	1.206	1.557
Switzerland	315.79 L	564.88	1.153	1.260
Turkey	642.98	1 488.40	1.553	1.944
United Kingdom	464.66	680.18	1.521	1.706
United States	307.94	644.76	0.674	0.624

Nat Gas for Industry (10^7 kcal GCV[e])	Nat Gas for Households (10^7 kcal GCV[e])	Steam Coal for Industry[f] (tonne)	Electricity for Industry[g] (kWh)	Electricity for Households[g] (kWh)	
377.37 L	x	21.07	0.0218 L	0.0592 L	South Africa
398.25	618.77	..	0.1283	0.1733	Slovak Republic
373.18	840.73	..	0.0913 L	0.1647 L	Spain
..	..	..	..	..	Sweden
566.75	850.61	103.00	0.0816	0.1325	Switzerland
402.78	479.19	65.25	0.1008	0.1128	Turkey
379.48 L	801.12	88.39 L	0.1322 L	0.2205	United Kingdom
304.93	464.33	56.77	0.0613	0.1002	United States

C2d2 – Energy prices as equilibrium point of technical-economic (inverse) supply-demand curves



Typical representation of an energy commodity in MARKAL - TIMES.
The algorithm maximises the global surplus over thousands such markets.

C2d3 – The unit price of emissions as equilibrium point of supply – demand curves

Emissions / wastes (i.e. commodities with negative values) are specified in terms of avoided emissions / wastes, where:

- Q = emission reduction;
- The (inverse) supply curve (Q) = the cost of emission reduction technologies and options (the 'cost' is zero when reductions are not taking place, it increases when alternative less polluting technologies are used); and
- The (inverse) demand curve (Q) = the damage function of actual emissions (the 'cost' is maximum when the emission is not reduced and decreases when reductions increase).

The unit (marginal) value of the emission is given by the crossing point of the two curves at the economic equilibrium.

C3 – Control of system's future developments

1. Policy and decision makers define targets
2. Analysts calculate possible development paths of the system (energy fuels and technologies, costs and emissions (exploratory scenarios)
3. From a menu of "control" tools offered by political sciences, analysts identify optimal control strategies for each target, evaluate their impacts and tradeoffs between diverging objectives / dimensions (policy or normative scenarios)
4. Decision makers adopt a strategy or ask for more analyses or define alternative targets

ETSAP has developed an innovative methodology and tools for carrying out steps 2 and 3 through <u>models</u>

D – Where the IEA Energy Technology Systems Analysis Program contributes?

1. Identification and representation of Reference Energy Systems
2. Integration of the four main quantitative dimensions of the problem: energy, engineering, economy and environment
3. Representation of the systems and their developments in technical economic equilibrium models (MARKAL – TIMES models generators; ANSWER – VEDA users' interfaces)
4. Generation of development paths of energy system flows, technologies, costs and emissions (scenarios)
5. Evaluation of the energy, technological, economic and environment impact of different policy objectives and control strategies to be adopted, under uncertainty.