Integrated course „Energy Economics“
- Energy Balances -

Chair of Energy Systems | Department of Energy Systems
Technische Universität Berlin

Outline

- Energy sources
- Energy flow chart
- Energy balances
- Tutorial on energy balances
- Data sources
- Explore energy statistics in groups

Introduction: Energy economics

Economics is a social science studying production, distribution and consumption of goods and services.

Economics deals with allocation of scarce resources.

Energy is abundant in the nature but mostly not immediately applicable for doing useful work.

Engineering know-how + Economic viability

Primary and secondary energy sources

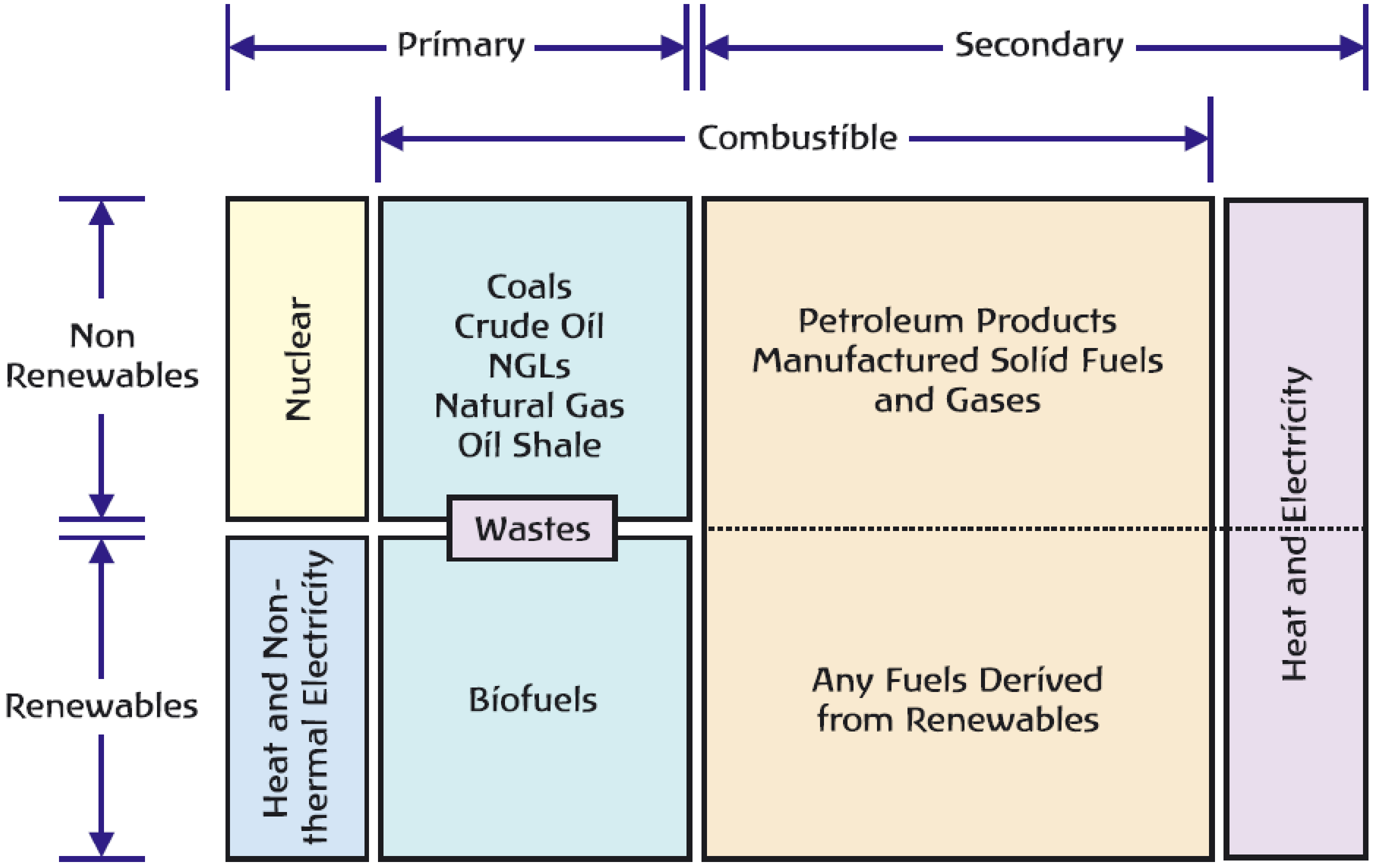
Primary energy sources are in the form as found in nature and have not undergone any transformation.

- oil, coal, natural gas, nuclear, wind, solar, biomass, geothermal, hydropower

Secondary energy sources are forms of energy after conversion, either chemical or physical.

- electricity, refined fuels (e.g. gasoline), synthetic fuels (e.g. hydrogen)
- easily usable form

Classification of Energy Sources



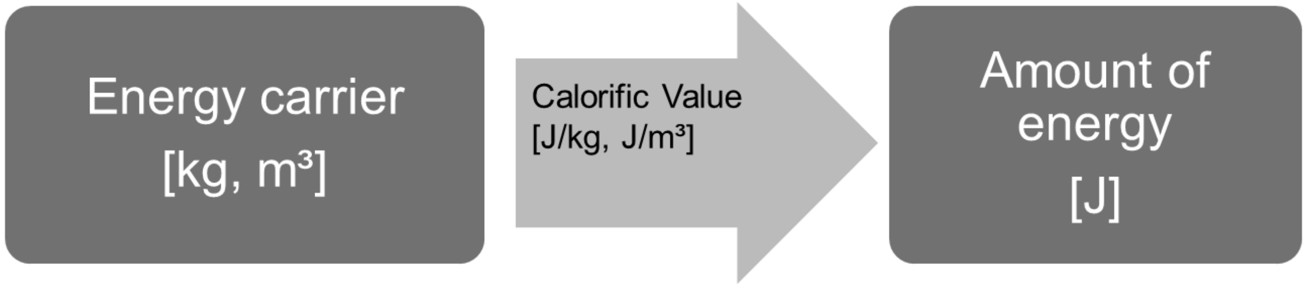
Source: OECD/IEA Energy Statistics Manual, 2005

Measuring primary energy

Primary energy sources are originally measured in units corresponding to their natural form: volume, mass etc.

Original units can be converted into energy units.

Calorific value is used for energy sources that can be converted into heat through combustion: coal, gas, oil, biomass.



@ Ensys

Upper and lower calorific/heating values

- Lower Heating Value H_i (Heating Value): maximum amount of usable heat from combustion (without counting the conensation enthalpy of water vapor contained in the exhaust gas).

- Upper Heating Value H_s (Gross Calorific Value): condensation enthalpy of water vapor (2.44 MJ/kg at 25°C) is included.

  For methane H_s is 111% of H_i.

Lower calorific value of energy fuels

	Density	Energy [10^9 J]	Remarks
1 t Crude oil	0.86 g/cm^3	39–43	Mean: 41.9·10^9 J
1 Barrel (bbl) crude oil		5.7	=159 l (ca. 50/365 t.o.e.)
1 t Heating oil el.	0.84 g/cm^3	42.5	at 15–20 ºC
1 t Gasoline	0.75 g/cm^3	43.1	at 15–20 ºC
1 t Methanol (CH_3OH)	0.80 g/cm^3	19.7	
1 t Ethanol (C_2H_5OH)	0.80 g/cm^3	26.9	
1 t Liquefied Petroleum Gas LPG	0.53 g/cm^3	45.9	at 2–18 bar
1 t Liquefied Natural Gas LNG	0.47 g/cm^3	47.2	at –164 ºC
1 t Hydrogen (LH_2)	0.071 g/cm^3	120.4	at –252 ºC
1000 m^3 Natural gas L	0.82 kg/m^3	33.4	Mean: 35.6·10^9 J
1000 m^3 Natural gas H	0.79 kg/m^3	36.6	
1000 m^3 Compressed gas CNG	156 kg/m^3	7000	at 200 bar
1000 m^3 Petroleum gas		40.7	
1000 m^3 Methane (CH_4)	0.65 kg/m^3	35.8	
1000 m^3 Propane (C_3H_8)	1.87 kg/m^3	86.7	
1000 m^3 hydrogen (H_2)	0.09 kg/m^3	10.8	
1000 m^3 Liquefied hydrogen (H_2)	15.6 kg/m^3	1950	at 200 bar
1 t Hard coal		29–35	Mean 29.3· 10^9 J
1 t Lignite		7.5–13	
1 t Wood	0.6 g/cm^3	14.6	3.5 · 10^6 kcal
1 t Uranium oxide (U_3O_8)		414'000	Light Water Reactor LWR

Energy units

Energy unit conversion						
	MJ	**kcal**	**kWh**	**t.o.e.**	**Barrel**	**t.c.e.**
1 MJ	1	238,8	0,2778	23,88 E^{-6}	175 E^{-6}	34,14 E^{-6}
1 kcal	0,0042	1	0,00116	0,1 E^{-6}	0,73 E^{-6}	0,143 E^{-6}
1 kWh	3,6	860	1	86 E^{-6}	630 E^{-6}	123 E^{-6}
1 t.o.e.	41.880	10 E^{+6}	11.630	1	7,33	1,430
1 Barrel	5.713	1,36 E^{+6}	1.587	0,1364	1	0,195
1 t.c.e.	29.290	6,995 E^{+6}	8.136	0,6995	5,127	1

Source: Zweifel / Praktiknjo / Erdmann, 2017

Example: Energy units conversion

Unit	Density	Energy [10^9 J]	Remarks
1 t of crude oil	0,86 g/cm^3	39-43	mean: 41,9 · 10^9 J
1 barrel (bbl) of crude oil		5,7	= 159 l (rule of thumb: 50/365 t.o.e.)
1000 m^3 of natural gas (H gas)	0,79 kg/m^3	36,6	
1 t of hard coal		29-35	mean: 29,3 · 10^9 J

1 t.o.e. (tonne of oil equivalent) is equivalent to the energy content of:

- 1 t of crude oil*, or*
- 41,9 GJ / 5,7 GJ = 7,35 barrel or crude oil*, or*
- 41,9 GJ / 36,6 GJ = 1,1448 · 10^3 m^3 = 1144,8 m^3 of natural gas*, or*
- 41,9 GJ / 29,3 GJ = 1,43 t of hard coal

Unit Prefixes

Unit prefixes		
10^3	k	Kilo
10^6	M	Mega
10^9	G	Giga
10^{12}	T	Tera
10^{15}	P	Peta
10^{18}	E	Exa

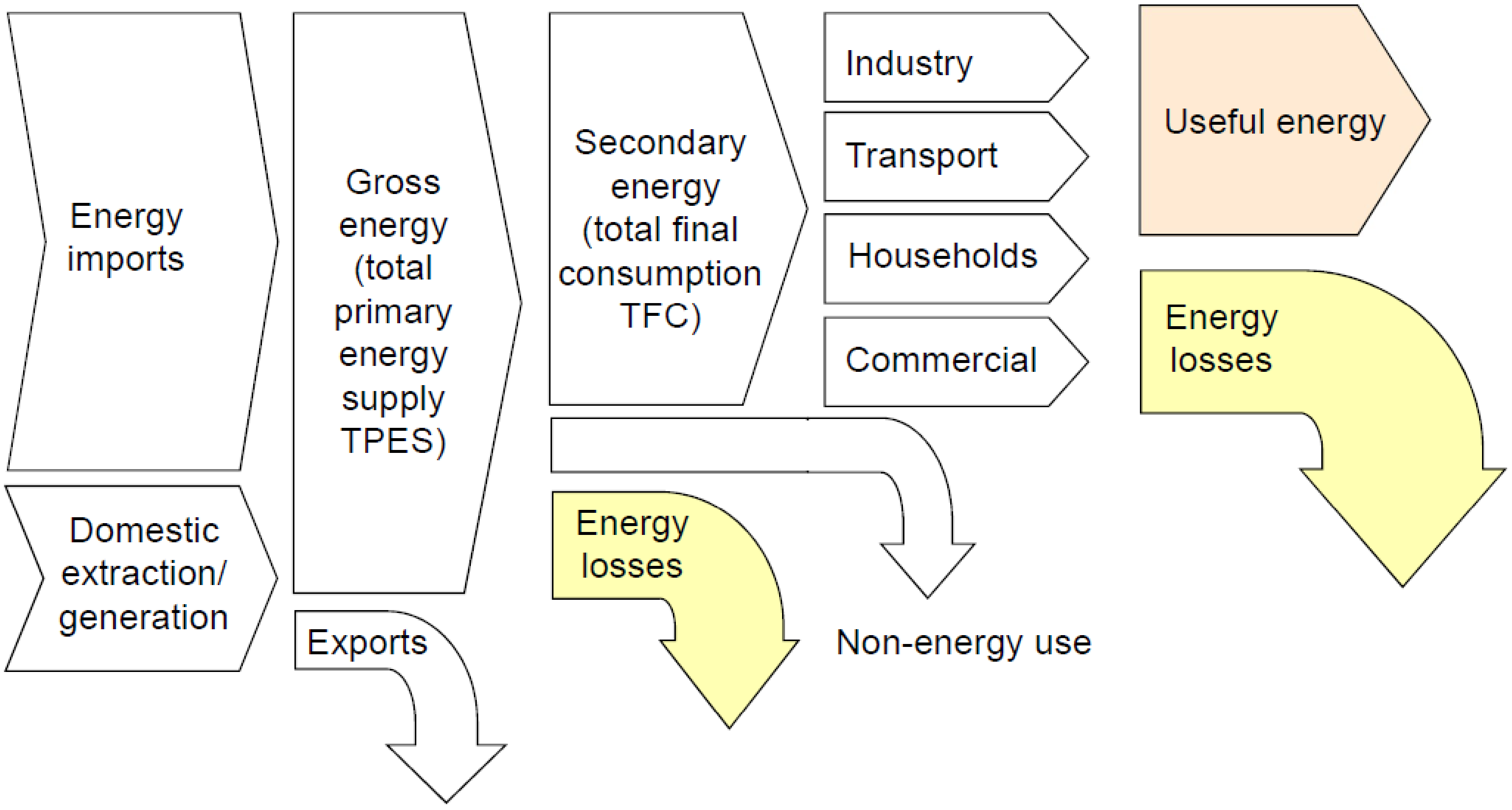
Energy conversion efficiency

Efficiency of an energy conversion device:

$$\eta = \frac{\text{Useful energy output}}{\text{Energy input}}$$

Example: How much natural gas is required for generating 100 MWh of electricity in a gas power plant with an efficiency of 50%?

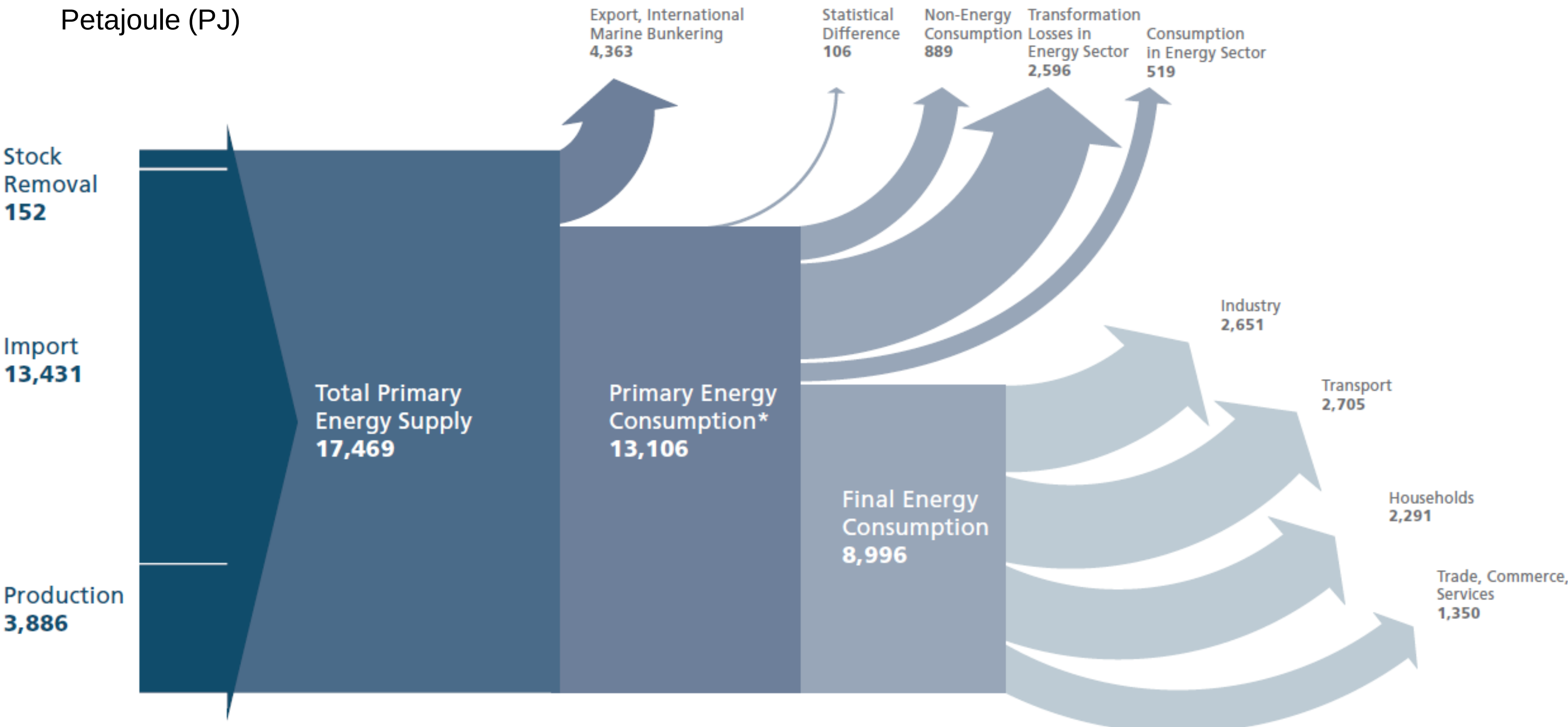
Energy flow chart



Source: Zweifel / Praktiknjo / Erdmann, 2017

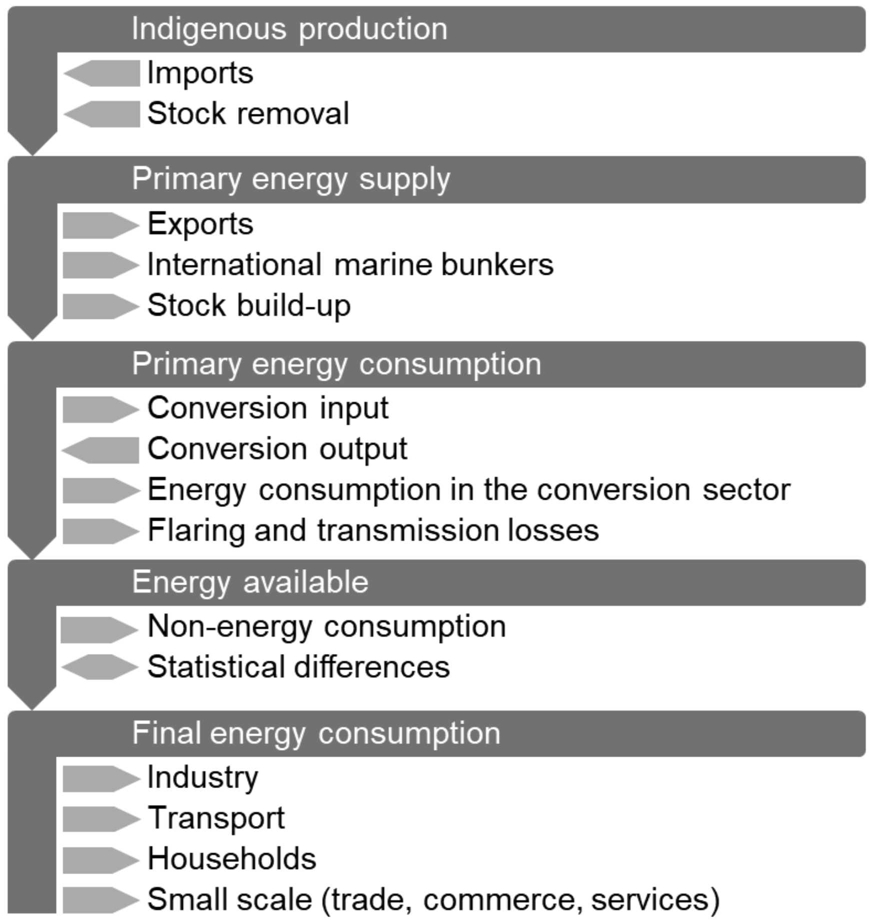
Energy Balances: Energy flow chart for Germany in 2018

Petajoule (PJ)



Source: AGEB, 2019

Energy balance structure (AGEB)



EU Energy Balance: Simplified structure

EU-28, 2014 (ktoe)	Total (all products)	Solid fossil fuels	Crude oil & petroleum products	Gas	Nuclear heat	Renewable energies	Non-renewable wastes	Electricity	Derived heat
+ Primary production	770 722	149 335	70 030	117 019	226 132	195 814	12 392		
+ Primary production receipt	9 370		9 370						
+ Other sources (recovered products)	4 909	685	3 968	256					
+ Recycled products	1 125		1 125						
+ Imports	1 411 681	159 831	882 362	320 253		15 704	255	33 270	
+ Stock changes	- 9 349	- 4 041	358	- 5 451		- 220	6		
- Exports	530 788	37 293	362 306	89 161		10 057	29	31 937	
- Bunkers	41 622		41 622						
- Direct use	10 116		10 116						
Gross inland consumption	1 605 931	268 517	553 168	342 917	226 132	201 241	12 624	1 332	
Transformation input	1 277 176	253 214	627 959	102 222	226 132	57 134	9 297	192	1 02
+ Conventional thermal power stations	357 010	190 639	12 879	92 227		51 703	8 536		1 02
+ Nuclear power stations	226 132				226 132				
+ District heating plants	19 484	3 816	1 048	8 521		5 146	761	192	
+ Coke ovens	39 002	38 367	624	11					
+ Blast furnaces	13 421	13 421							
+ Gas works	736	710	1	25					
+ Refineries	613 159		613 159						
+ Patent fuel plants	245	171	74						
+ BKB/PB plants	4 958	4 958							
+ Charcoal production plants	227					227			
+ Coal liquefaction plants	839	839							
+ For blended natural gas	231		175			56			
+ Gas-To-Liquids (GTL) plants									
+ Non-specified Transformation Input	1 734	293		1 439		2			
Transformation output	932 177	33 008	612 716	21 162		69		209 643	55 57
+ Conventional thermal power stations	173 718							134 296	39 42
+ Nuclear power stations	75 437							75 348	8
+ District heating plants	16 068								16 06
+ Coke ovens	35 927	28 712		7 214					
+ Blast furnaces	13 421			13 421					
+ Gas works	526			526					
+ Refineries	612 716		612 716						
+ Patent fuel plants	207	207							
+ BKB/PB plants	4 089	4 089							
+ Charcoal production plants	69					69			
Exchanges, transfers and returns	2 428		2 428			- 61 990		61 990	
Consumption of the energy branch	77 518	669	31 050	18 131		912	62	22 536	4 15
Distribution losses	24 960	48	47	2 810		25	0	17 505	4 52
Available for final consumption	1 160 881	47 595	509 255	240 915		81 249	3 264	232 733	45 87
Statistical difference	*- 191*	*- 499*	*2 277*	*- 2 198*		*- 129*	*- 0*	*32*	*32*
Final non-energy consumption	99 387	1 518	84 020	13 849					
Final energy consumption	1 061 684	46 576	422 957	229 264		81 378	3 264	232 701	45 54

+ Industry
+ Transport
+ Other sectors

Source: Eurostat

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Accounting for RES

How to value energy carriers which do not have a calorific value, e.g. wind, PV, nuclear energy, electricity imports, water, geothermal heat?

- Substitution Principle: amount of fuel that would be necessary to produce that amount of electricity in a thermal powerplant (35-40%)
- Efficiency Principle: actual efficiency of respective technology (hydro 80-90%, wind 30-55%, solar 10-25%)
- Fictive Efficiency Principle (IEA): 100% for wind, solar, hydro (underestimated RES share)

Energy Balance: Cumulated energy requirement

Cumulated energy requirement is total primary energy amount required for production, use and disposal of a product over its lifetime.

$$CER = CER_P + CER_U + CER_D$$

CER is used in life-cycle assessment to account for all environmental impacts of an industrial process.

'Grey energy‘

Energy required for production/recycling is not reflected in the national energy balances in this case.

Task 1) Basics

a) Explain the difference between primary and secondary energy sources!

b) Why does the primary energy consumption comprise secondary energy sources?

c) All power plants and all industrial plants require energy for their construction. Where do those energy flows appear in the energy balance?

Task 1) Basics

d) What are the consequences of this fact for the real share of useful energy on the amount of primary energy?

e) There is another important category of energy imports that does not appear in the energy balance. What could this be?

Task 1) Basics

f) The average efficiency of all fossil power plants in an exemplary country is 36 %. The share of renewables of electricity production is 10 %. What is the share of renewables of total primary energy consumption if you use the substitution method and what, if you use the IEA-method?

Task 2) German Energy Balance of 2015

Please have a look at the German energy balance of 2015 and answer the following questions:

a) How much electricity was generated overall in 2015 (in GWh) and how high was the share of renewables (in percent)?

b) What is the average efficiency (in percent) of a German public thermal power station?

c) What is the assumed efficiency (in percent) of nuclear power plants and how is it calculated?

d) Please calculate the internal electricity consumption at electricity production and the conduction losses at the transport from power plant to end user (absolute and percentage values with respect to the total conversion output).

e) The calculation of renewable primary energy consumption is based on the ________-method. Give reasons for your answer.

f) If the substitution-method is used, what is the primary energy consumption in PJ (PJ = 1000 TJ) of Hydro-, Wind- and Photovoltaic Power Plants?

g) What does the negative primary energy consumption of motor gasoline imply and how much of motor gasoline was consumed in 2015?

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Energy Balances: Recap

Define the components of an energy flowchart and draw a scheme with the given components.

- Energy imports
- Domestic extraction
- Gross Energy
- Export
- Total Final Consumption (TFC)
- Losses
- Non-energy consumption
- Industry, Transport, Households, Commercial
- Useful Energy

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Energy Balances: Recap

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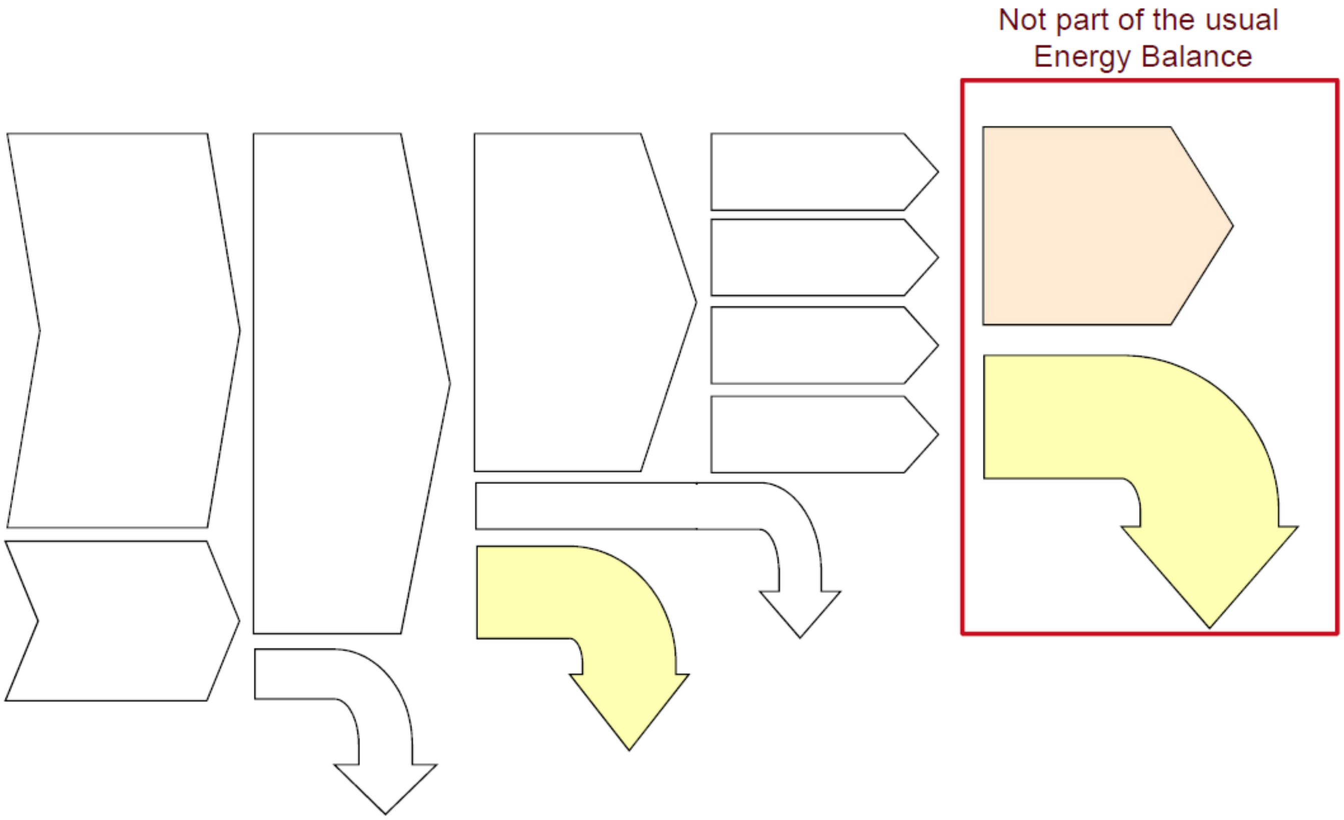

Task 3) Comparison of 2007 and 2015

For the following questions please work with the German energy balances of 2007 and 2015. The balances are taken from www.ag-energiebilanzen.de.

a) What is the share (in percent) of the transport sector (total transport, including rail transport, road transport, aviation, and shipping) of the total primary energy consumption in the years 2007 and 2015?

b) How did the energy consumption of road transport change between 2007 and 2015 in Germany? What was the average yearly increase? Please give exact results (3 digits):

c) Give at least two reasons that could lead to an increase of energy consumption of road transport and two different reasons that could lead to a decrease. Give technical and non-technical reasons.

d) What is the share of the energy consumption of diesel vehicles of the total energy consumption of road transport in 2007 and in 2015?

e) What could be the reason that today we have more diesel consumption than 2007? Give two possible reasons.

f) What is the share of biofuels of the total energy consumption of road transport in Germany in the year 2007?

g) Which policy instruments are responsible for this?

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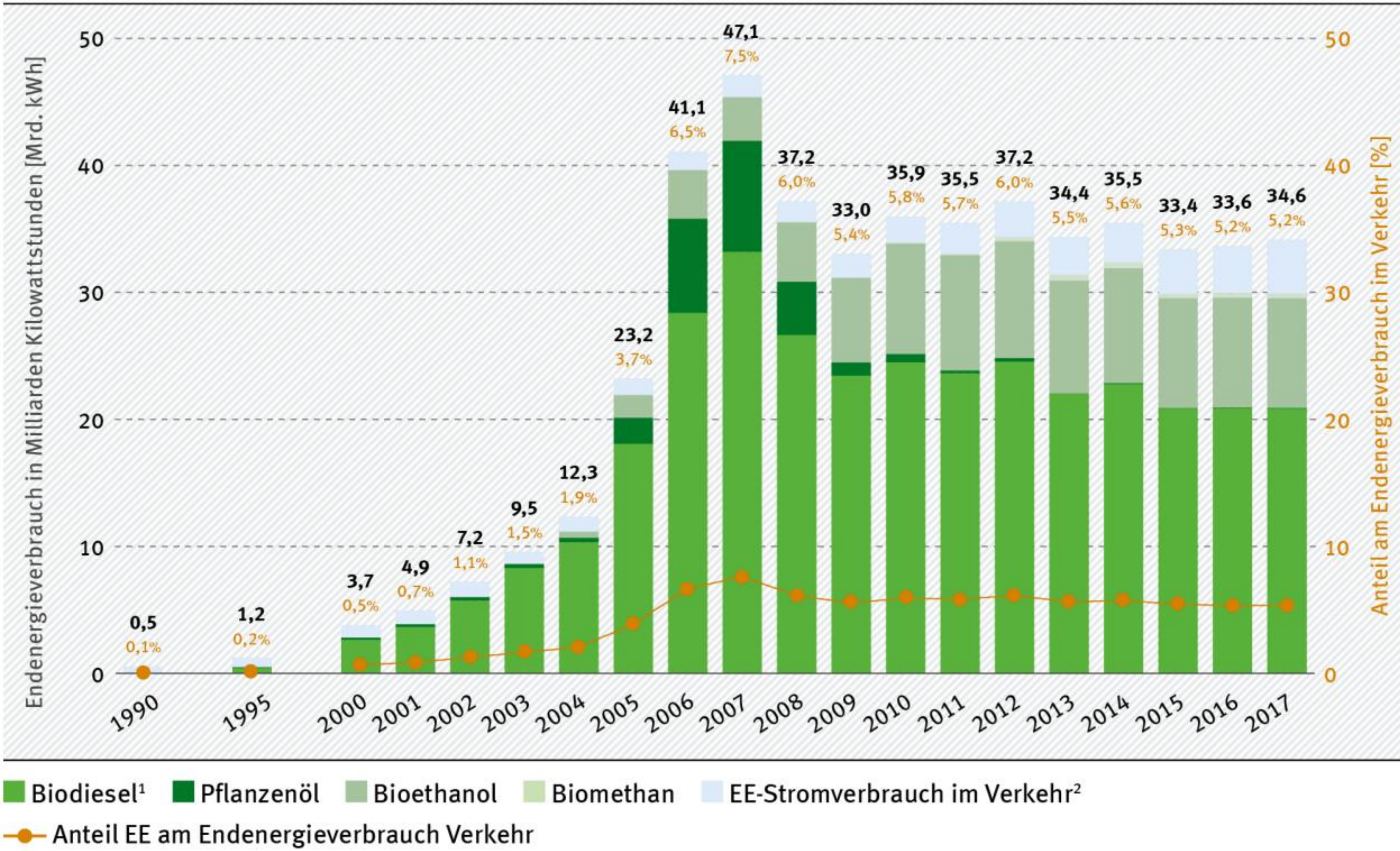
RES in the transport sector

Source: UBA 2018



Data sources: Energy statistics online

- IEA
- BP Review
- U.S. Energy Information Administration
- Eurostat
- ENTSO-E, ENTSO-G
- EEX
- AGEB
- BNetzA
- BMWi

Data sources: IEA

International Energy Agency (IEA) is an automonous intergovernmental organisation providing authoritative analysis on global energy topics (publications, data and statistics, trainings).

OECD member countries (30 out of 36)

- IEA World Energy Outlook
- IEA Market Reports
- Key World Energy Statistics

https://www.iea.org/statistics/

Data Sources: BP Review of World Energy

British Petroleum is a multinational oil and gas company.

- BP Energy Outlook
- BP Statistical Review of World Energy

https://www.bp.com/en/global/corporate/energy-economics.html

Data Sources: U.S. EIA

U.S. Energy Information Administration (EIA) is a federal agency responsible for energy statistics and analysis (part of the U.S. Federal Statistical System).

www.eia.gov

International Energy Statistics

Data Sources: Eurostat

Eurostat is a division of European Commission tasked with providing statistical information to the institutions of the European Union and with promoting harmonisation of statistics across EU member states.

https://ec.europa.eu/eurostat/web/energy/data/energy-balances

Data Sources: ENTSO-E

European Network of Transmission System Operators for Electricity (ENTSO-E) is an association of 43 electricity TSOs from 36 countries across Europe.

- Policy positions
- Technical cooperation among TSOs, network codes
- Long-term pan-European network development plan
- Reports on system adequacy
- Research coordination

ENTSO-E Transparency Platform

pan-European generation, transportation and consumption data

https://transparency.entsoe.eu/

Data Sources: ENTSO-G

European Network of Transmission System Operators for Gas (ENTSO-G) is an association of 44 electricity TSOs (+3 associated partners and 8 observers).

- Policy positions
- Technical cooperation among TSOs, network codes
- Long-term development plan for European gas infrastructure
- Reports on security of supply

ENTSO-G Transparency

https://transparency.entsog.eu/

Data Sources: EEX

European Energy Exchange (EEX) in Leipzig is an exchange for energy and energy-related products.

electricity, gas, coal, crude oil, CO_2 emission certificates etc.

EEX, EPEX SPOT, PEGAS/Powernext

www.eex.com > Market Data

Data Sources: AG Energiebilanzen (AGEB)

Working Group on Energy Balances (Energy Balances Group)

German association tasked with scientific analysis of energy statistics (four federations of the energy industry and five research institutions).

Compiles yearly energy balances of Germany

www.ag-energiebilanzen.de

Data Sources: BNetzA

Federal Network Agency (BNetzA) is a German agency tasked with regulation in the electricity, gas, telecommunication, post and railway sectors.

SMARD – information platform

electricity generation, consumption, wholesale prices, imports/exports, system stability

www.smard.de

BNetzA Monitoring reports - key findings in English

https://www.bundesnetzagentur.de/EN/Areas/Energy/Companies/DataCollection_Monitoring/DataCollectionMonitoring_node.html

Data Sources: BMWi

German Federal Ministry of Economics and Energy (BMWi)

Energy Data: Complete Edition

Compilation of data from various sources

https://www.bmwi.de/Redaktion/EN/Artikel/Energy/energy-data.html