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.

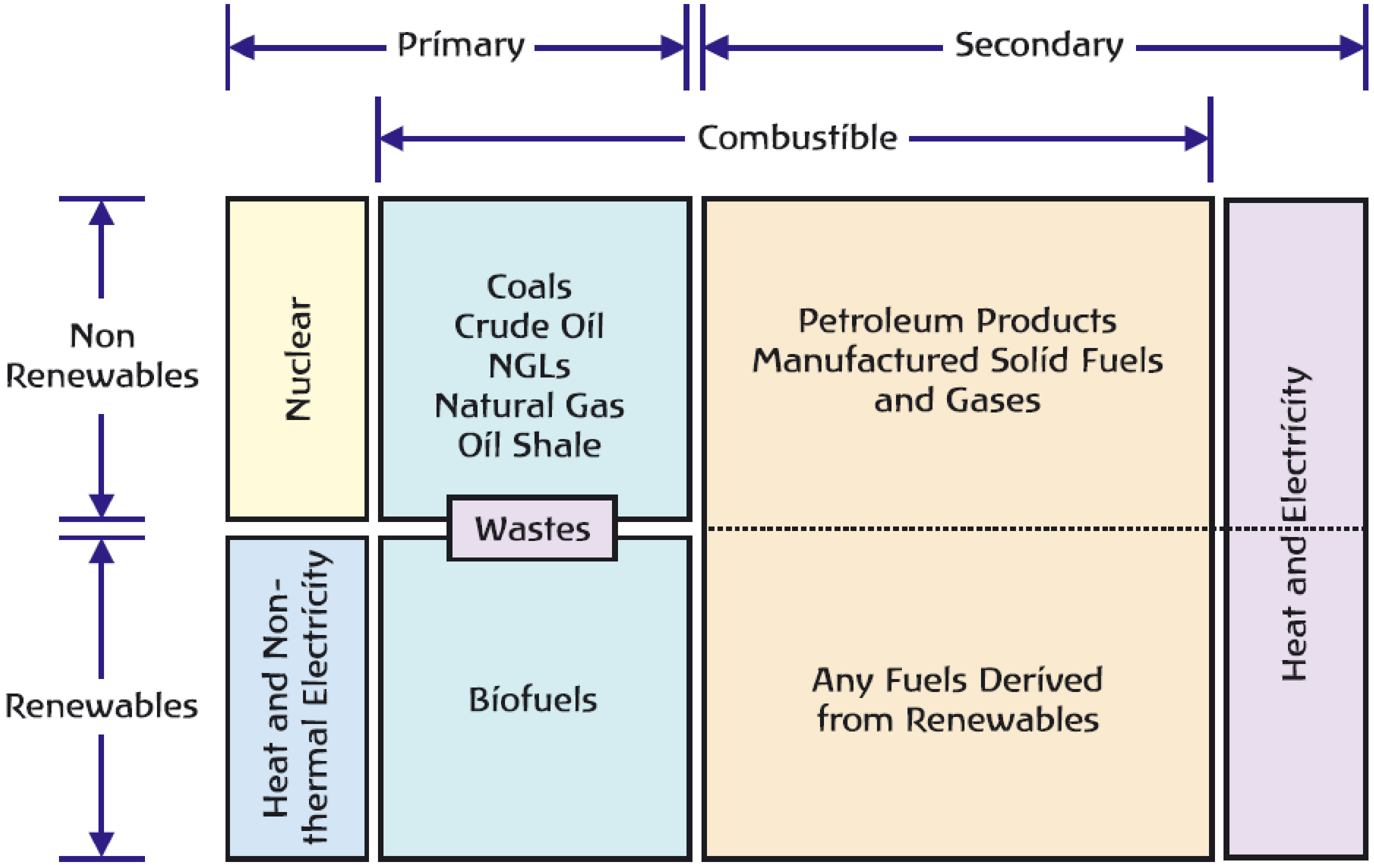
oil, coal, natural gas, nuclear, wind, solar, biomass, geothermal, hydropower

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



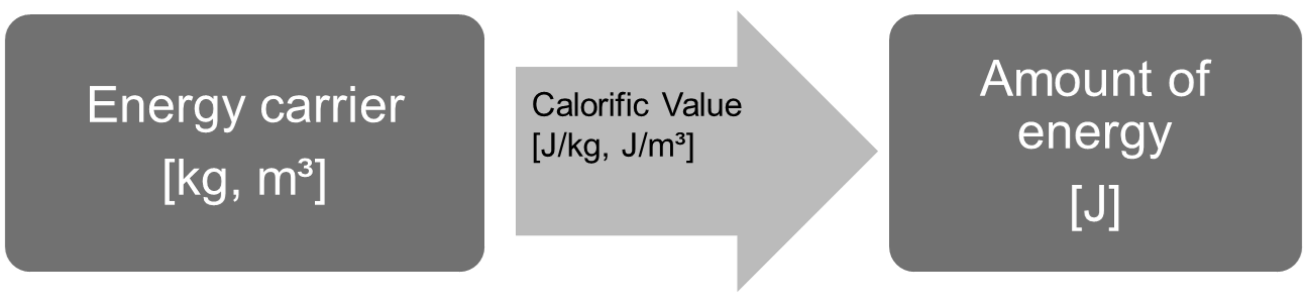
Source: OECD/IEA Energy Statistics Manual, 2005

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.



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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.

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Lower calorific value of energy fuels

	Density	Energy [10^9 J]	Remarks
1 t Crude oil	0.86 g/cm³	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/cm³	42.5	at 15–20 ºC
1 t Gasoline	0.75 g/cm³	43.1	at 15–20 ºC
1 t Methanol (CH_3OH)	0.80 g/cm³	19.7	
1 t Ethanol (C_2H_5OH)	0.80 g/cm³	26.9	
1 t Liquefied Petroleum Gas LPG	0.53 g/cm³	45.9	at 2–18 bar
1 t Liquefied Natural Gas LNG	0.47 g/cm³	47.2	at –164 ºC
1 t Hydrogen (LH_2)	0.071 g/cm³	120.4	at –252 ºC
1000 m³ Natural gas L	0.82 kg/m³	33.4	Mean: 35.6·10^9 J
1000 m³ Natural gas H	0.79 kg/m³	36.6	
1000 m³ Compressed gas CNG	156 kg/m³	7000	at 200 bar
1000 m³ Petroleum gas		40.7	
1000 m³ Methane (CH_4)	0.65 kg/m³	35.8	
1000 m³ Propane (C_3H_8)	1.87 kg/m³	86.7	
1000 m³ hydrogen (H_2)	0.09 kg/m³	10.8	
1000 m³ Liquefied hydrogen (H_2)	15.6 kg/m³	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/cm³	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/cm³	39-43	mean: $41{,}9 \cdot 10^9$ J
1 barrel (bbl) of crude oil		5,7	= 159 l (rule of thumb: 50/365 t.o.e.)
1000 m³ of natural gas (H gas)	0,79 kg/m³	36,6	
1 t of hard coal		29-35	mean: $29{,}3 \cdot 10^9$ 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 = $1{,}1448 \cdot 10^3$ m³ = 1144,8 m³ 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

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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%?

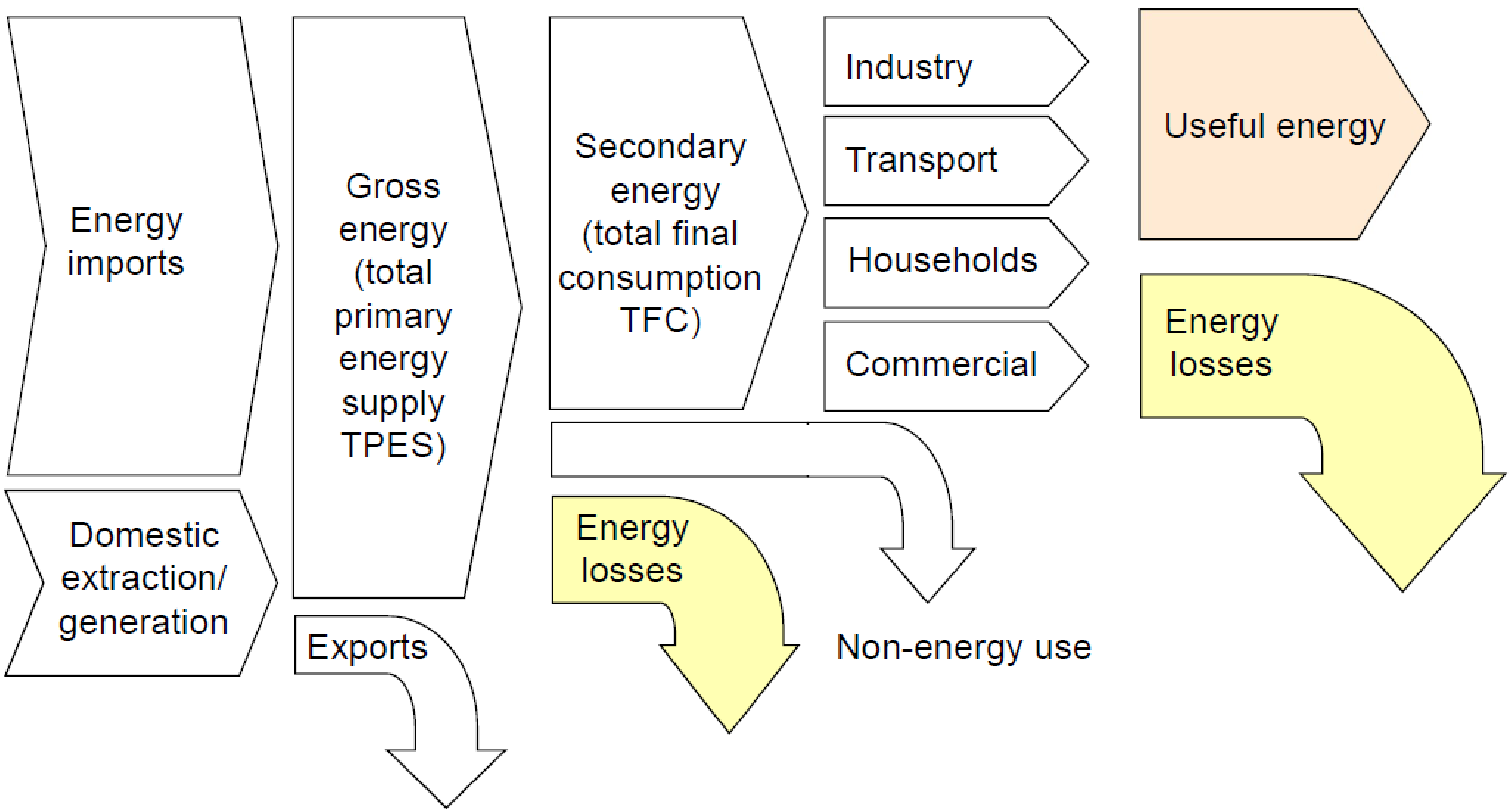
$$\text{Energy input} = \frac{\text{Energy output}}{\eta}$$

$$\frac{100\ MWh_{el}}{0{,}5\ \frac{MWh_{el}}{MWh_{th}}} = 200\ MWh_{th}$$

SE

PE

Energy flow chart

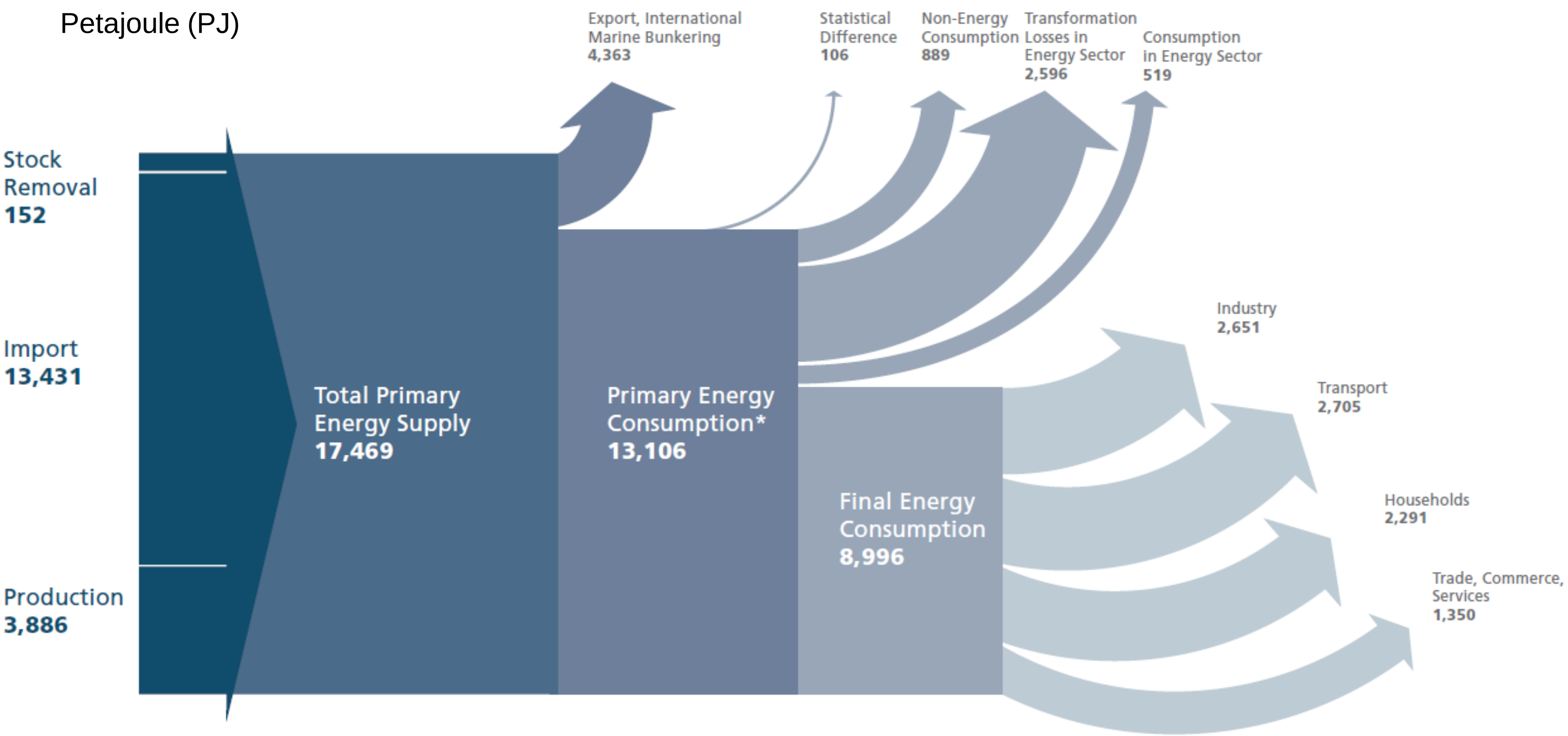


Source: Zweifel / Praktiknjo / Erdmann, 2017

Terms and definitions

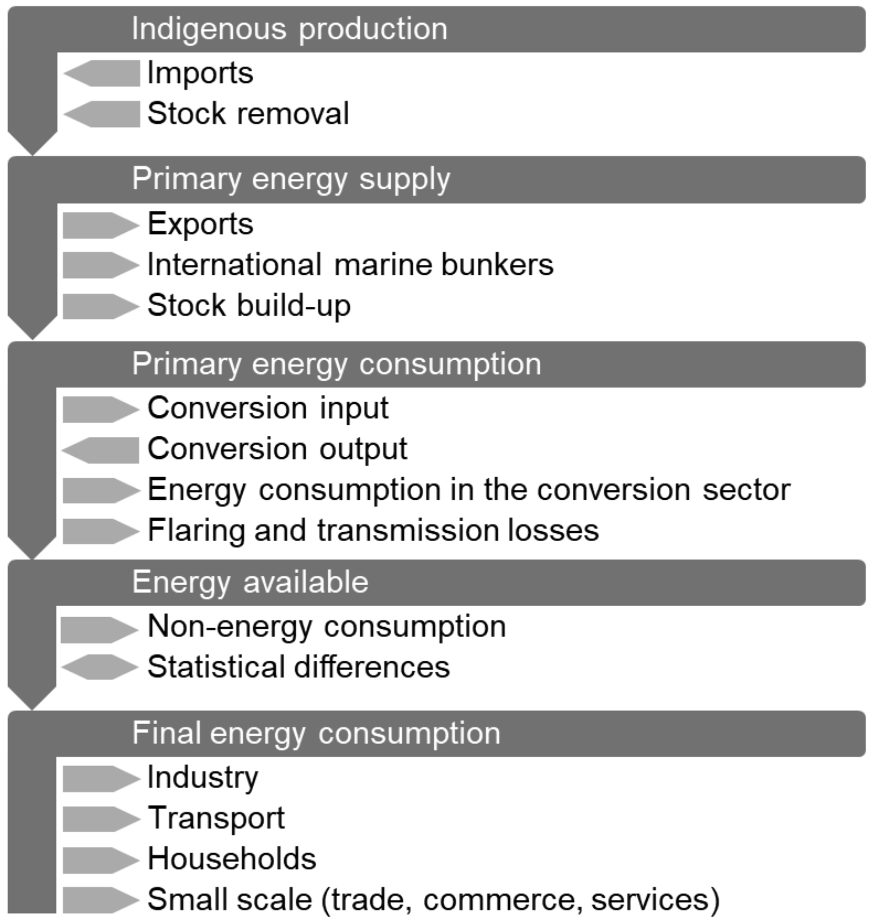
- **Gross energy** / Primary energy: Aggregate energy supply from domestic sources and imports minus energy exports
- **Final energy supply** (intermediate good): Energy sold by energy companies to end users for energetic use
- Treatment of **non-energy use** (raw material in chemistry)
- **Useful energy**: Energy that is supplied from heaters, radiators, coolers, motors, light bulbs etc. to end users
- **Energy Services**: Not the energy from radiators matters but the well being of people in a well tempered room …

Energy Balances: Energy flow chart for Germany in 2018



Source: AGEB, 2019

Energy balance structure (AGEB)



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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); 33% for nuclear

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' → imported goods → disposal of goods abroad

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.

Primary energy sources occur naturally.

Secondary energy sources have undergone at least one conversion process.

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

Accounting for imports of secondary energy sources for completeness (e.g. electricity, motor gasoline etc.)

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

Final consumption (manufacture of machinery etc.)

Task 1) Basics

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

The real share of useful energy is lower than expected, as part of final energy consumption is used for conversion purposes.

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

Imported goods (“grey energy”)

“Gasoline tourism” (cars fuelled in a neighbouring country)

Task 1) Basics

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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?

$P_{el,conv.} = 90ue$ (units of energy)

$P_{el,RE} = 10ue$

IEA: $PE_{RE,IEA} = \frac{10ue}{100\%} = 10ue_{PE}$

$PE_{conv} = \frac{90ue}{0,36} = 250ue_{PE}$

$\Rightarrow \alpha_{RE,IEA} = \frac{PE_{RE,IEA}}{PE_{total}} = \frac{10}{260} = 3,86\%$

Substitution method: $\alpha_{RE,subst.} = 10\%$

Task 2) German Energy Balance of 2015

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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?

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)?

$2\,328\,797\,TJ \cdot 0{,}278\ GWh/TJ =$

$= 647\,406\ GWh$

Electricity from RES: 663 111 TJ

$$\frac{663\,111\,TJ}{2\,328\,797\,TJ} = 28{,}45\,\%$$

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}
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1 t.c.e.	29.290	6,995 E^{+6}	8.136	0,6995	5,127	1

Task 2) German Energy Balance of 2015

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

$$\eta = \frac{output_{el}}{input_{th}} = \frac{1135050\,TJ}{2773967\,TJ} = 41{,}6\,\%$$

Task 2) German Energy Balance of 2015

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

$$\eta_{nuclear} = \frac{Output_{nuc.}}{Input_{nuc.}} = \frac{330\,431\ TJ}{1\,001\,297\ TJ} = 33\%$$