Energy Systems, Summer Semester 2024
Lecture 2: Energy Balances

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Measuring energy

Goal: Understand Energy Flow Through the Economy

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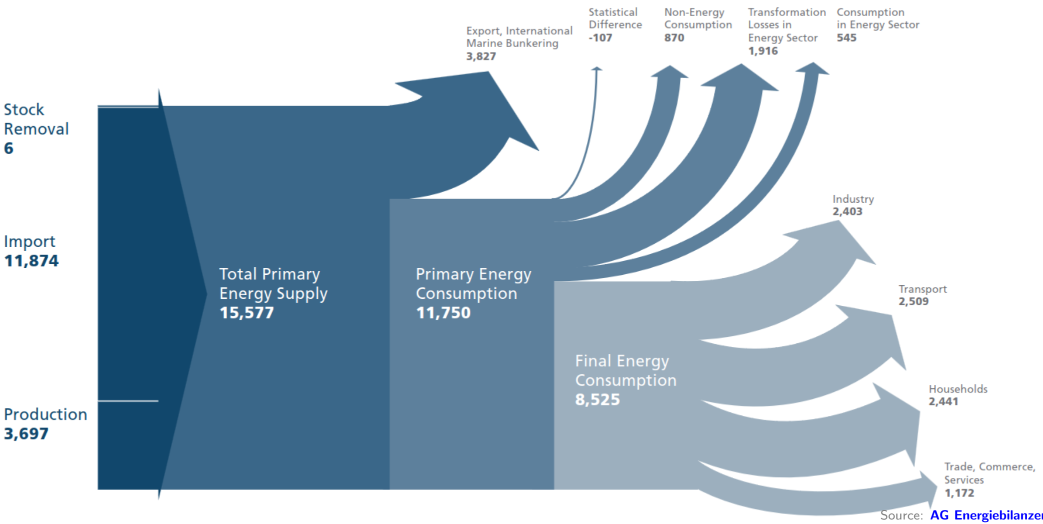
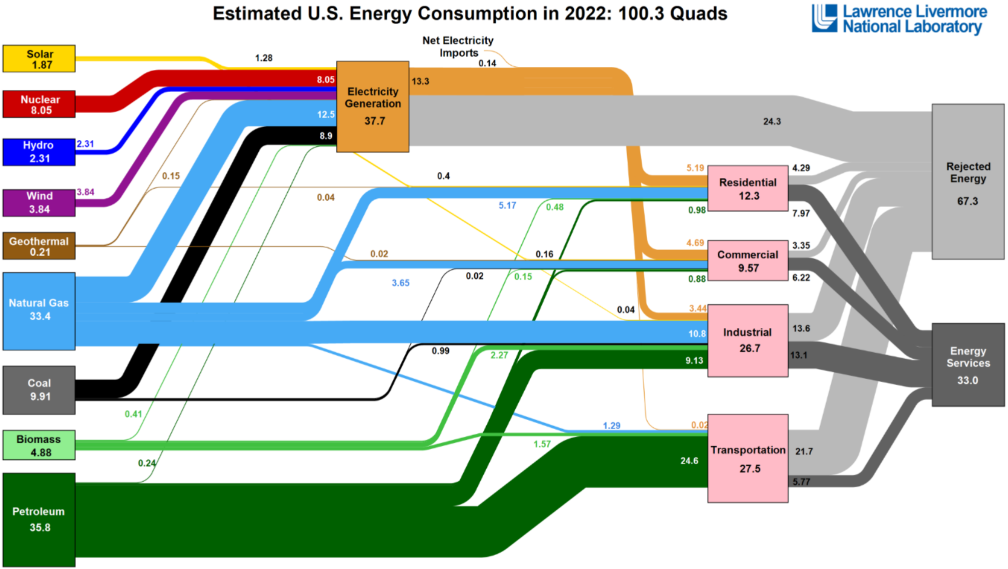
Example: **energy balance** for Germany in 2022 in Petajoule (PJ)



Source: AG Energiebilanzen, 2023

Example: Sankey diagram for US in 2022



Source: LLNL, 2023

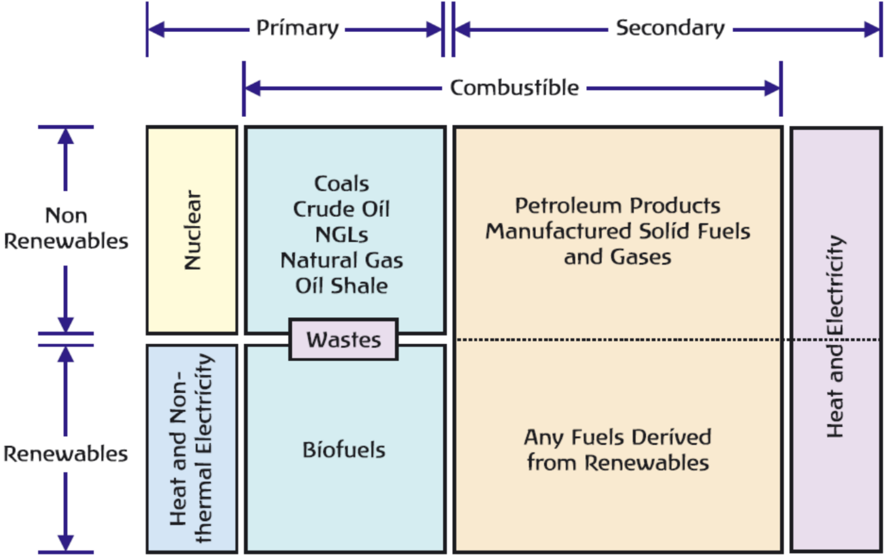
Definitions: Primary Versus Final Versus Useful Energy

Definitions of energy are oriented towards conventional energy sources like coal, oil and gas.

- **Primary energy** is energy as found in nature before it undergoes any transformation (crude oil, coal, gas, biomass, nuclear, wind, solar).
- **Secondary energy** is energy after conversion processes, either chemical or physical (refined fuels like gasoline, electricity from a coal power plant).
- **Final energy** is the energy as it is sold to end users (electricity, refined fuels like gasoline, gas for building heating).
- **Useful energy** is the energy after conversion by the consumer, available to be used (heat in a home, light, mechanical work).
- **Energy services** is what the consumer actually wants: a warm home, transportation from A to B, manufactured goods, etc.

The two most commonly used definitions are **primary** and **final** energy, since they are **easier to measure** in a fossil-fuelled world. With more focus on renewables and electrification, this **may change**!

Classification of Energy Sources



Source: OECD/IEA Energy Statistics Manual, 2005

Units of Energy: Joule and tonne of oil equivalent

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Joule (J) is the SI unit of energy.

Conventional primary energy sources are often measured in units corresponding to their natural form: volume, mass etc.

We can convert from measurements of mass [kg] and volume [m^3] to energy units using the **calorific value** [J/kg, J/m^3], which measures the heat from combustion.

Example: the unit **tonne of oil equivalent** (toe) is the energy generated by burning one metric ton of oil. Since the calorific value of oil is 41.88 MJ/kg, we have

$$1 \text{ toe} = 41.88 \text{ GJ}$$

[Reminder: k = kilo = 1e3, M = Mega = 1e6, G = Giga = 1e9, T = Tera = 1e12, P = Peta = 1e15, E = Exa = 1e18.]

Lower Heating Values 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 °C
1 t Gasoline	0.75 g/cm^3	43.1	at 15–20 °C
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 °C
1 t Hydrogen (LH_2)	0.071 g/cm^3	120.4	at –252 °C
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

Higher and Lower Heating Values

- **Lower Heating Value (LHV)** is the maximum amount of usable heat from combustion without counting the condensation enthalpy of water vapor contained in the exhaust gas.
- **Higher Heating Value (HHV)** includes the condensation enthalpy of water vapor contained in the exhaust gas. It is always higher than the LHV (e.g. 11% higher for methane).

Fuel	State at ambient temperature and pressure	HHV (MJ/kg)	LHV (MJ/kg)
Hydrogen	Gas	141.9	119.9
Methane	Gas	55.5	50
Ethane	Gas	51.9	47.8
Gasoline	Liquid	47.5	44.5
Diesel	Liquid	44.8	42.5
Methanol	Liquid	20	18.1

LHV is most commonly used in European statistics. HHV becomes relevant in e.g. condensing combined heat and power plants (CHP) where vapor is condensed.

Power: Flow of energy

Power is the rate of consumption of energy.

It is measured in **Watts**:

$$1 \text{ Watt } = 1 \text{ Joule per second}$$

The symbol for Watt is W, 1 W = 1 J/s.

$$1 \text{ kilo-Watt} = 1 \text{ kW} = 1{,}000 \text{ W}$$

$$1 \text{ mega-Watt} = 1 \text{ MW} = 1{,}000{,}000 \text{ W}$$

$$1 \text{ giga-Watt} = 1 \text{ GW} = 1{,}000{,}000{,}000 \text{ W}$$

$$1 \text{ tera-Watt} = 1 \text{ TW} = 1{,}000{,}000{,}000{,}000 \text{ W}$$

Power: Examples of consumption

At full power, the following items consume:

Item	Power
New efficient lightbulb	10 W
Old-fashioned lightbulb	70 W
Single room air-conditioning	1.5 kW
Kettle	2 kW
Factory	∼1-500 MW
CERN	200 MW
Germany total demand	35-80 GW

If all energy is electrified in 2050 and energy consumption equalises between nations, the average electricity consumption of the world would be around 12 TW.

Suppose half is met with wind (capacity factor 33.3%) and half is met with solar PV (capacity factor 16.6%). [Capacity factor = average generation / capacity.] How much wind and solar capacity does the world need (assuming perfect lossless storage)?

Source: IRENA Statistics 2023

Power: Supplying world's energy with wind and solar

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If all energy is electrified in 2050 and energy consumption equalises between nations, the average electricity consumption of the world would be around 12 TW.

Suppose half is met with wind (capacity factor 33.3%) and half is met with solar PV (capacity factor 16.6%). [Capacity factor = average generation / capacity.] How much wind and solar capacity does the world need (assuming perfect lossless storage)?

Wind: 6 TW / 0.333 = 18 TW (around 900 GW was installed by 2022)

Solar: 6 TW / 0.166 = 36 TW (around 1050 GW was installed by 2022)

Source: IRENA Statistics 2023

If installed wind density on average is 10 MW/km^2 and solar is 72 MW/km^2, what percentage of world land (510 million km^2) is taken with each?

If installed wind density on average is 10 MW/km^2 and solar is 72 MW/km^2, what percentage of world land (510 million km^2) is taken with each?

Wind: 18 $TW/(10\ MW/km^2) = 1.8$ million km^2 (around 0.35% of total land = area of Indonesia)

Solar: 36 $TW/(72\ MW/km^2) = 0.5$ million km^2 (around 0.1% of total land = area of Spain)

Nota Bene:

- Wind doesn't interfere with other land uses like agriculture; can also be built offshore
- 10 MW/km^2 is a **local** maximum installation density for wind, but to allow wind replenishment over large areas 2 MW/km^2 is suitable as a **wide-area** limit
- Solar can be rooftop or combined with agriculture = agrivoltaics

Units of energy: Watt-hour

In the electricity sector, energy is usually measured in 'Watt-hours', Wh.

1 kWh = power consumption of 1 kW for one hour

E.g. a 10 W lightbulb left on for two hours will consume

10 W * 2 h = 20 Wh

It is easy to convert this back to the SI unit for energy, Joules:

1 kWh = (1000 W) * (1 h) = (1000 J/s)*(3600 s) = 3.6 MJ

Yearly energy to power

Germany consumes around 600 TWh per year, written 600 TWh/a.

What is the *average* power consumption in GW?

Yearly energy to power

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What is the *average* power consumption in GW?

$$
\begin{aligned}
600\ \mathrm{TWh/a} &= \frac{(600\ \mathrm{TW}) * (1\ \mathrm{h})}{(365 * 24\ \mathrm{h})} \\
&= \frac{600}{8760}\ \mathrm{TW} \\
&= 68.5\ \mathrm{GW}
\end{aligned}
$$

Tables for converting units

multiply by:	GJ	Toe	MBtu	MWh
GJ	1	0.024	0.948	0.278
Toe	41.868	1	39.683	11.630
MBtu	1.055	0.025	1	0.293
MWh	3.600	0.086	3.412	1

Units used in the United States:

- British thermal unit (Btu), 1 million Btu = MBtu (often written MMBtu) = 0.293 MWh
- Quad = 1e15 Btu = 293 TWh

Energy conversion

Energy conversion/transformation processes

Output Input	Mechanical energy	Thermal energy	Chemical energy	Electricity	Radiation
Mechanical energy	–	Frictional heat	–	Hydropower turbine	–
Thermal energy	Heat engine	–	Thermo-chemistry	Electrical generator	–
Chemical energy	Combustion engine	Boiler	–	Fuel cell	Gas lamp
Electricity	Electric engine	Induction heater	Electrolysis	–	Electric bulb
Radiation	Laser	Microwave oven	Solar chemistry	Photovoltaic	–
Nuclear energy	–	Nuclear reactor	–	–	Radioactivity

Source: Zweifel, Praktiknjo & Erdmann (2017)

Energy conversion efficiency

Efficiency of an energy conversion device (e.g. power plant, vehicle engine):

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

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

Efficiency

When fuel is consumed, much/most of the energy of the fuel is lost as waste heat rather than being converted to electricity.

The thermal energy, or calorific value, of the fuel is given in terms of MWh_{th}, to distinguish it from the electrical energy MWh_{el}.

The ratio of input thermal energy to output electrical energy is the **efficiency**.

Fuel	Calorific energy MWh_{th}/tonne	Per unit efficiency MWh_{el}/MWh_{th}	Electrical energy MWh_{el}/tonne
Lignite	2.5	0.4	1.0
Hard Coal	6.7	0.45	2.7
Gas (CCGT)	15.4	0.58	8.9
Uranium (unenriched)	150000	0.33	50000

Fuel costs to marginal costs

The cost of a fuel is often given in €/kg or €/MWh_{th}.

Using the efficiency, we can convert this to €/MWh_{el}.

For the full marginal cost, we have to also add the CO_2 price and the variable operation and maintenance (VOM) costs.

Fuel	Per unit efficiency MWh_{el}/MWh_{th}	Cost per thermal €/MWh_{th}	Cost per elec. €/MWh_{el}
Lignite	0.4	4.5	11
Hard Coal	0.45	11	24
Gas (CCGT)	0.58	19	33
Uranium	0.33	3.3	10

CO2 emissions per MWh

The CO_2 emissions of the fuel.

Fuel	t_{CO2}/t	t_{C02}/MWh_{th}	t_{CO2}/MWh_{el}
Lignite	0.9	0.36	0.9
Hard Coal	2.4	0.36	0.8
Gas (CCGT)	3.1	0.2	0.35
Uranium	0	0	0

Current CO_2 price in EU Emissions Trading Scheme (ETS) is around €50-100/t_{CO2}

You calculate: What CO_2 price to switch gas and lignite?

What CO_2 price, i.e. x €/t_{CO2}, is required so that the marginal cost of gas (CCGT) is lower than lignite?

NB: It helps to track units.

You calculate: What CO_2 price to switch gas and lignite?

What CO_2 price, i.e. x $€/t_{CO2}$, is required so that the marginal cost of gas (CCGT) is lower than lignite?

NB: It helps to track units.

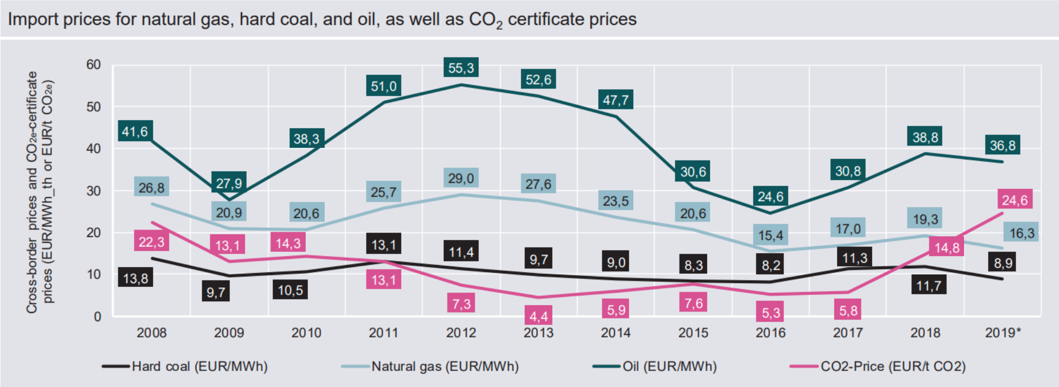
We need to solve for the switch point by adding the CO_2 price to the fuel cost. Left is lignite, right is gas:

$$11\ €/\mathrm{MWh_{el}} + (0.9\ \mathrm{tCO_2/MWh_{el}}) \cdot (x\ €/\mathrm{tCO_2}) = 33\ €/\mathrm{MWh_{el}} + (0.35\ \mathrm{tCO_2/MWh_{el}}) \cdot (x\ €/\mathrm{tCO_2})$$

Solve:

$$x = \frac{33 - 11}{0.9 - 0.35} = 40$$

CO2 and import costs change over time...



Source: Agora Energiewende, 2019

...which affects the marginal costs of generation

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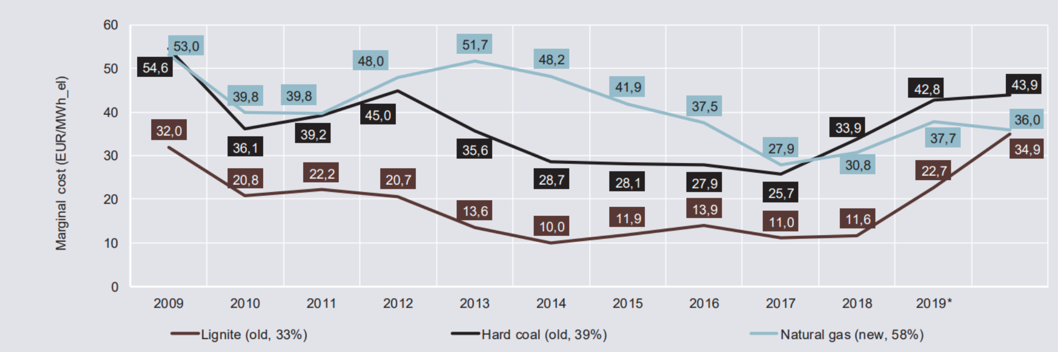
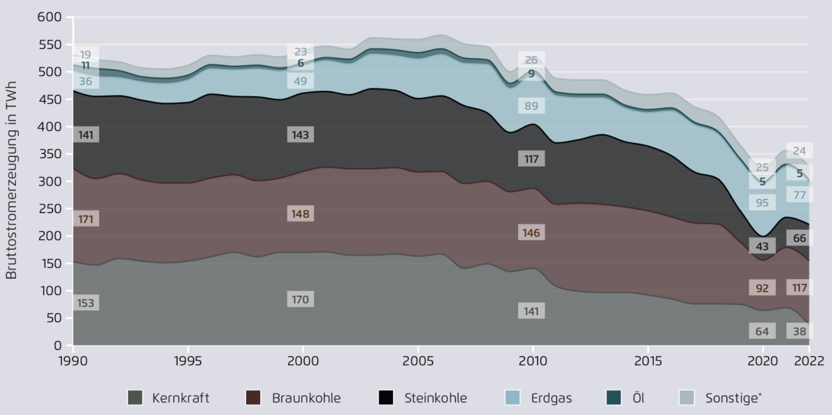
Marginal costs for new natural-gas power plants and old power plants fired with lignite and hard coal



Source: Agora Energiewende, 2019

CO2 emissions from electricity sector

CO_2 emissions in electricity generation stagnated for years because of coal, which is slowly being pushed out by the CO_2 price and in the longer term by the Kohleausstieg.



Source: Agora Energiewende Jahresauswertung 2022

Hydrogen in REPowerEU by 2030

The European Commission's REPowerEU plan, published in March 2022, aims for 10 Mt/a of clean hydrogen to be produced domestically in the European Union by 2030, with another 10 Mt imported.

If electrolysis of water to hydrogen is 70% efficient (LHV) and there is 33 MWh/tH_2 (LHV), what will be the electricity consumption from electrolysis for hydrogen in the EU in 2030?

Hydrogen in REPowerEU by 2030

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If electrolysis of water to hydrogen is 70% efficient (LHV) and there is 33 MWh/tH_2 (LHV), what will be the electricity consumption from electrolysis for hydrogen in the EU in 2030?

Consumption will be

$$\frac{10 \text{ MtH}_2/\text{a} * 33 \text{ MWh}_{\text{H}_2}/\text{tH}_2}{0.7 \text{ MWh}_{\text{H}_2}/\text{MWh}_{\text{el}}} = 471 \text{ TWh}_{\text{el}}/\text{a}$$

Compare to the current electricity consumption in Europe of around 3200 TWh_{el}/a.

Capacity Factors and Full Load Hours

A generator's **capacity factor** is the average power generation divided by the power capacity.

For variable renewable generators it depends on weather, generator model and curtailment; for dispatchable generators it depends on market conditions and maintenance schedules.

A generator's **full load hours** are the equivalent number of hours at full capacity the generator required to produce its yearly energy yield. The two quantities are related:

$$\text{full load hours} = \text{per unit capacity factor} \cdot 365 \cdot 24 = \text{per unit capacity factor} \cdot 8760$$

Typical values for Germany:

Fuel	capacity factor [%]	full load hours
wind	20-35	1600-3000
solar	10-12	800-1000
nuclear	70-90	6000-8000
open-cycle gas	20	1500

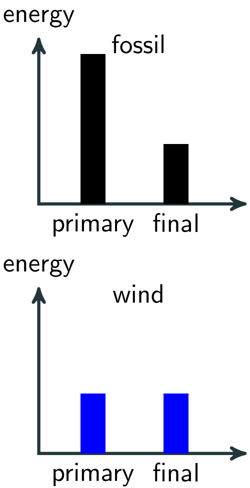
Measuring primary energy of renewables

How to value primary energy of carriers which do not have a calorific value, e.g. wind, solar PV, hydroelectricity?

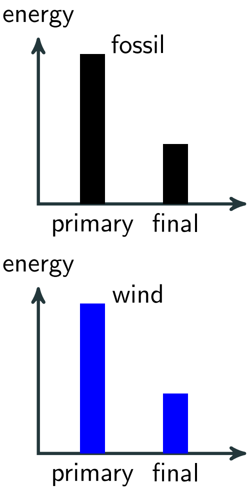
- **Fictive Efficiency Principle:** (also known as 'Physical Energy Accounting Method' or 'Direct Equivalent Method') (most common: used by IEA, OECD, Eurostat, IPCC) assume there is a 1-to-1 correspondence between primary energy and electricity for wind, solar, hydro (i.e. 100% conversion efficiency)
- **Substitution Principle:** (also know as the 'Input-Equivalent Method') (used by BP) assume the conversion efficiency from primary energy to electricity is the same as in a thermal (fossil or nuclear) powerplant (e.g. 35-45%)
- **Efficiency Principle:** actual efficiency of respective technology (hydro 80-90% gravitational potential energy of water to electricity, wind 30-55% kinetic energy of air to electricity, solar 10-25% radiation to electricity)

Fictive Efficiency vs Substitution Principle for Electricity Generation

Fictive Efficiency Principle



Substitution Principle



Beware: primary energy can underestimate renewables share

Suppose 50% of electricity is provided by wind and solar, the rest by fossil plants with 33% efficiency.

What is the fraction of renewables in primary energy from renewables:

1. Using the Substitution Principle
2. Using the Fictive Efficiency Principle

Beware: primary energy can underestimate renewables share

Suppose 50% of electricity is provided by wind and solar, the rest by fossil plants with 33% efficiency.

What is the fraction of renewables in primary energy from renewables:

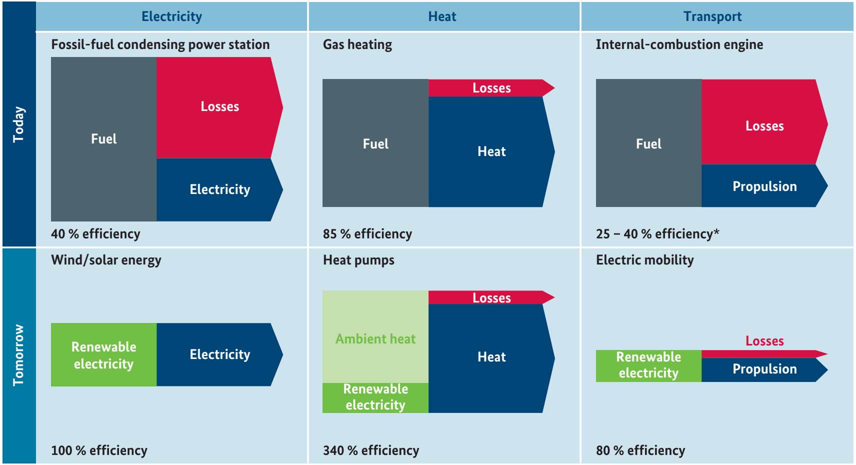
1. Using the Substitution Principle
2. Using the Fictive Efficiency Principle

1. 50% (since we assume renewables need as much primary energy for each unit of electricity as a thermal plant)
2. $\frac{50}{50+50/0.33}\% = \frac{50}{50+150}\% = 25\%$

Bad faith actors will often present renewable shares in terms of primary energy to make it look small.

Primary and final energy change with electrification

Primary energy in grey and green; useful energy in blue. NB: Also in **industry**, **electrification** of process heat can be more efficient since the heat can be focused better than e.g. burning gas.



* The efficiency of internal-combustion engines in other applications (e.g. maritime transport, engine-driven power plants) can exceed 50 %.

Source: BMWi White Paper 2015

Primary and final energy change with renewables and electrification

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Switching from thermal power plants to wind, solar and hydro leads to an **automatic decline in primary energy** using the Fictive Efficiency Principle, since thermal losses are no longer counted.

With electrification and efficiency, **final energy also decline** (compare gasoline required for a car versus electricity need; similarly natural gas for boiler versus electricity for a heat pump).

Both primary and final energy will decline! Primary by $\sim 50\%$, final by $\sim 33\%$.

Expect roughly **double electricity demand** (assuming widespread electrification of end demands, indirect electrification with H2 and efficiency measures).

Electricity will become the dominant final energy, primary energy will become less relevant.

Most important metrics become: fraction of electricity from non-emitting sources; efficiency of electricity meeting energy services.

Energy Balances

Energy Balances

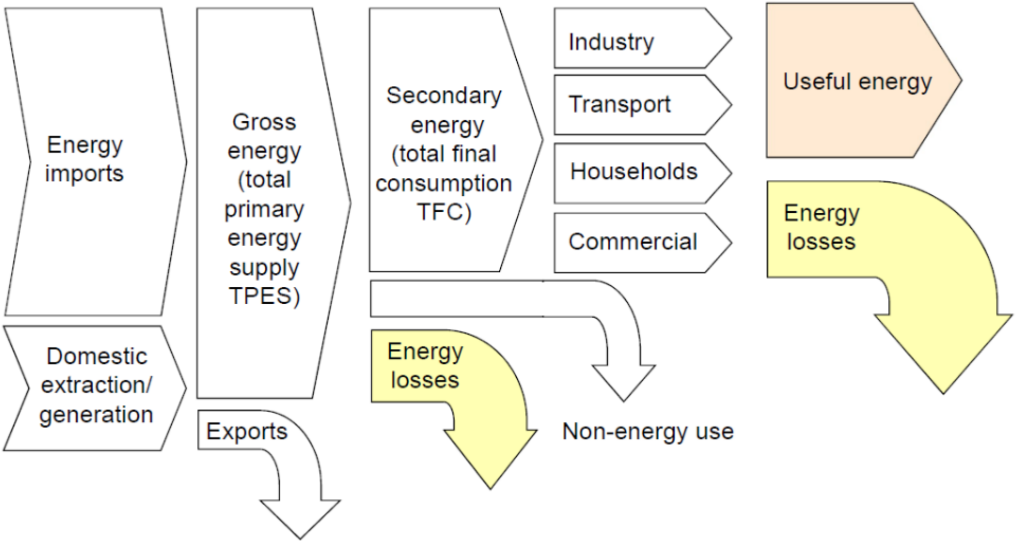
Energy is always **conserved** as it flows through the energy system.

Energy balances tabulate this energy conservation at each step of conversion from primary energy supply to primary energy consumption to final energy to energy services for consumers.

At each interface, inputs and outputs **balance**.

Source: Wikimedia

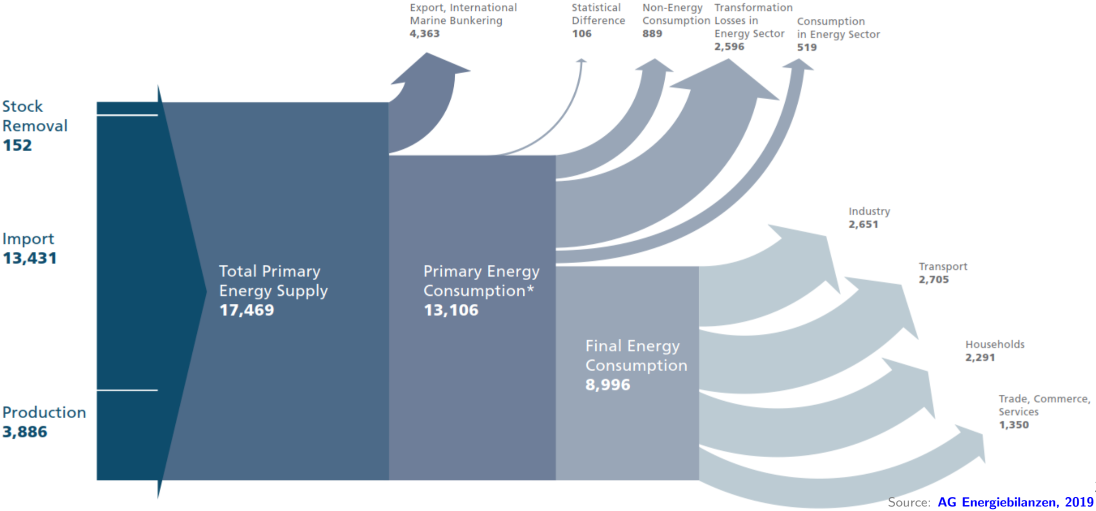
Principles of Energy Flow



Source: Zweifel, Praktiknjo & Erdmann (2017)

Energy Flow In Germany

Example: energy flow chart for Germany in 2018 in Petajoule (PJ)



Source: AG Energiebilanzen, 2019

Energy Balance Structure (AGEB)

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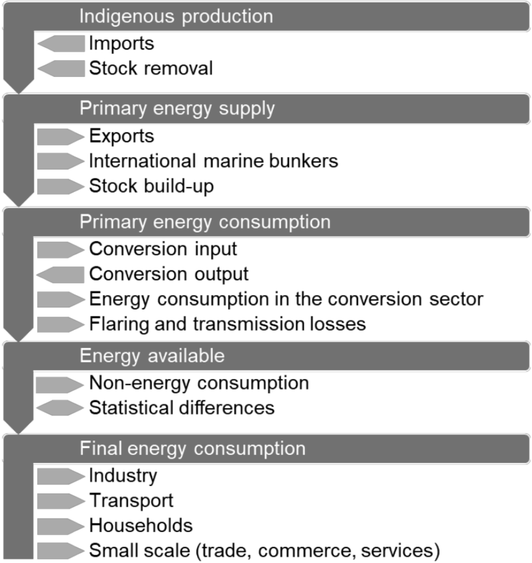

Source: **AG Energiebilanzen**

Simplified Energy Balance for EU28 in 2016

ktoe	EU28	2016	Total all products	Solid fuels	Oil (total)	Gas	Total Renewables	Wastes (non ren.)	Nuclear heat	Derived heat	Electricity
+ Primary production		B_100100	755,389	131,850	74,354	107,238	210,708	14,537	216,703		
+ Primary production receipt		B_100110	9,397		9,397						
+ From other sources (Recovered products)		B_100200	4,522	404	3,818	300					
+ Recycled products		B_100210	1,044		1,044						
+ Imports		B_100300	1,483,219	134,902	941,564	357,102	16,395	385		6	32,865
+ Stock changes		B_100400	21,263	11,807	3,423	5,944	89	0			
- Exports		B_100500	579,508	38,239	411,746	87,613	10,574	29		5	31,301
- Bunkers		B_100800	44,152		44,151	1					
- Direct use		B_100112	10,559		10,559						
Gross inland consumption		B_100900	**1,640,615**	**240,724**	**567,142**	**382,969**	**216,618**	**14,893**	**216,703**	**1**	**1,564**
Transformation input		B_101000	**1,294,958**	**224,492**	**654,689**	**125,132**	**61,875**	**11,027**	**216,703**	**768**	**272**
+ Conventional Thermal Power Stations		B_101001	358,478	165,433	12,820	114,576	54,977	9,905		768	
+ Nuclear Power Stations		B_101002	216,703						216,703		
+ Coke-ovens		B_101004	36,597	36,215	355	27					
+ Blast-furnaces		B_101006	12,918	12,918							
+ Gas works		B_101007	695	674		21					
+ Refineries		B_101008	640,308		640,308						
+ District heating plants		B_101009	21,015	3,544	963	8,654	6,459	1,122			272
+ Patent fuel plants		B_101010	219	142	77						
+ BKB / PB Plants		B_101011	4,385	4,385							
+ Coal Liquefaction Plants		B_101012	901	901							
+ For Blended Natural Gas		B_101013	391		162		230				
+ Charcoal production plants (transformation)		B_101015	209				209				
+ Gas-to-Liquids (GTL) Plants (transformation)		B_101016									
+ Non-specified Transformation Input		B_101020	2,138	279	4	1,855					
Transformation output		B_101100	**963,032**	**31,378**	**640,125**	**20,223**	**62**			**59,192**	**212,054**
+ Conventional Thermal Power Stations		B_101101	181,172							41,319	139,854
+ Nuclear power stations		B_101102	72,303							103	72,200
+ Coke-ovens		B_101104	34,193	27,365		6,828					
+ Blast-furnaces		B_101106	12,918			12,918					
+ Gas works		B_101107	477			477					
+ Refineries		B_101108	640,125		640,125						
+ Patent Fuel Plants		B_101110	173	173							
+ BKB / PB Plants		B_101111	3,840	3,840							
+ Charcoal production plants		B_101115	62				62				
+ District Heating Plants		B_101109	17,770							17,770	
Exchanges and transfers, returns		B_101200	**2,969**		**2,969**		**-65,240**				**65,240**
Consumption of the energy branch		B_101300	**80,128**	**636**	**33,402**	**19,028**	**654**	**87**		**4,913**	**21,408**
Distribution losses		B_101400	**26,372**	**35**	**53**	**3,093**	**24**			**5,554**	**17,612**
Available for Final Consumption		B_101500	**1,205,158**	**46,938**	**522,093**	**255,939**	**88,886**	**3,780**		**47,957**	**239,565**
Final non-energy consumption		B_101600	**97,773**	**1,763**	**82,480**	**13,530**					
Final energy consumption		B_101700	**1,107,818**	**45,338**	**437,131**	**245,284**	**88,949**	**3,780**		**47,932**	**239,405**
+ Industry		B_101800	276,823	33,774	27,513	86,242	22,542	3,524		16,112	87,115
+ Transport		B_101900	367,272	12	344,648	3,284	13,840				5,488
+ Other Sectors		B_102000	463,723	11,552	64,969	155,758	52,567	256		31,820	146,801
+ Services		B_102035	150,043	923	15,668	46,281	4,889	255		9,274	72,754
+ Residential		B_102010	284,832	9,507	33,139	105,175	45,369			22,148	69,494
+ Agriculture / Forestry		B_102030	24,079	1,082	12,992	3,426	2,132	1		252	4,194
+ Fishing		B_102020	1,426		1,236	2	46				142

- Gross inland consumption = Primary energy consumption = Production + Imports + Stock changes - Exports - Bunkers
- Bunkers is e.g. marine fuel stored at ports
- Around 330 Mtoe lost in transformation
- Final consumption = Final non-energy + Final energy consumption

Source: Eurostat Energy Balances

Questions

- What is the average electrical efficiency of conventional power stations in the EU?
- What is the average electrical efficiency of nuclear power stations in the EU?
- What fraction of industry/transport/residential final energy consumption is electricity?
- What is non-energy consumption?

Includes more granular estimates of useful energy, efficiency, CO_2 emissions, breakdown e.g. industry by process.

From Joint Research Centre (JRC) of the European Commission.

https://data.jrc.ec.europa.eu/dataset/jrc-10110-10001

"The 'Integrated Database of the European Energy Sector' (JRC-IDEES) is a one-stop data-box that incorporates in a single database all information necessary for a deep understanding of the dynamics of the European energy system, so as to better analyse the past and to create a robust basis for future policy assessments. JRC-IDEES offers a consistent set of disaggregated energy-economy-environment data, compliant with the EUROSTAT energy balances, as well as widely acknowledged data on existing technologies. It provides a plausible decomposition of energy consumption, allocating it to specific processes and end-uses."

JRC IDEES: Residential energy appliances

Technische Universität Berlin

EU28 - Residential / specific electric uses	2010	2011	2012	2013	2014	2015
Final energy consumption (ktoe)	**39,989.2**	**39,993.1**	**39,731.9**	**39,096.5**	**38,404.6**	**37,433.3**
White appliances	15,205.1	15,357.2	15,569.5	15,703.9	15,963.3	16,147.7
Refrigerators and freezers	8,168.9	8,233.9	8,318.9	8,346.1	8,493.3	8,591.8
Washing machine	3,042.6	3,059.4	3,091.5	3,101.5	3,125.0	3,146.0
Clothes dryer	2,173.8	2,210.6	2,257.8	2,309.7	2,351.5	2,386.8
Dishwasher	1,819.7	1,853.4	1,901.4	1,946.6	1,993.6	2,023.2
Brown appliances	13,675.5	14,040.8	14,315.5	14,447.2	14,438.4	14,282.0
TV and multimedia	10,960.1	11,240.8	11,423.7	11,489.8	11,451.5	11,304.6
ICT equipment	2,715.5	2,800.0	2,891.8	2,957.4	2,986.9	2,977.3
Lighting and other electricity uses	11,108.5	10,595.0	9,846.8	8,945.3	8,002.9	7,003.6
Lighting	7,303.9	6,706.6	5,874.6	4,909.8	3,908.0	2,871.8
Other appliances (vacuum cleaners, irons etc.)	3,804.6	3,888.5	3,972.2	4,035.5	4,094.9	4,131.8
Total MW installed (in average operating mode)	**1,793,429.5**	**1,803,111.1**	**1,808,318.2**	**1,798,855.9**	**1,785,602.2**	**1,760,140.1**
White appliances	198,249.6	201,660.3	204,205.7	205,003.0	206,377.1	206,322.5
Refrigerators and freezers	10,843.3	10,929.5	11,042.4	11,078.6	11,273.9	11,404.6
Washing machine	46,970.9	46,636.3	46,501.5	46,097.7	46,013.4	45,439.7
Clothes dryer	103,001.4	106,198.2	108,150.6	108,822.7	109,478.3	109,645.3
Dishwasher	37,434.0	37,896.3	38,511.3	39,004.0	39,611.6	39,832.9
Brown appliances	113,857.3	116,148.5	118,037.1	118,656.8	118,007.3	116,001.5
TV and multimedia	71,905.5	73,160.4	73,861.1	73,760.4	72,967.2	71,455.6
ICT equipment	41,951.7	42,988.1	44,176.0	44,896.4	45,040.0	44,546.0
Lighting and other electricity uses	1,481,322.7	1,485,302.2	1,486,075.4	1,475,196.2	1,461,217.8	1,437,816.1
Lighting	161,113.5	147,979.3	129,850.0	108,601.0	86,429.1	63,403.5
Other appliances (vacuum cleaners, irons etc.)	1,320,209.2	1,337,322.9	1,356,225.3	1,366,595.2	1,374,788.7	1,374,412.6
Total number of appliances						
White appliances						
Refrigerators and freezers	281,386,019	291,932,612	304,497,583	316,257,646	329,569,096	342,024,030
Washing machine	183,768,546	190,087,533	199,158,165	209,279,726	219,587,016	232,061,615
Clothes dryer	64,612,619	68,086,186	71,170,754	73,924,700	77,176,183	81,093,406

- NB: Peak electricity consumption in Europe is around 500 GW.
- If all 1760 GW of appliances came on simultaneously, system would be overwhelmed.
- What do you notice about the ratio of total energy consumption to installed power?

Source: JRC IDEES

JRC IDEES: Residential heating efficiency

EU28 - System efficiency indicator of total stock	2010	2011	2012	2013	2014	2015
Ratio of energy service to energy consumption	0.669	0.673	0.681	0.690	0.696	0.705
Space heating	0.675	0.679	0.686	0.696	0.702	0.712
Solids	0.512	0.513	0.514	0.516	0.517	0.519
Liquified petroleum gas (LPG)	0.641	0.647	0.654	0.662	0.666	0.672
Gas/Diesel oil incl. biofuels (GDO)	0.652	0.656	0.665	0.675	0.682	0.685
Gases incl. biogas	0.681	0.684	0.691	0.697	0.702	0.707
Biomass and wastes	0.542	0.545	0.550	0.556	0.559	0.564
Geothermal energy	0.820	0.830	0.837	0.840	0.848	0.851
Derived heat	0.805	0.808	0.810	0.822	0.824	0.831
Advanced electric heating	1.679	1.815	1.946	2.116	2.240	2.392
Conventional electric heating	0.787	0.791	0.798	0.807	0.808	0.815
Electricity in circulation	1.000	1.000	1.000	1.000	1.000	1.000
Space cooling	2.323	2.463	2.611	2.746	2.881	3.009
Air conditioning	2.323	2.463	2.611	2.746	2.881	3.009
Water heating	0.626	0.629	0.632	0.636	0.638	0.643
Solids	0.448	0.450	0.452	0.454	0.455	0.456
Liquified petroleum gas (LPG)	0.585	0.588	0.592	0.596	0.598	0.599
Gas/Diesel oil incl. biofuels (GDO)	0.570	0.572	0.577	0.580	0.584	0.586
Gases incl. biogas	0.589	0.591	0.595	0.598	0.600	0.604
Biomass and wastes	0.485	0.488	0.491	0.494	0.497	0.500
Geothermal energy						
Derived heat	0.847	0.850	0.850	0.855	0.858	0.860
Electricity	0.744	0.747	0.752	0.757	0.761	0.764
Solar	1.000	1.000	1.000	1.000	1.000	1.000
Cooking	0.615	0.620	0.624	0.628	0.632	0.638
Solids	0.344	0.345	0.346	0.347	0.348	0.349
Liquified petroleum gas (LPG)	0.461	0.463	0.466	0.469	0.470	0.472
Gases incl. biogas	0.505	0.508	0.510	0.513	0.515	0.518
Biomass and wastes	0.337	0.338	0.339	0.340	0.340	0.342
Electricity	0.839	0.841	0.843	0.846	0.848	0.850

- Ratio of final energy to actual heating for space/water/cooking.
- Which fuel source is most efficient?
- Why is 'air conditioning' efficiency greater than one?
- Why is 'advanced electric heating' efficiency greater than one?

Source: JRC IDEES