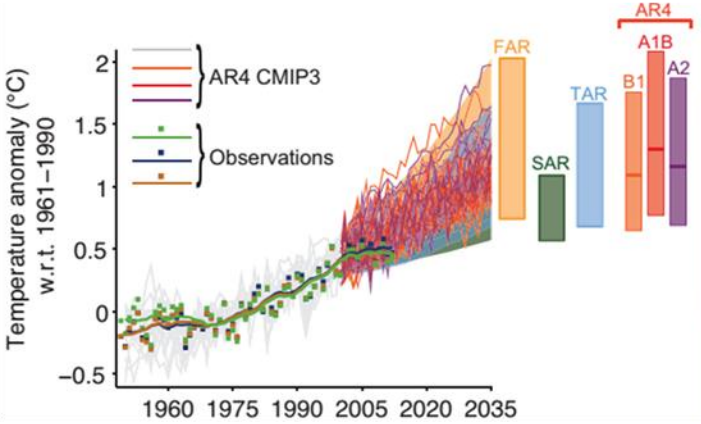
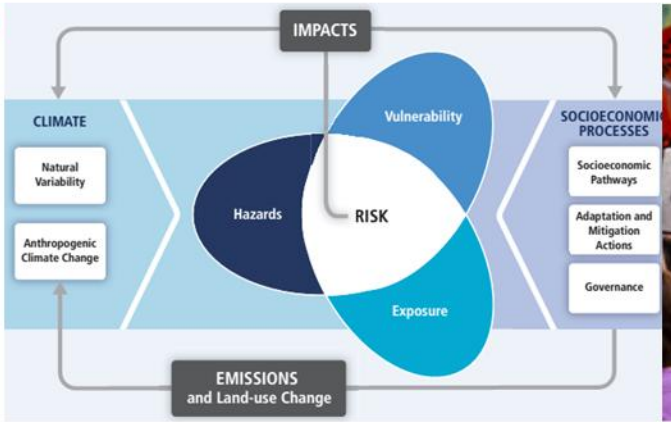




Energy Systems & Climate Change



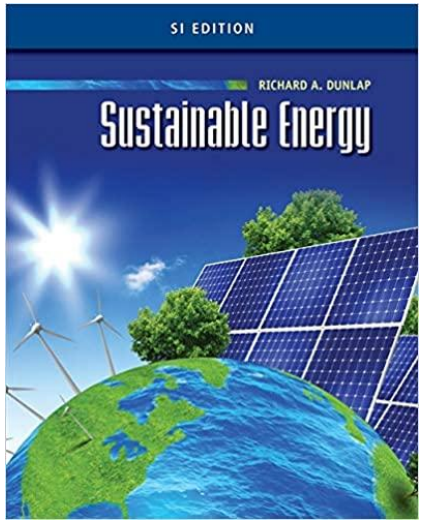


Introduction

Dr. William Smith

Room 309, Engineering

william.smith@ucd.ie



Course: ~33 lectures (copies of slides on Brightspace)

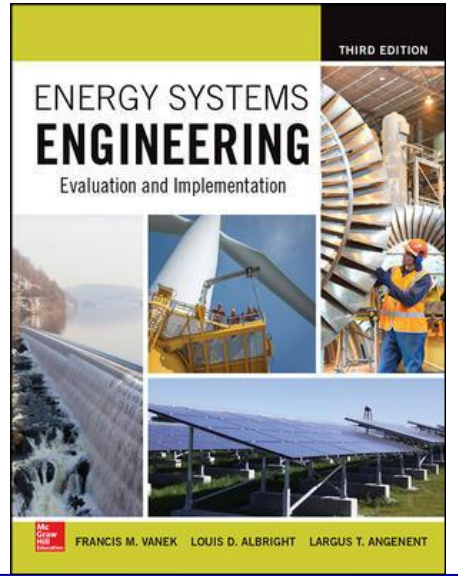
Students are **expected** to spend an additional ~2 hours per lecture on independent study

Text books suggested:

Energy Systems Engineering, 3rd edition. Vanek, Albright and Angenent, McGraw-Hill, 2016. ISBN: 9781259585098

This text is freely available as an electronic resource from UCD Library:
http://lib.myilibrary.com.eproxy.ucd.ie/Open.aspx?id=383160

Sustainable Energy, 2nd edition. Dunlap, Cengage, 2019.
ISBN: 9781259585098



Introduction

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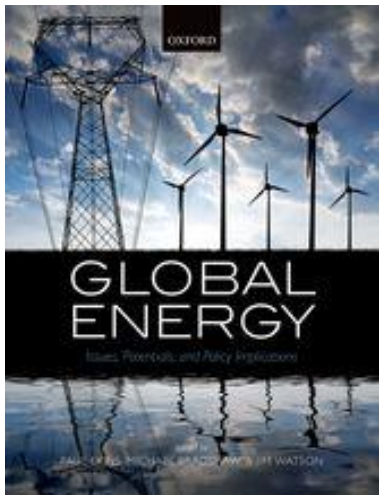
Suggested reading: Global Energy: Issues, Potentials, and Policy Implications. Ekins, Bradshaw, and Watson. Oxford, 2015. ISBN-13: 9780198719526



- Supplementary texts will be recommended for specific sections of the course
- Additional material on the Brightspace site
- Students are encouraged / expected to source additional reference material of their own.

Introduction

Assessment:

Group assignment	week 6	30%
Individual assignment	week 9	30%
End of trimester exam	open book	40%

Allocated in week 4

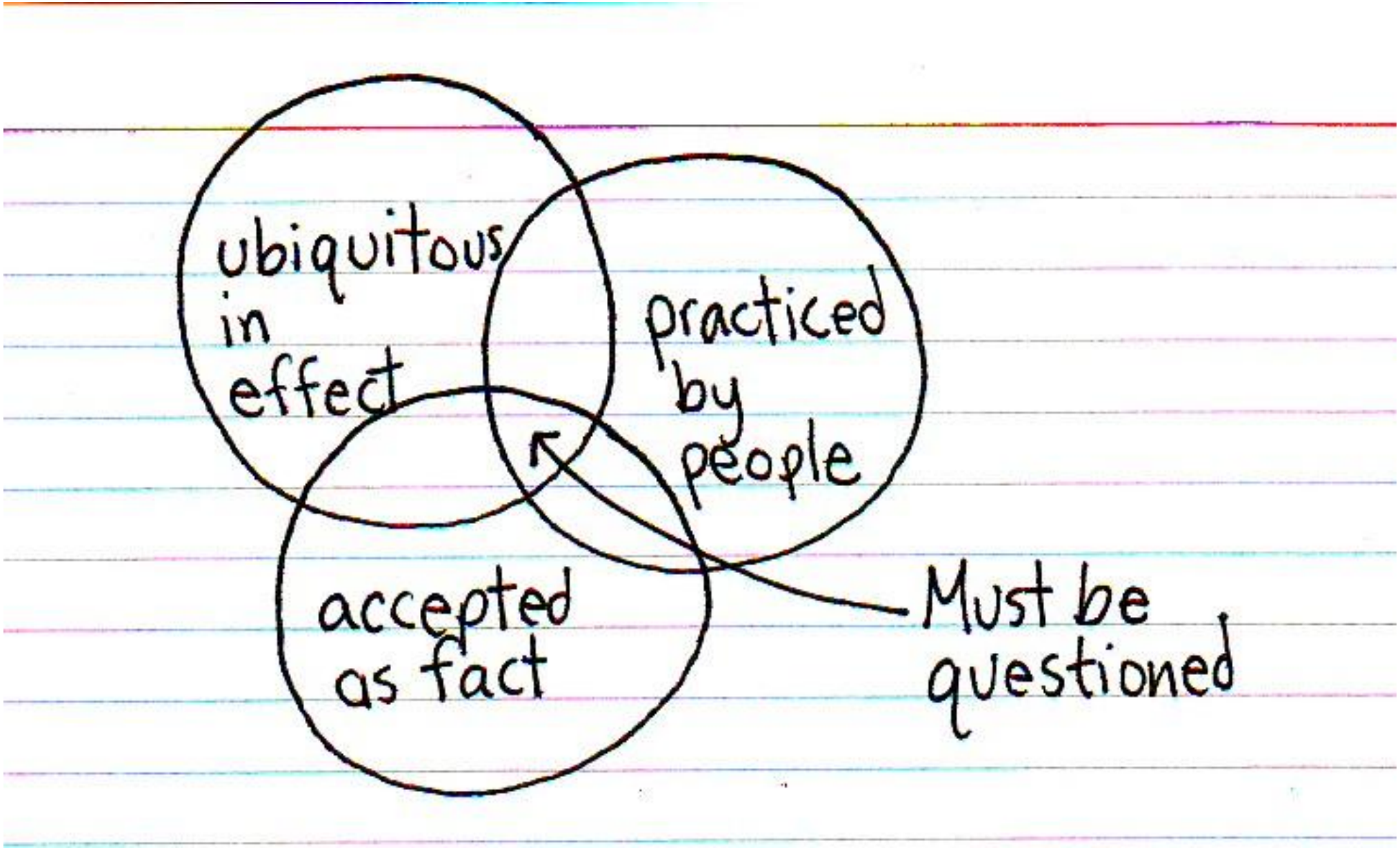
Group mark (product)

+

Peer mark (process)

Allocated in week 7

All components will be graded.


ubiquitous in effect
practiced by people
accepted as fact
Must be questioned

Course outline

- **Topic 1: The global energy system**
  - 1a. Global energy demand
  - 1b. Global energy supply
- **Topic 2: Combustion, CO_2 and the greenhouse effect**
  - 2a: Combustion and CO_2
  - 2b: CO_2 & the greenhouse effect
- **Topic 3: Climate change: science and policy**
  - 3a: What is climate (change)?
  - 3b: Modelling Earth's climate
  - 3c: The global response
- **Topic 4: Displacing fossil fuels: challenges & opportunities**
  - 4a: Evaluating alternatives
  - 4b: Energy efficiency
  - 4c: Wind
  - 4d: Biomass & biofuels
  - 4e: Solar
  - 4f: Hydrogen
- **Topic 5: The nuclear option**
- **Topic 6: Regional policy: perspectives & responses**

Course outline

Non-nuclear energy systems:

~28 lectures (WJS)

Nuclear power generation:

5 lectures

Dr. Luis Leon Vintro, UCD School of Physics

Today

- Context
- Course philosophy
- Some definitions
- A note on data sources
- Introduction to global energy demand

define


Context
risk
opportunity
data
process
complex
customer
plan
planning
analysis
retention
impact
sales
management
implementation
monitor
project
assessment
identification
probability
research
strategy
performance
cost
evaluation
organization
treatment
resources
important
context
scope

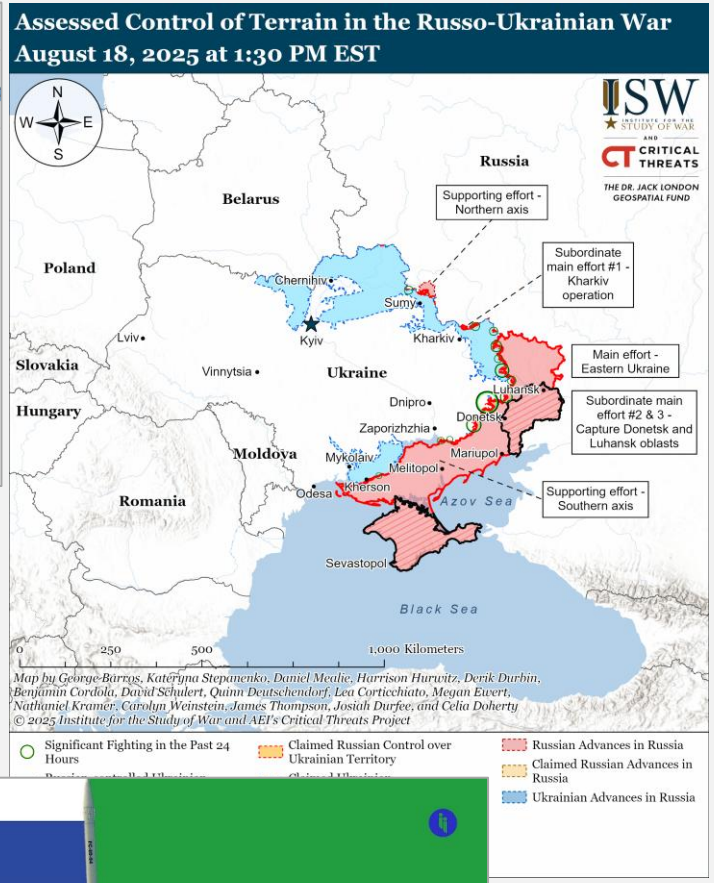
We live in an uncertain, capricious world.

The New York Times

Updates LIVE Trump-Zelensky Meeting 13m ago Tariff Tracker National Guard in D.C. Se

Suddenly, the Trump Administration Tightens the Vise on Wind Farms

rictions
public



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Trump moves nuclear submarines to 'appropriate regions' after Medvedev statements

Updated / Friday, 1 Aug 2025 20:02

China says it is ready for 'any type of war' with US

5 March 2025

Share

Laura Bicker
BBC News, Beijing

Where does this leave the EU?

- The global environment has become increasingly capricious and siloed.
- Trade wars, tariffs, and Chinese competition are stifling the EU economy.
- Major EU governments are moving to the right.
- The EU is committed to massive increases in defence expenditure.
- High interest rates make renewables much more expensive.
- The EU share of global emissions is becoming insignificant.

- …EU ambitions may moderate.

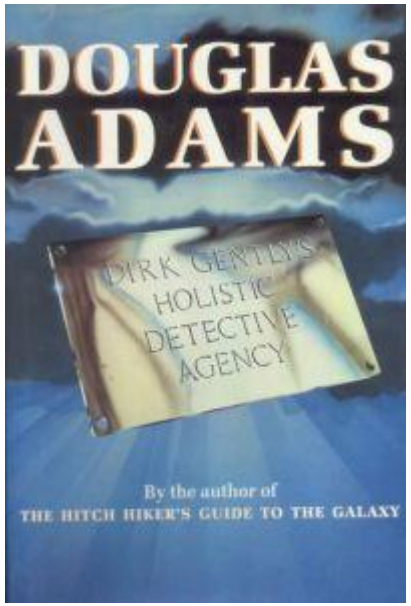
Module philosophy

In “the real world”, “knowledge” is frequently vague, imprecise, and ambiguous.

Outcomes frequently depend on the interaction between many independent variables.

Temporal evolution of the outcome may be:

- predictable
- stochastic
- chaotic
- completely unpredictable



Positive or negative feedback loops may connect some or all of these variables to each other and/or to additional external variables, in an ever-expanding web of complexity.

In that context, calculating precise values for individual variables may offer little insight.

This module is about *synthesis*, not *analysis*.

What is energy?

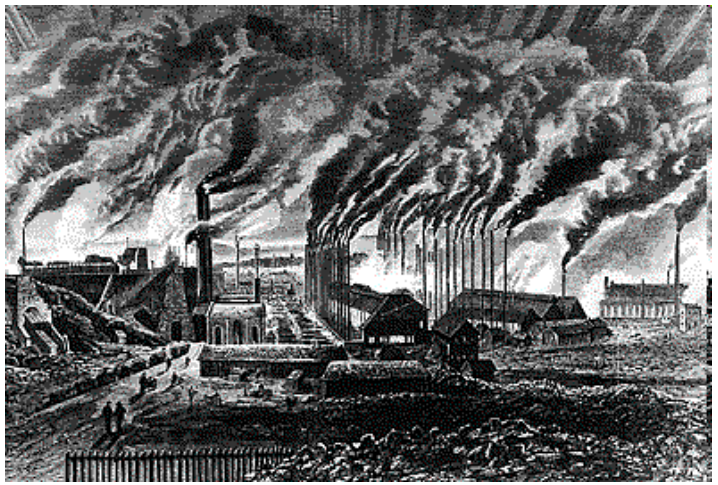
Some definitions

What do I mean by "energy"?

Energy as a *commodity*

...for producing heat (usually)

...that can be converted to work



Some definitions

What do I mean by “energy”?

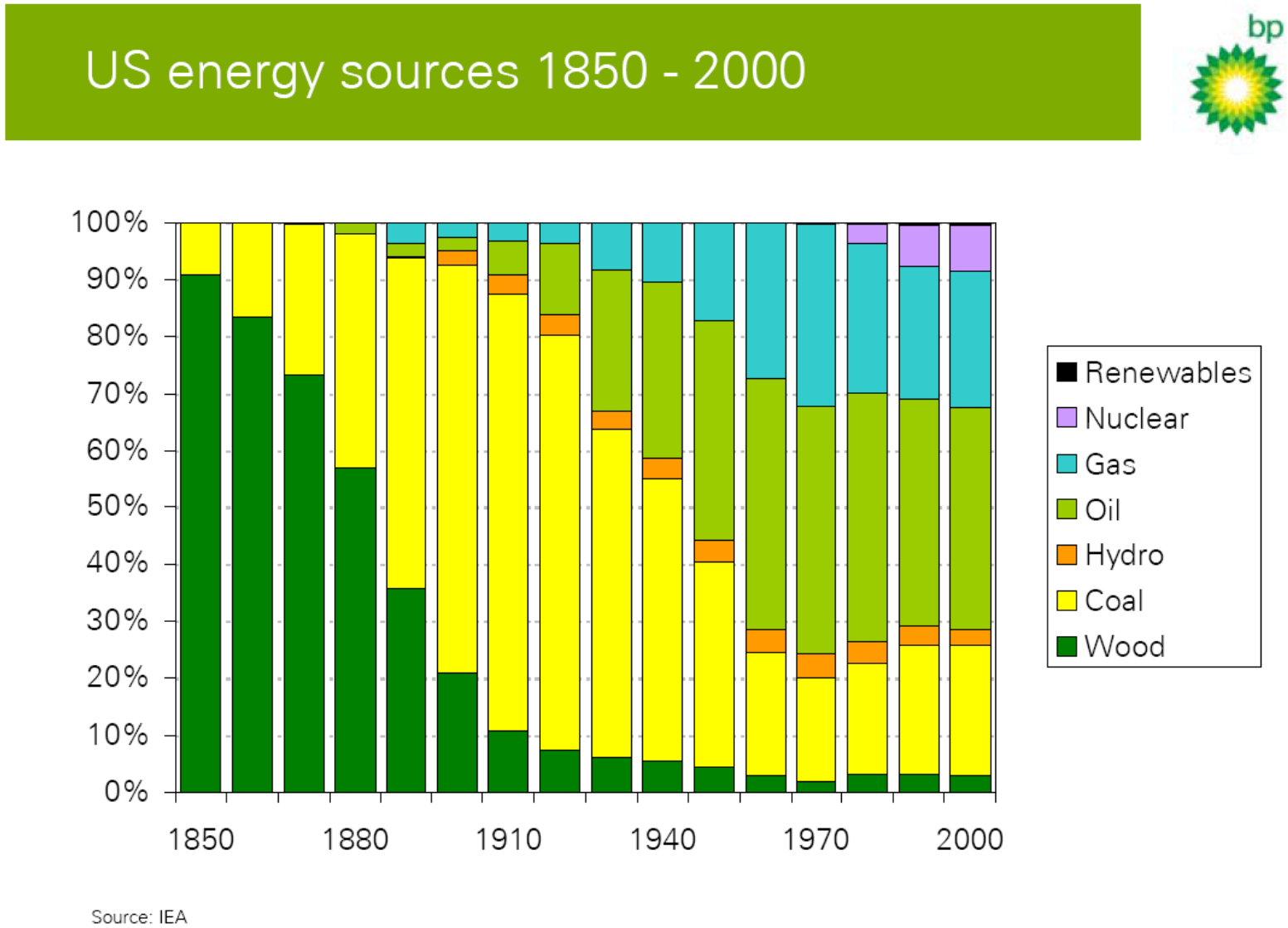
Competition for commodities whose stored energy can be converted to heat…

- cheaply
- easily
- on a massive scale
- using existing technology and infrastructure

The commodities of choice may change with time…

Some definitions

The commodities of choice may change with time…



Some definitions

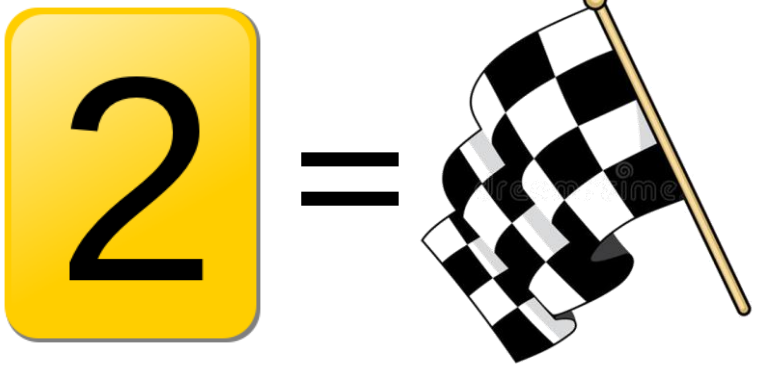
How much energy do we use?

(…and why?)

Some definitions

For accounting purposes, these energy commodities are generally classified as either:

Primary energy  or

Secondary energy, or Final energy 

A third classification of energy exists, but is never included in national or regional accounts:

Embodied energy (or embedded energy)

Some definitions

Primary energy

"**Primary energy** is energy embodied in sources which involve human induced extraction or capture, that may include separation from contiguous material, cleaning or grading, to make the energy available for trade, use or transformation."

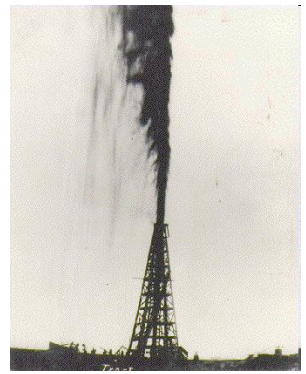
Øvergaard S. Issue Paper: Definition of Primary and Secondary Energy. Oslo Group on Energy Statistics, 2008. http://og.ssb.no

In national and regional energy accounts is referred to as PER, TPER, TPED, TPES, or GIC.

Primary energy is what we harvest: *e.g.* coal (more or less), crude oil, natural gas (more or less), wind (sort of), waste, etc…



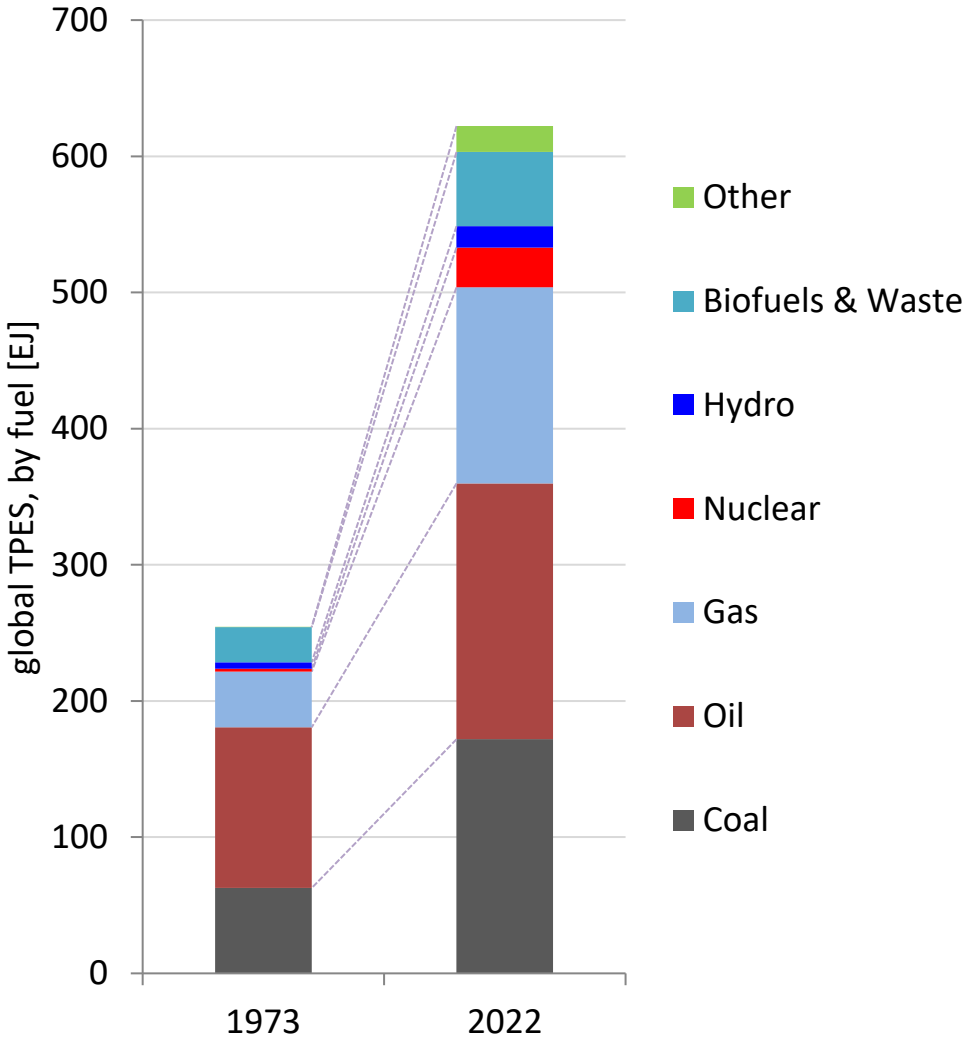


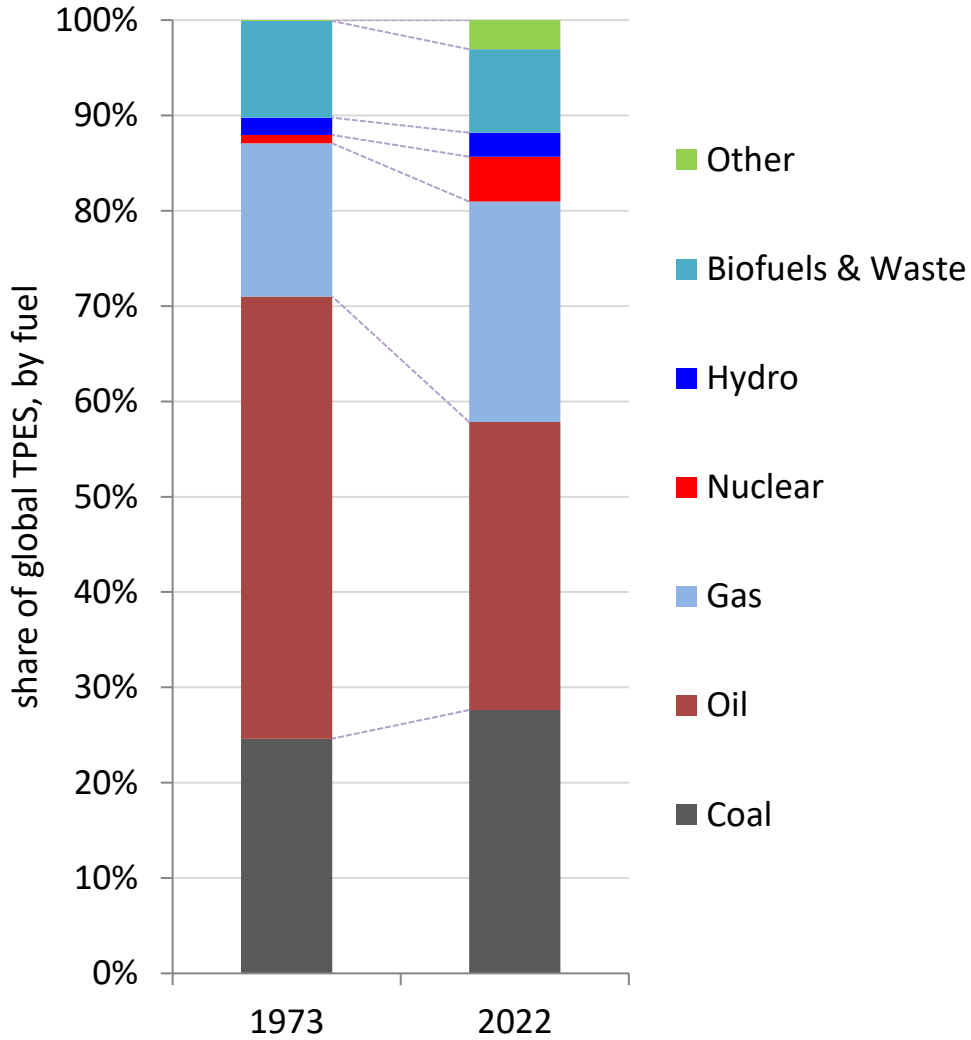


Some definitions

Primary energy

...what we harvest





Raw data: IEA Energy Statistics Data Browser

Some definitions

Final (Secondary) energy *…what people actually want*

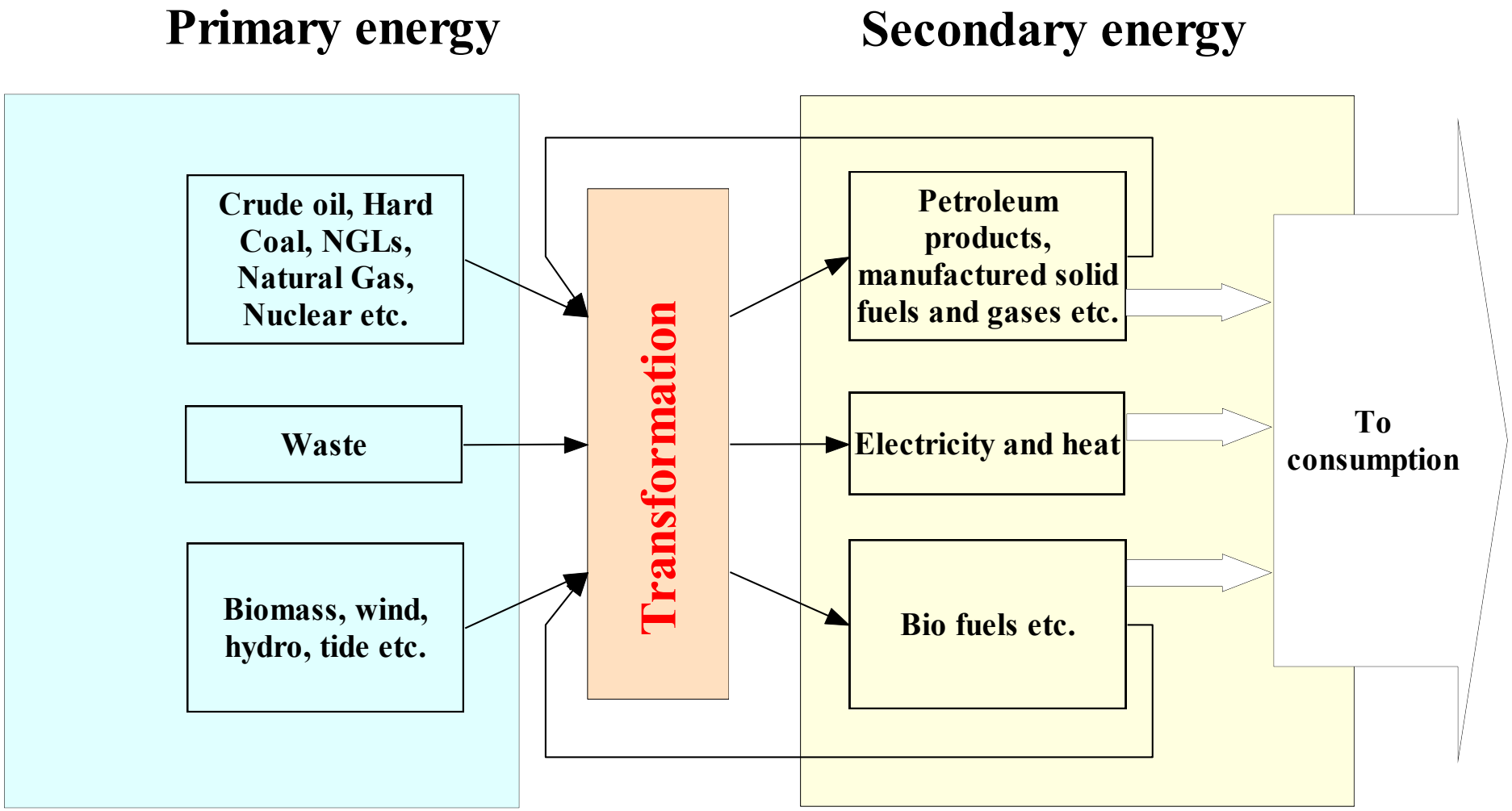
"**Secondary energy** is energy embodied in commodities that comes from human induced energy transformation."

Øvergaard S. Issue Paper: Definition of Primary and Secondary Energy. Oslo Group on Energy Statistics, 2008. http://og.ssb.no

In national energy accounts, referred to as FEC, TFC, GFC.

Final (secondary) energy is what we use: *e.g.* petrol, diesel, electricity, liquid biofuels, etc…

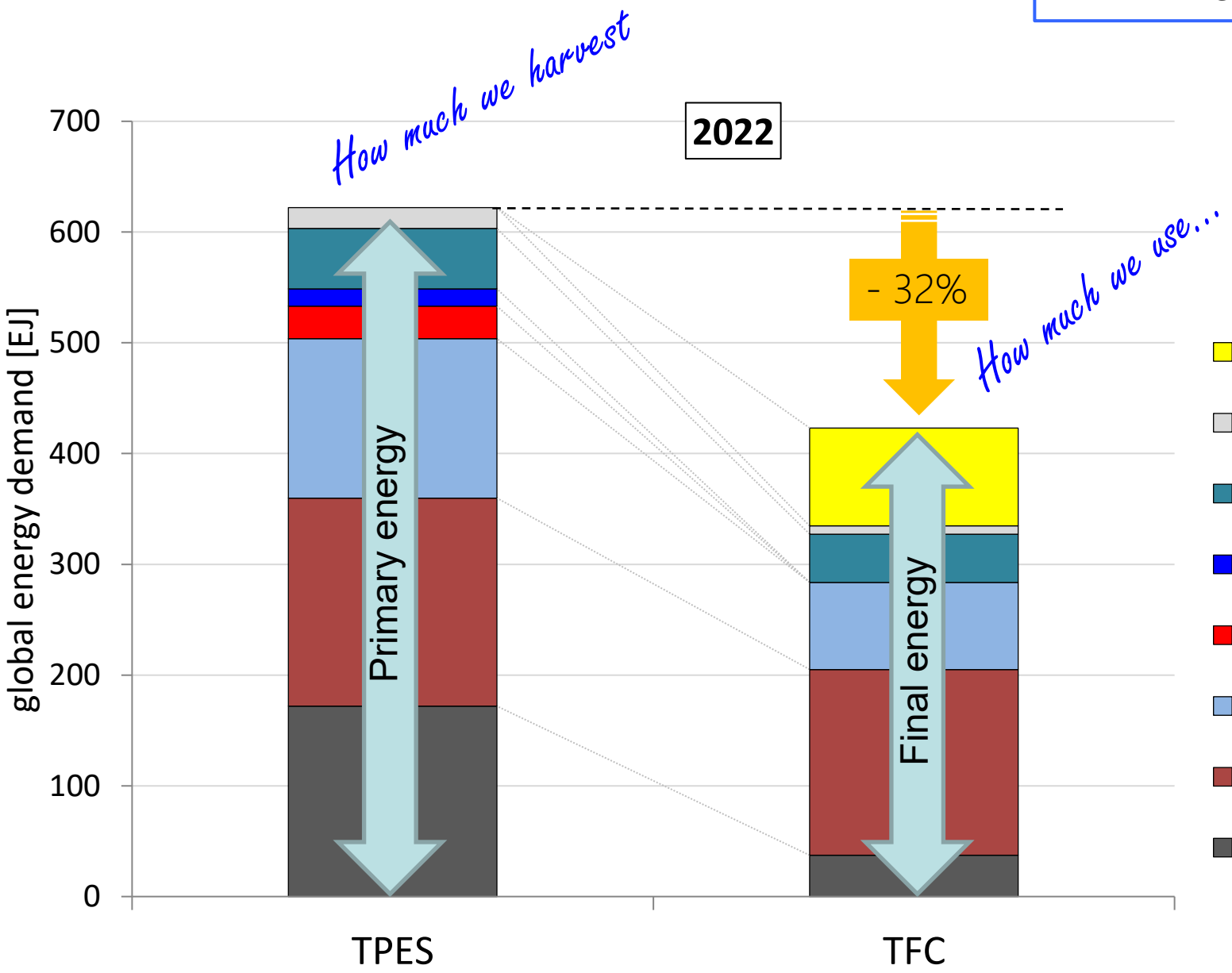
Some definitions



Øvergaard S. Issue Paper: Definition of Primary and Secondary Energy. Oslo Group on Energy Statistics, 2008. http://og.ssb.no

Some definitions

Global primary and final energy demand



Where does the coal and gas "go"?

Why don't we see the same shrinkage with oil, biofuels, and waste?

Raw data: IEA Energy Statistics Data Browser

Some definitions

Oil is traded in barrels (bbl), coal in tons, gas in GJ (or BTU!), etc.

Convenient to use a single (large) unit of measurement, based on the energy content of the fuel.

1 toe = tonne of oil equivalent = 41.868 GJ *

(LCV of petrol ≈ 44 $MJ.kg^{-1}$ = 44 $GJ.t^{-1}$)

(LCV of diesel ≈ 42.5 $MJ.kg^{-1}$ = 42.5 $GJ.t^{-1}$)

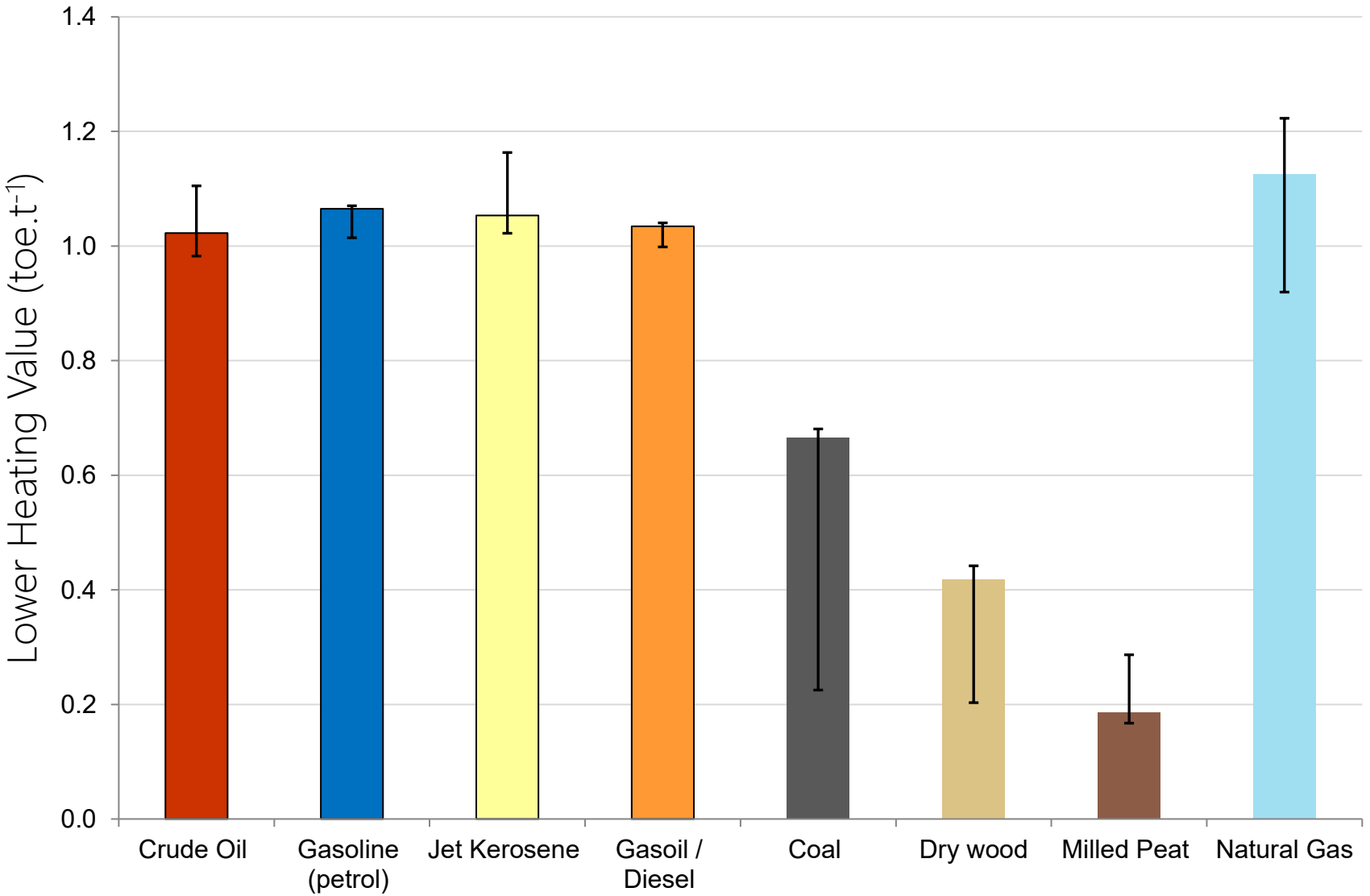
1 ktoe = 10^3 toe

1 Mtoe = 10^6 toe = 41.868 PJ

1 EJ = 23.88 Mtoe = 0.02388 Gtoe

**The precise value used varies from source to source, but this is almost standard. Also, sometimes toe refers to HHV, and sometimes to LHV..*

Some definitions



Some definitions

Sample primary energy analysis for EU27

EU27: REFERENCE SCENARIO									SUMMARY ENERGY BALANCE AND INDICATORS (A)				
ktoe	1990	1995	2000	2005	2010	2015	2020	2025	2030	'90-'00	'00-'10	'10-'20	'20-'30
										Annual % Change			
Production	**936047**	**950181**	**941860**	**900326**	**823118**	**794959**	**788108**	**765019**	**769894**	**0.1**	**-1.3**	**-0.4**	**-0.2**
Solids	366477	277810	213423	196277	167851	157230	139083	130204	124611	-5.3	-2.4	-1.9	-1.1
Oil	129551	171052	173006	134290	102925	74274	49602	40617	37067	2.9	-5.1	-7.0	-2.9
Natural gas	162447	188965	207559	188677	164145	128750	111020	91426	74901	2.5	-2.3	-3.8	-3.9
Nuclear	202589	223028	243761	257360	238768	240281	226615	229774	244047	1.9	-0.2	-0.5	0.7
Renewable energy sources	74984	89326	104111	123722	149430	194424	261787	272997	289268	3.3	3.7	5.8	1.0
Hydro	25101	28054	30374	26395	27808	28609	29347	30113	30748	1.9	-0.9	0.5	0.5
Biomass & Waste	46473	57201	67982	85129	97801	120894	154971	152833	153328	3.9	3.7	4.7	-0.1
Wind	67	350	1913	6061	13869	27864	45147	52085	59716	39.8	21.9	12.5	2.8
Solar and others	153	274	421	807	3261	9129	19191	21328	24186	10.7	22.7	19.4	2.3
Geothermal	3190	3447	3421	5331	6691	7929	13131	16638	21289	0.7	6.9	7.0	5.0
Net Imports	**756079**	**738600**	**826299**	**986048**	**993775**	**1049020**	**1045650**	**1059959**	**1039025**	**0.9**	**1.9**	**0.5**	**-0.1**
Solids	81846	79338	98645	126639	121637	125196	121958	132684	128533	1.9	2.1	0.0	0.5
Oil	535645	512185	533039	599851	580101	609993	607583	600309	577898	0.0	0.8	0.5	-0.5
- Crude oil and Feedstocks	508460	494000	513725	581995	578807	612244	615836	612364	594438	0.1	1.2	0.6	-0.4
- Oil products	27185	18185	19314	17856	1294	-2251	-8253	-12054	-16540	-3.4	-23.7		
Natural gas	135121	145288	192531	257366	288455	307433	300537	314560	318488	3.6	4.1	0.4	0.6
Electricity	3323	1508	1686	971	99	-613	-1684	-1781	-1867	-6.6	-24.7		
Gross Inland Consumption	**1660159**	**1662517**	**1723099**	**1825989**	**1766841**	**1792110**	**1781235**	**1771306**	**1753902**	**0.4**	**0.3**	**0.1**	**-0.2**
Solids	452940	364248	321007	319922	289488	282427	261040	262888	253144	-3.4	-1.0	-1.0	-0.3
Oil	631058	650858	658727	676859	632974	632398	604663	587254	559948	0.4	-0.4	-0.5	-0.8
Natural gas	294905	333268	393417	445998	452600	436183	411558	405987	393388	2.9	1.4	-0.9	-0.5
Nuclear	202589	223028	243761	257360	238768	240281	226615	229774	244047	1.9	-0.2	-0.5	0.7
Electricity	3323	1508	1686	971	99	-613	-1684	-1781	-1867	-6.6	-24.7		
Renewable energy forms	75343	89606	104501	124880	152912	201435	279043	287184	305242	3.3	3.9	6.2	0.9

Source: http://ec.europa.eu/energy/observatory/trends_2030/doc/trends_to_2030_update_2009.pdf

Some definitions

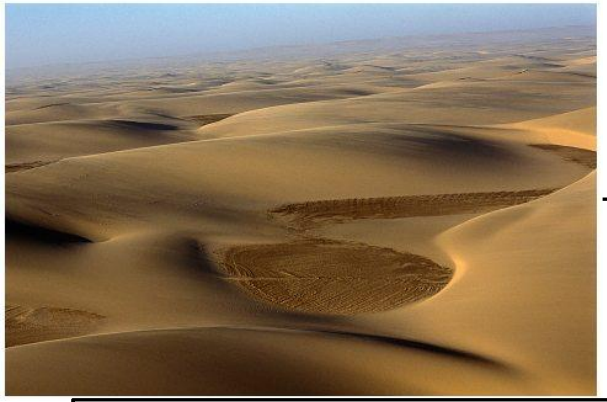
Embodied (embedded) energy

Embodied, or embedded, energy is defined as the commercial energy (fossil fuels, nuclear, etc) that was used to make any product, bring it to market, and dispose of it.

(This is a bit dodgy, since there's little consensus on where to locate the boundary of the "product".)

Embodied energy is <u>never</u> counted when calculating national energy demand (*i.e.* PER).

Energy Systems

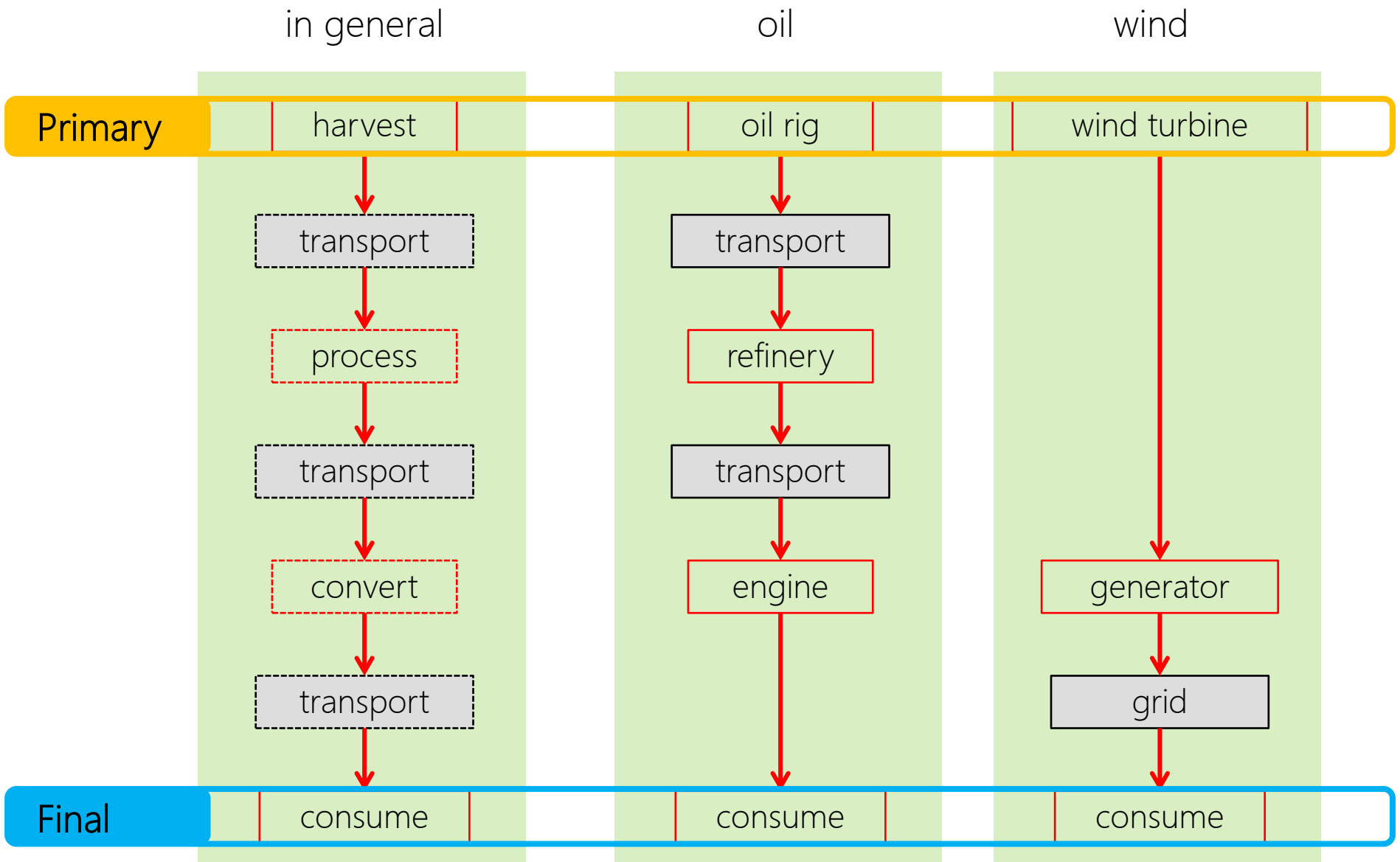








Energy Systems

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guides
simply
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help
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management
SIDEBAR
web
makes
made
offers
research
collections
offer
Library
subject
allow
book
content
important
system
make
use
systems
means
making
developers
several
work
libraries
right
community
others
world
Linux
first
tools
known
different
available
find
catalog
share
look
like
source
many
product
sites
proprietary
Scribus
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Evergreen
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WordPress
websites
used
FIGURE
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just
Ubuntu
think
CAPTION
open
even
GIMP
figure
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create
site
easily
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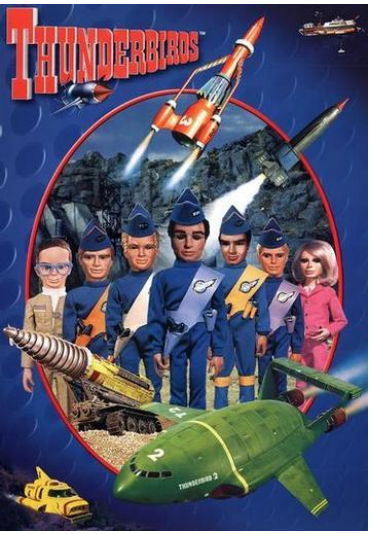
Useful sources of statistical data on energy:

- **Statistical Review of World Energy,** now provided via Energy Institute (energyinst.org)
  - Historical primary energy supply and demand, by region and fuel type
  - Excel spreadsheets and pdf reports, annual updates

- **International Energy Agency** (via OECD iLibrary, UCD Library website)
  - World Energy Outlook; Key World Energy Statistics; Special Reports
  - Emphasis on projecting future demand

- **US Energy Information Administration** (ww.eia.gov)
  - International Energy Outlook: projections, plus historic data
  - Pdfs, plus Excel data

- **World Bank** (data.worldbank.org)
  - Energy, GDP, population
  - Pdfs, plus Excel data

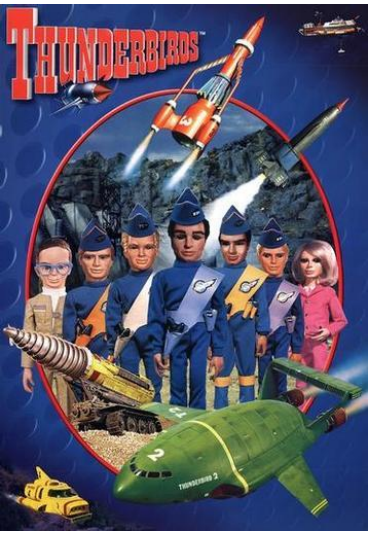


A note on data sources

Several high-level international bureaucracies have been established, e.g.:

- United Nations Statistics Division (unstats.un.org)
- International Energy Agency (iea.org)
- World Energy Council (worldenergy.org)
- Eurostat (ec.europa.eu/eurostat)
- Energy Information Administration (eia.gov)

Private-sector companies have a strong interest, e.g.: platts, OIL&GAS JOURNAL, Bloomberg NEW ENERGY FINANCE, bp



A note on data sources

However, the task is fraught with difficulties:

Data sources are diverse, diffuse, and of variable quality (e.g. EU versus Rwanda, China, Chad…)

Much data is commercially, or nationally, sensitive

Significant time lags may exist

Some estimates refer to HHV (GCV), some to LHV (NCV)

…etc.

So treat all data with caution!

Global primary energy demand[1]

2024:

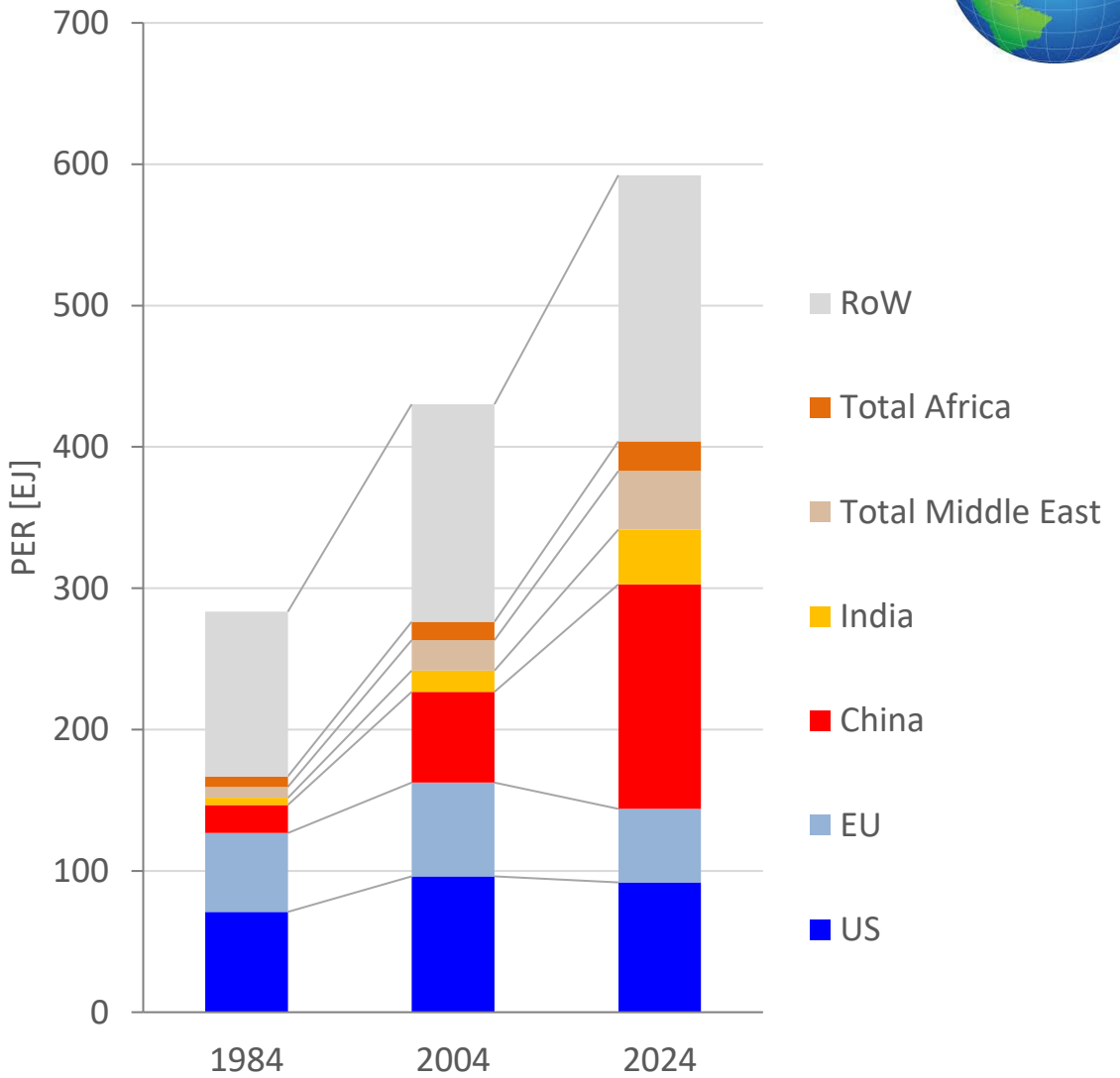
592 EJ = 14.1 billion toe (Gtoe)

≈ 1.8 toe per capita per annum

≈ 6.3 litres of petrol equivalent, per person, per day

≈ 44 *billion* litres of petrol equivalent *per day*

19.2 TW 2.4 kW per capita (BMR ~ 0.115 kW)



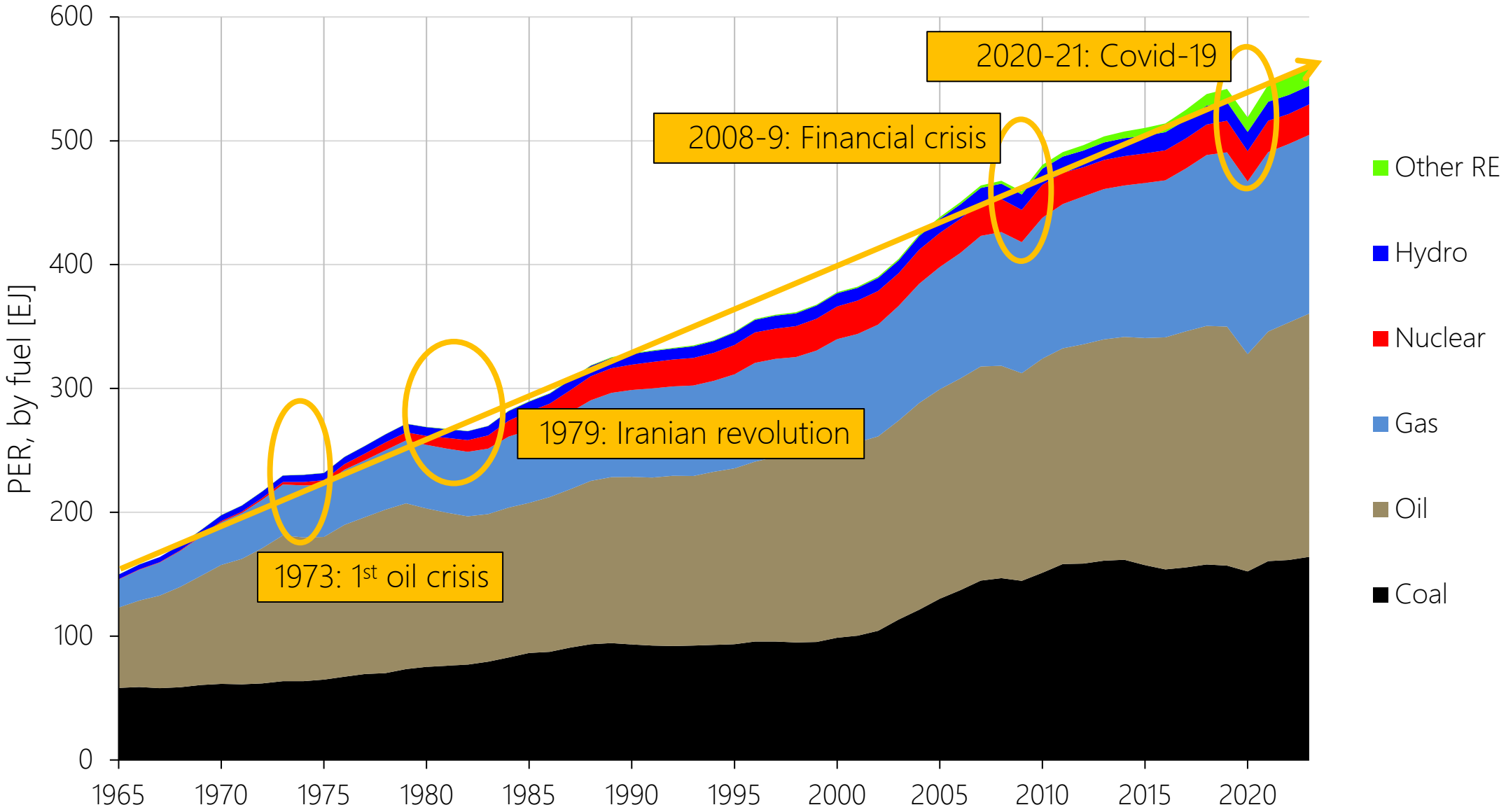
NB: Solar insolation ~ 100,000 TW

[1]*Raw data: Statistical Review of World Energy, www.energyinst.org*

Trends and patterns

Sources of primary energy*

1 Mtoe = 10^6 toe = 41.868 PJ = 0.041868 EJ 1 EJ = 23.88 Mtoe



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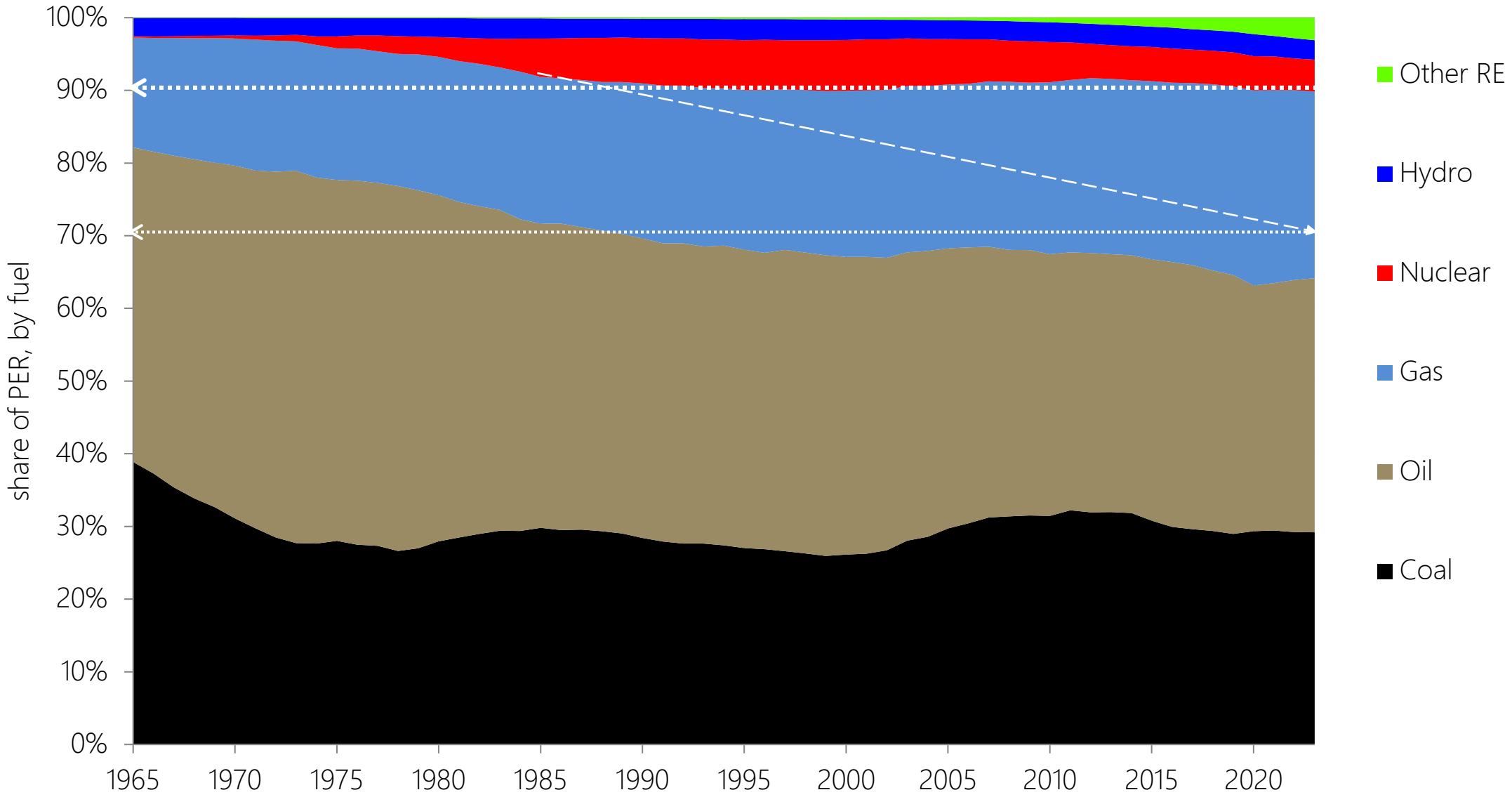
Sources of primary energy*



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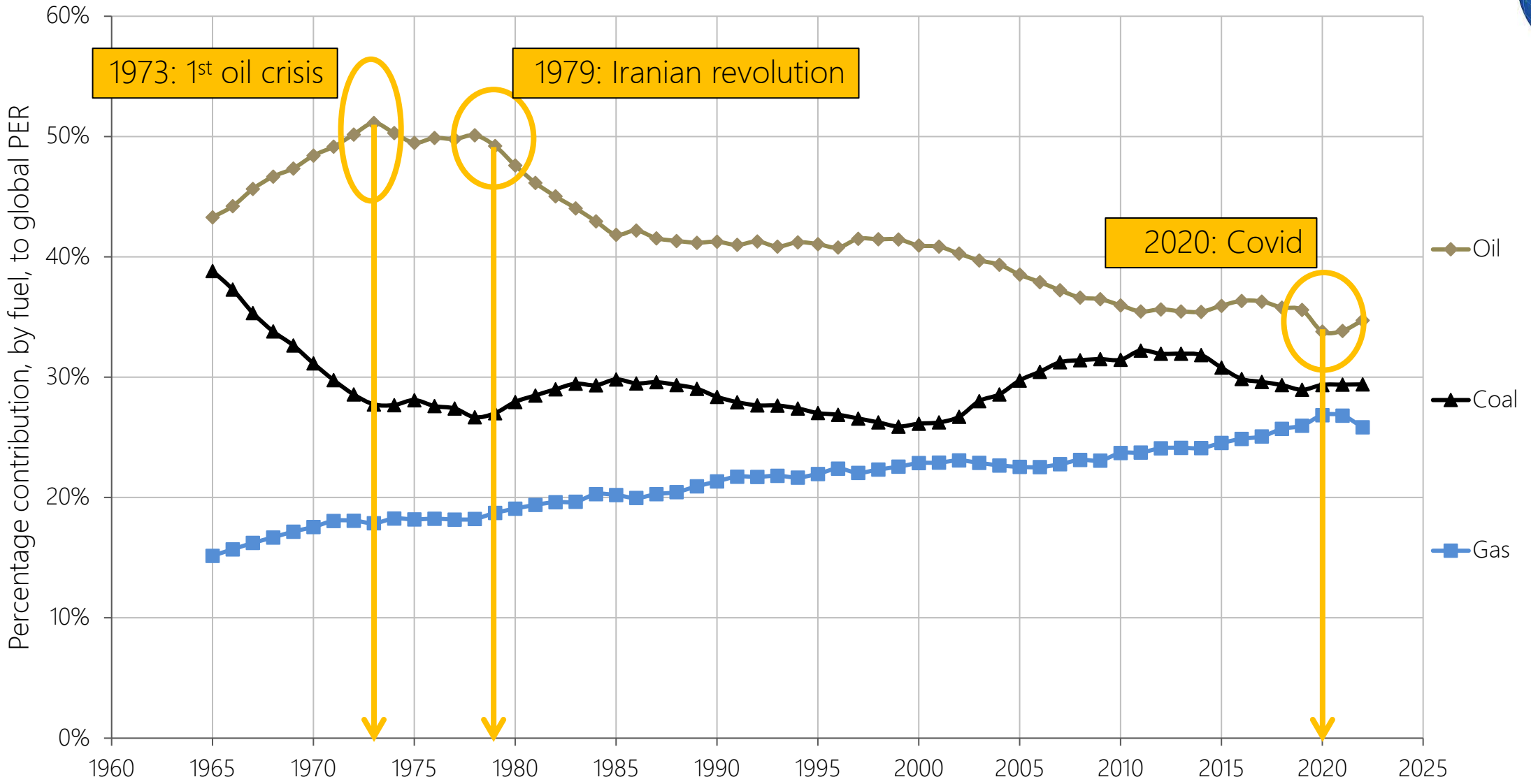
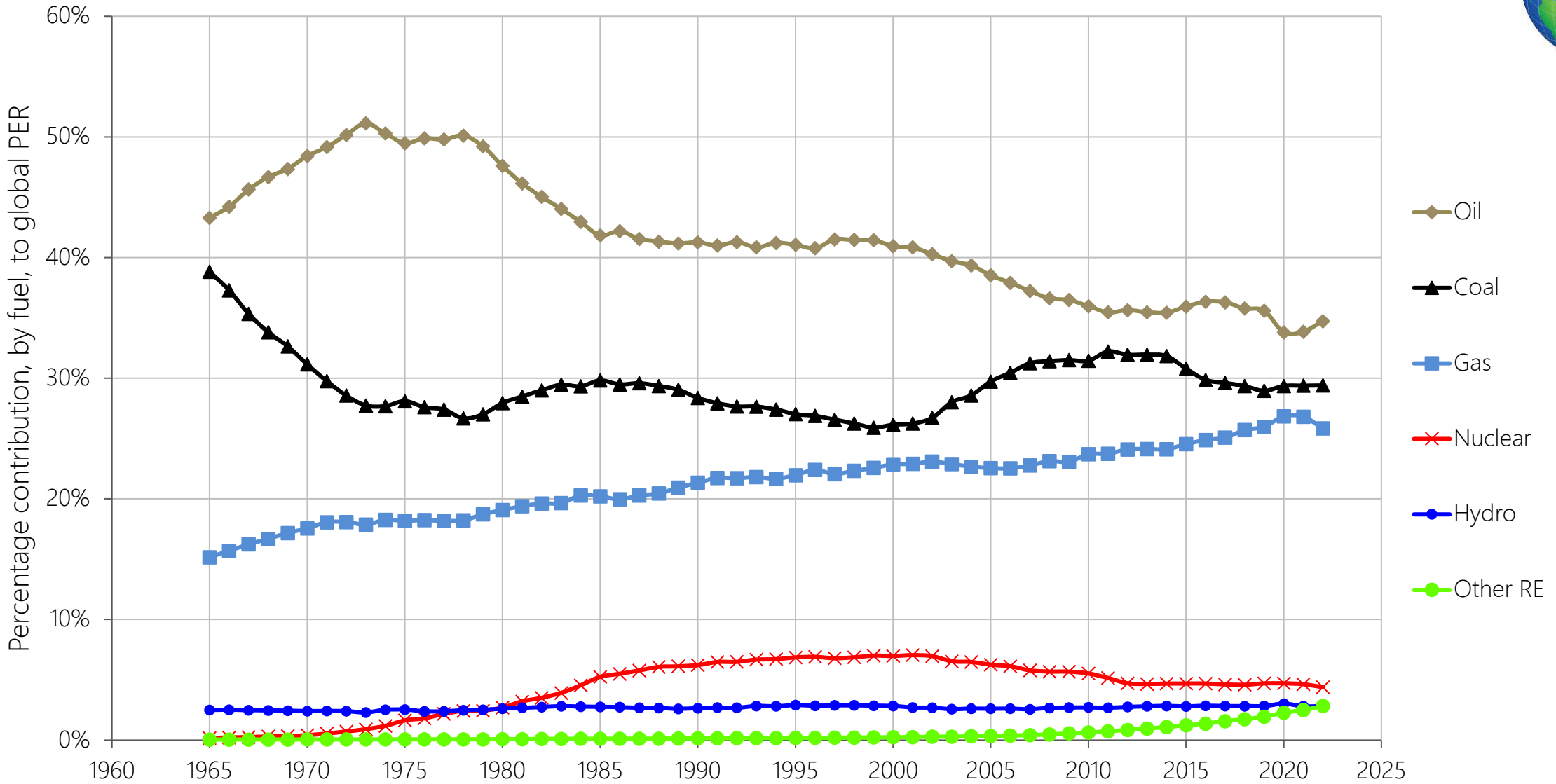
Sources of primary energy*



[1]*Raw data: Statistical Review of World Energy, www.energyinst.org*

Sources of primary energy*

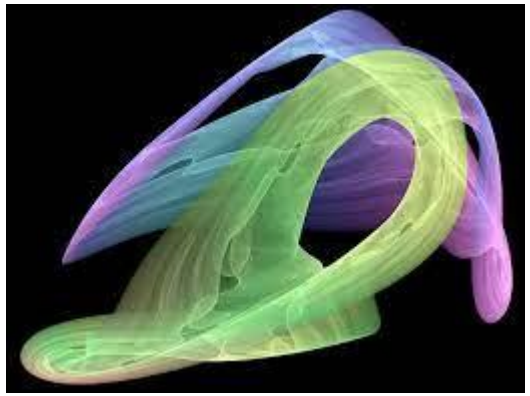


[1]*Raw data: Statistical Review of World Energy, www.energyinst.org*

Interim summary 1

- We're looking at energy *systems* as a whole

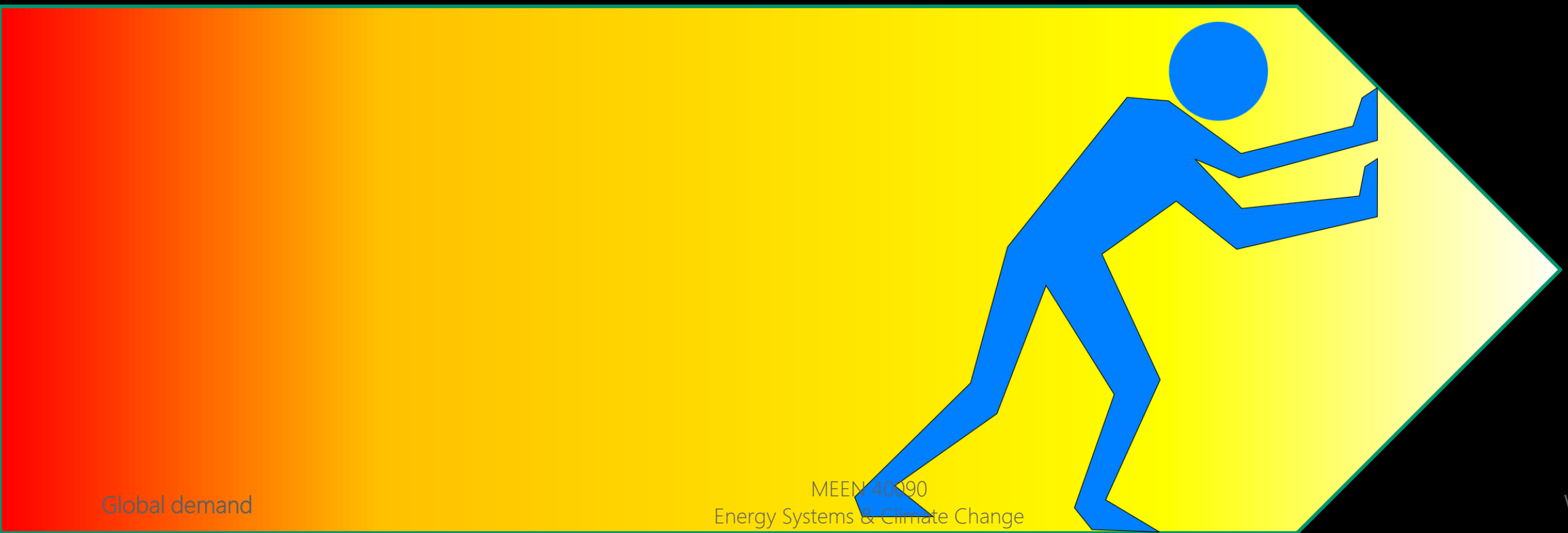
- The behaviour of these systems may be (probably is?) chaotic



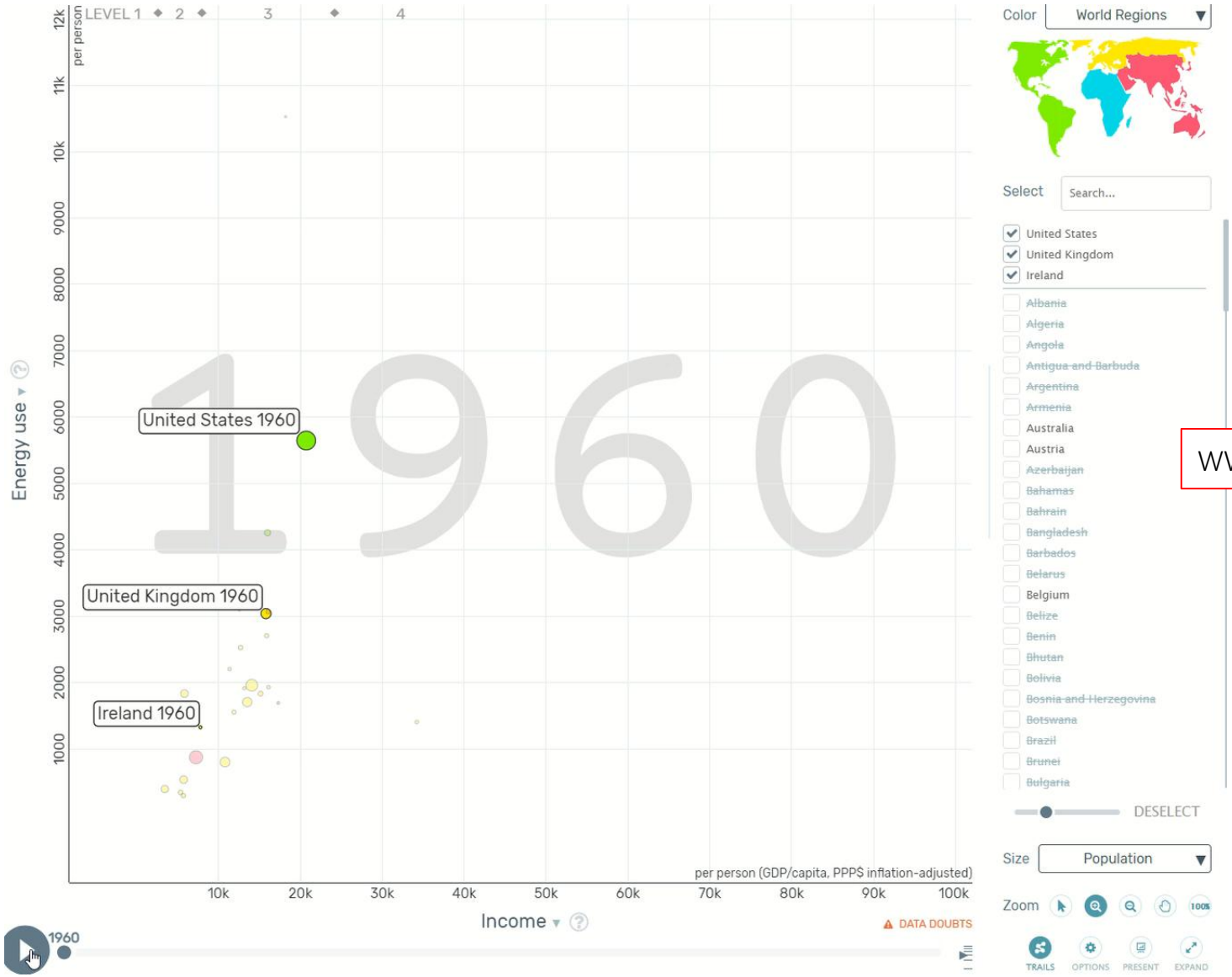
- Data quality is variable

- Nonetheless, clear trends can be discerned in historic data

What drives demand?

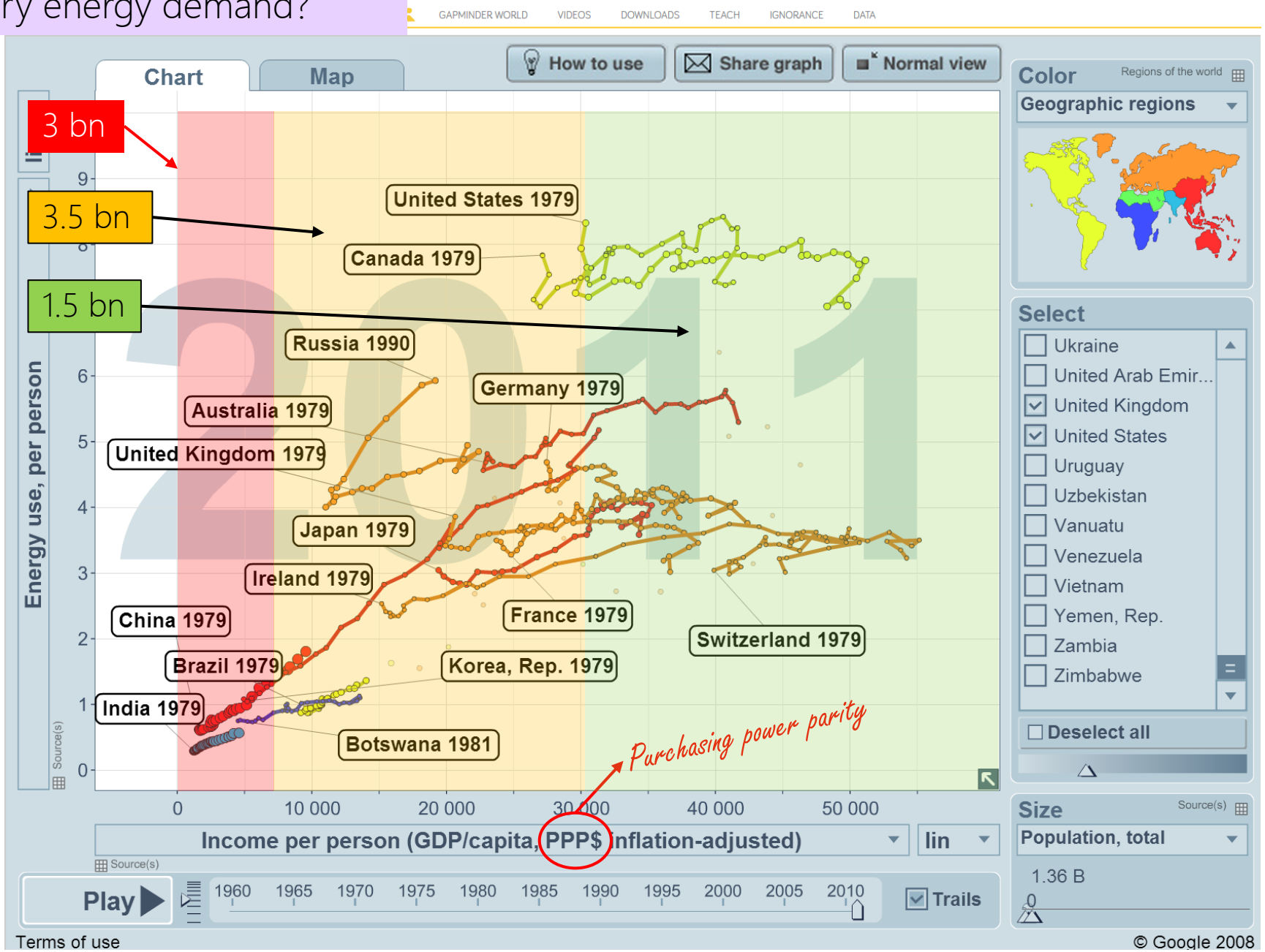


What drives primary energy demand?

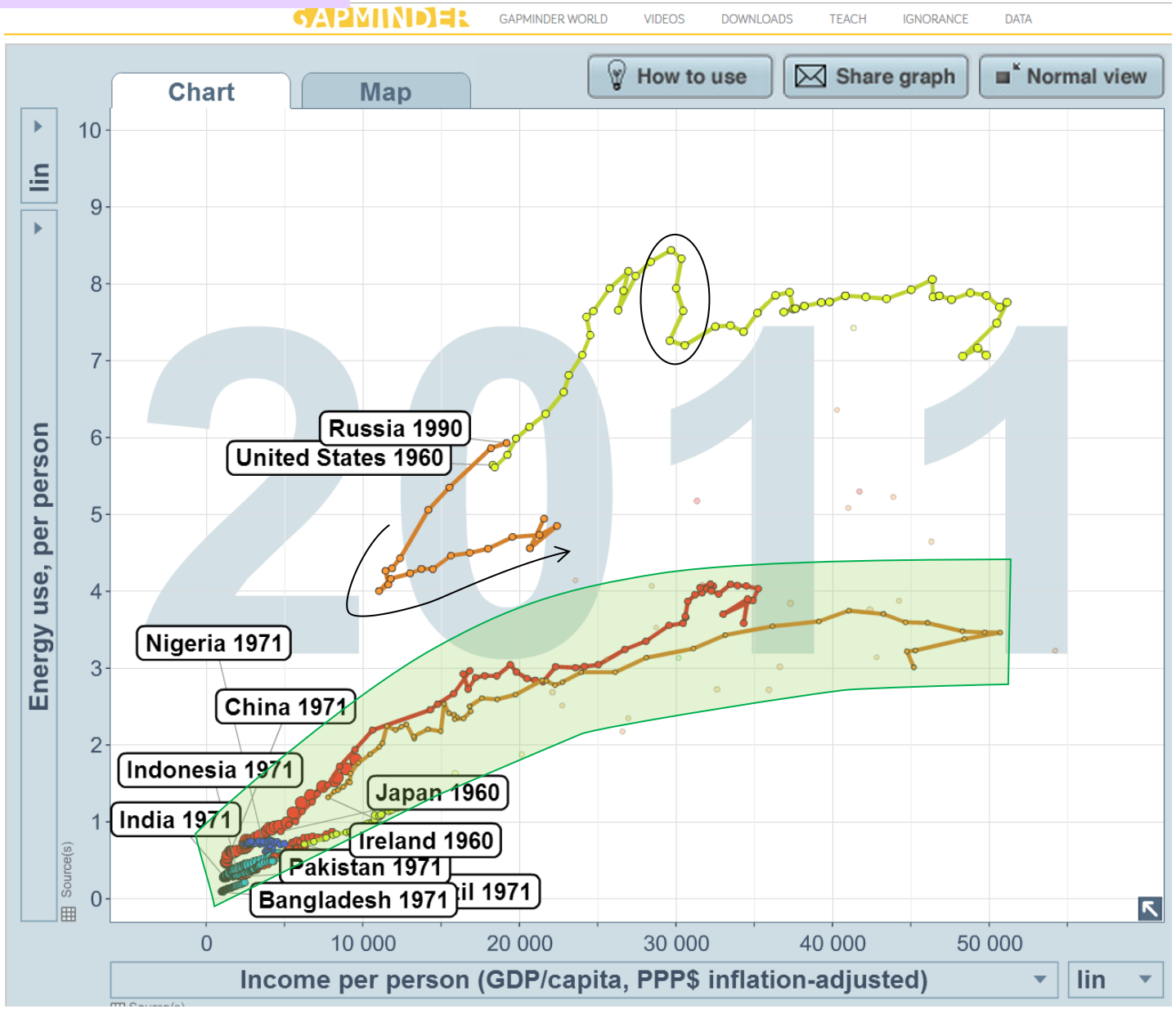


www.gapminder.org

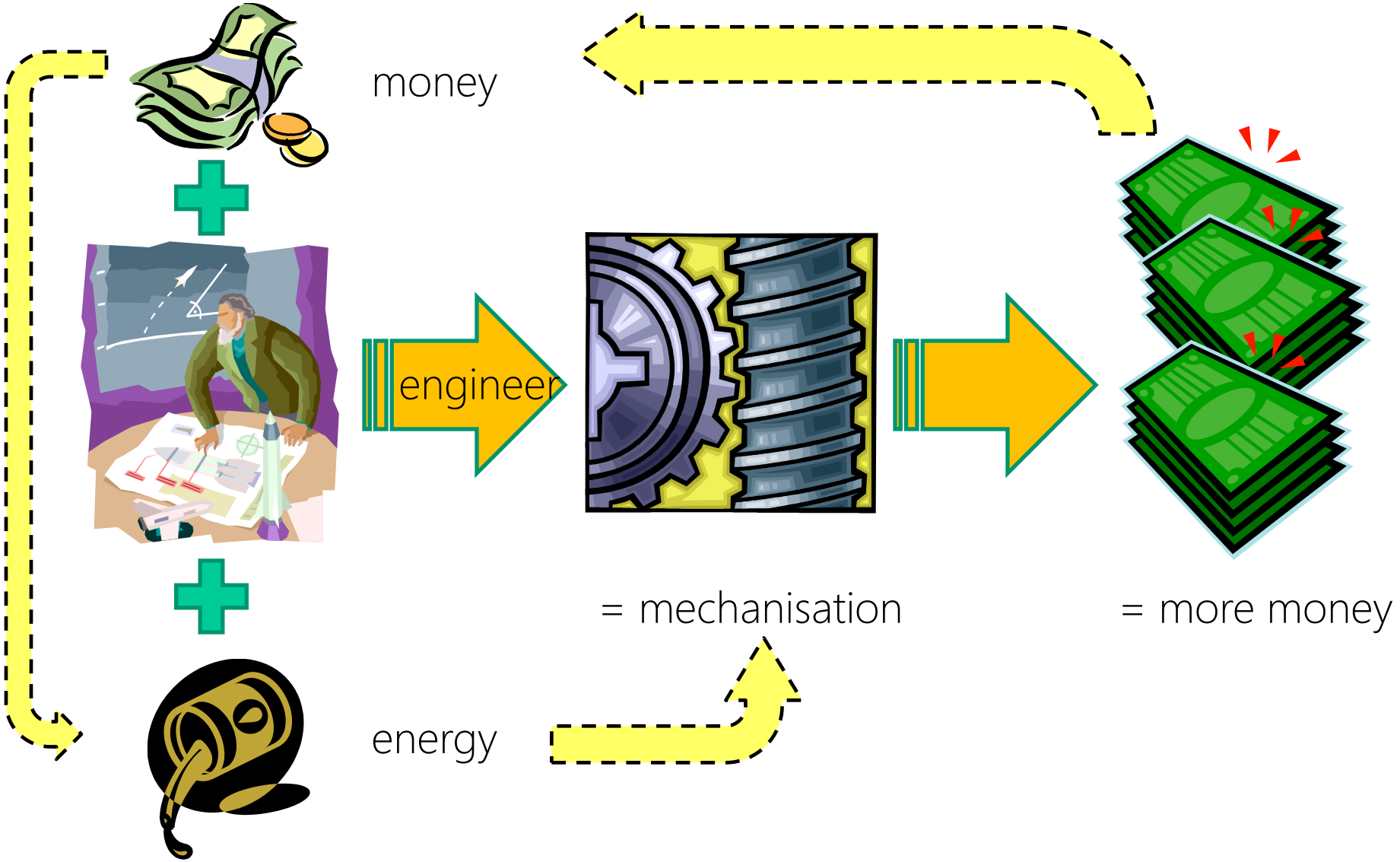
What drives primary energy demand?



What drives primary energy demand?

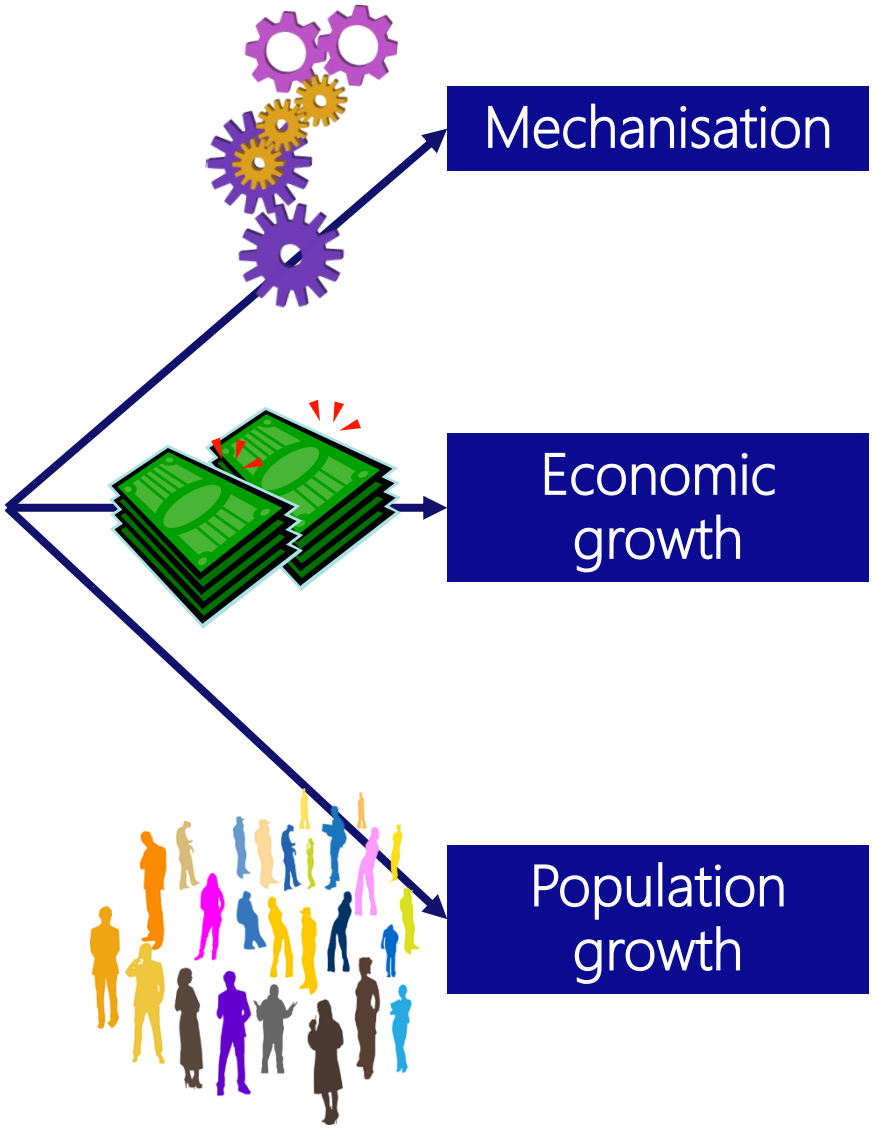


What drives energy demand?

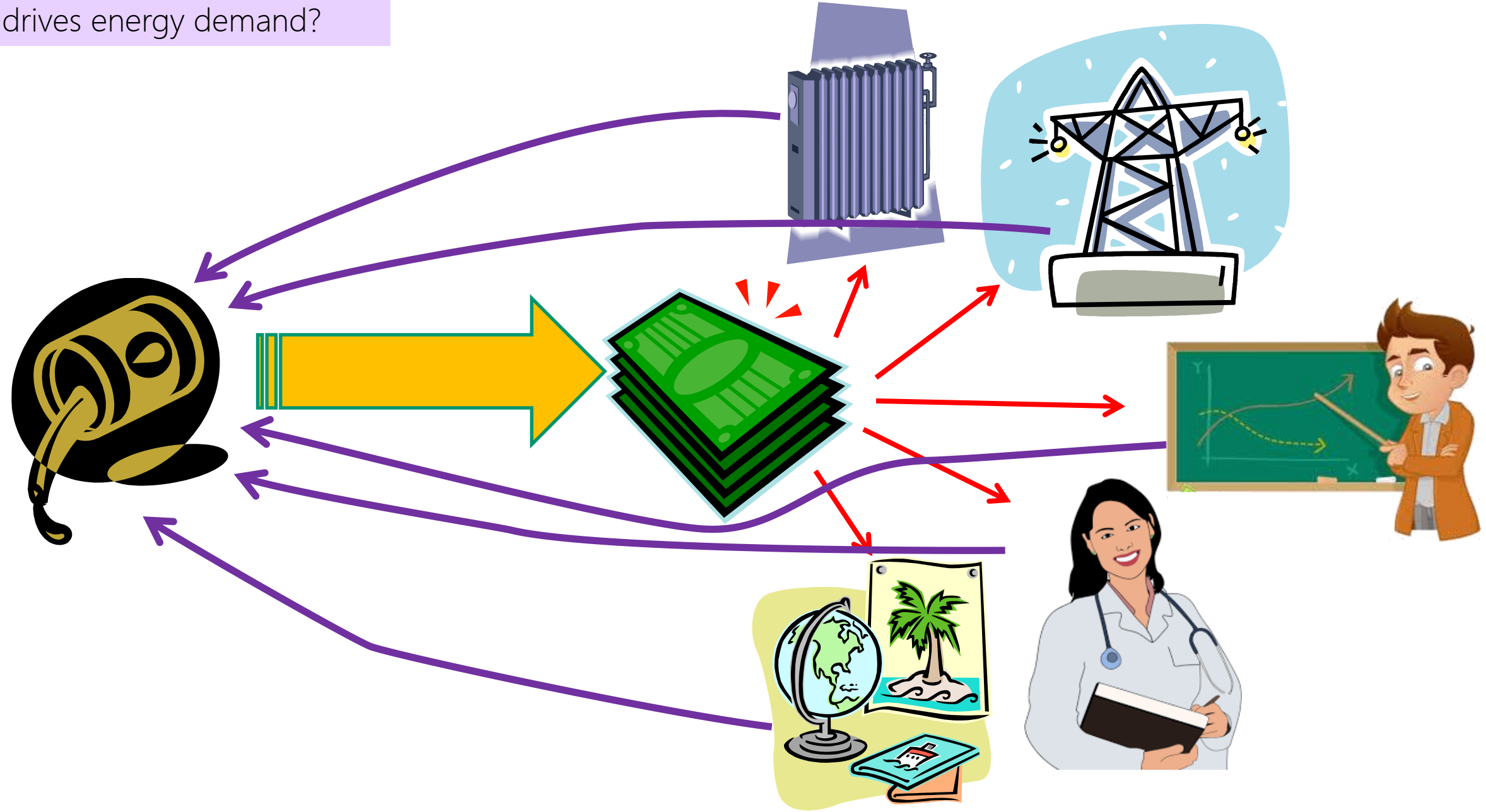


What drives energy demand?

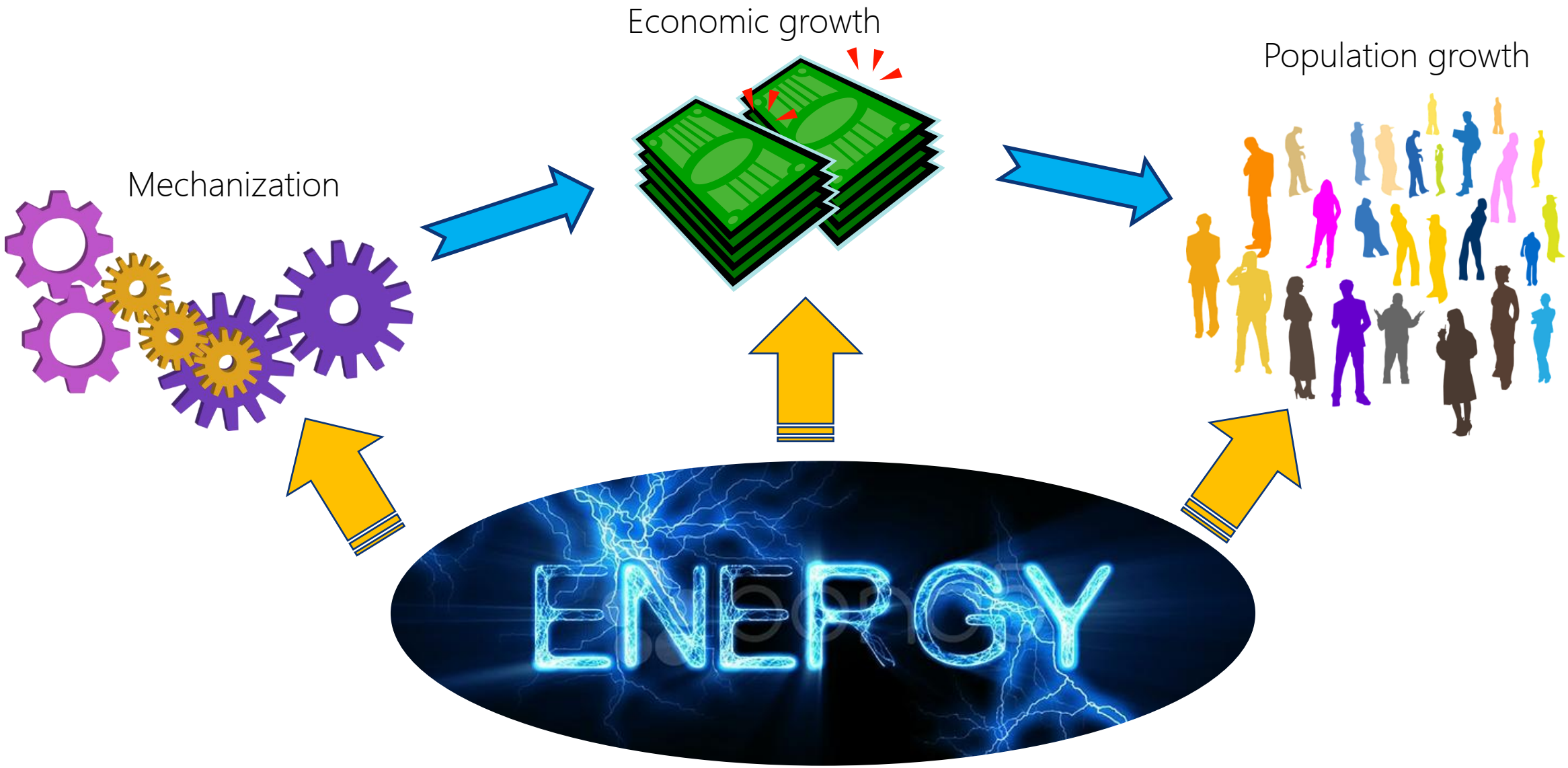
3 main factors drive energy demand:



What drives energy demand?



What drives energy demand?



What drives primary energy demand?

\+
energy

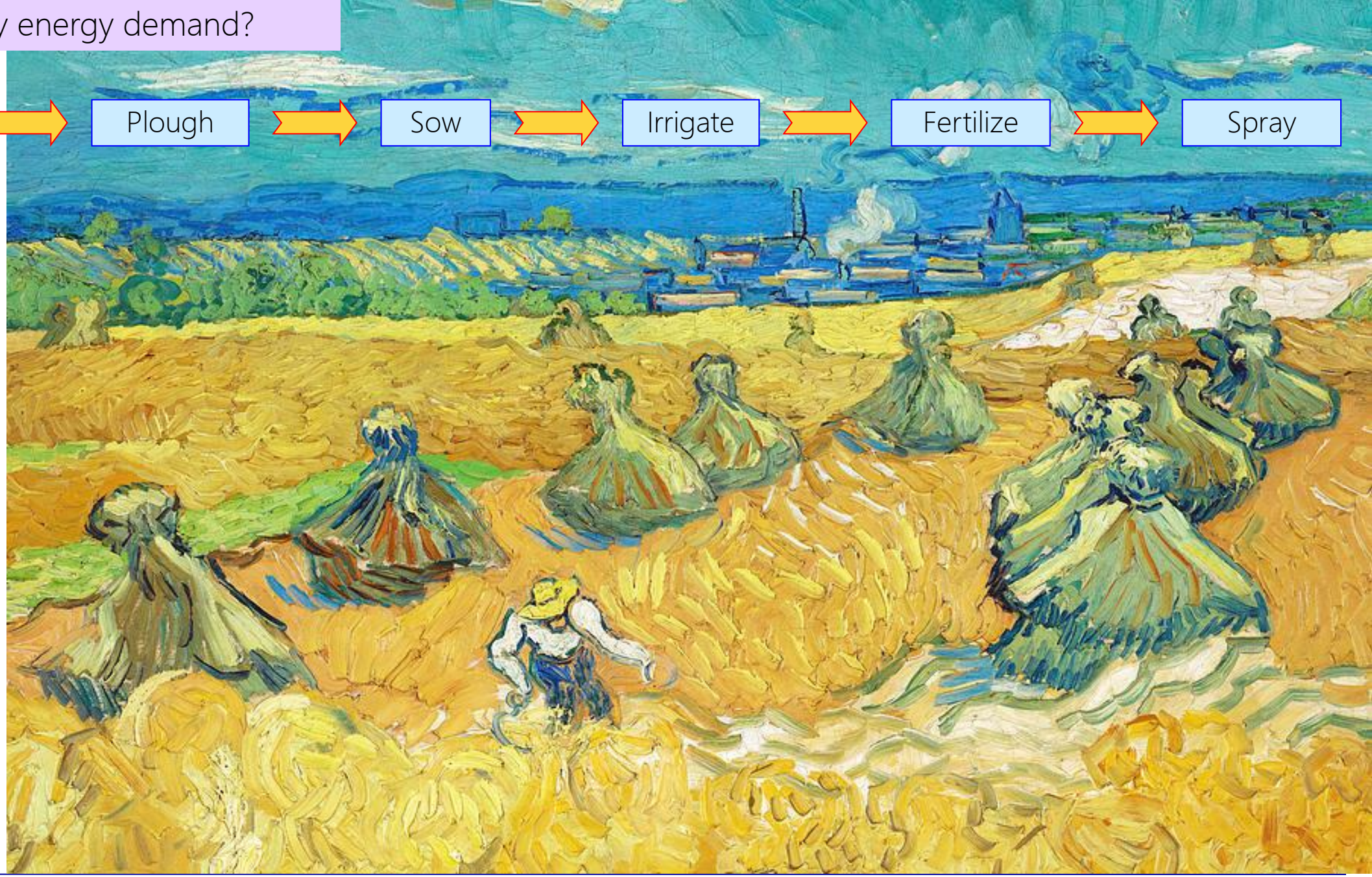
What drives primary energy demand?

Grow → Plough → Sow → Irrigate → Fertilize → Spray

Harvest

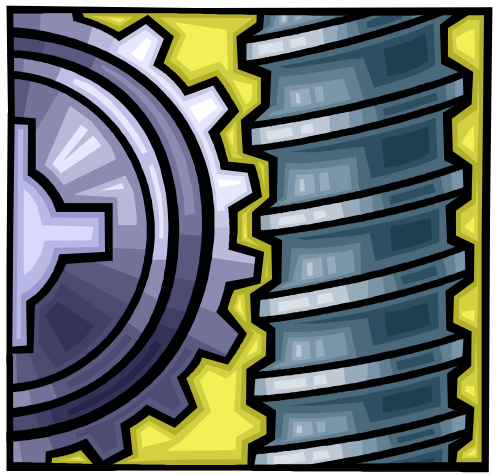
Process

Sell



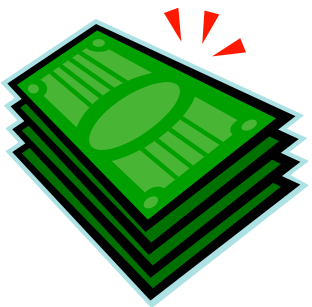
What drives primary energy demand?

Mechanisation

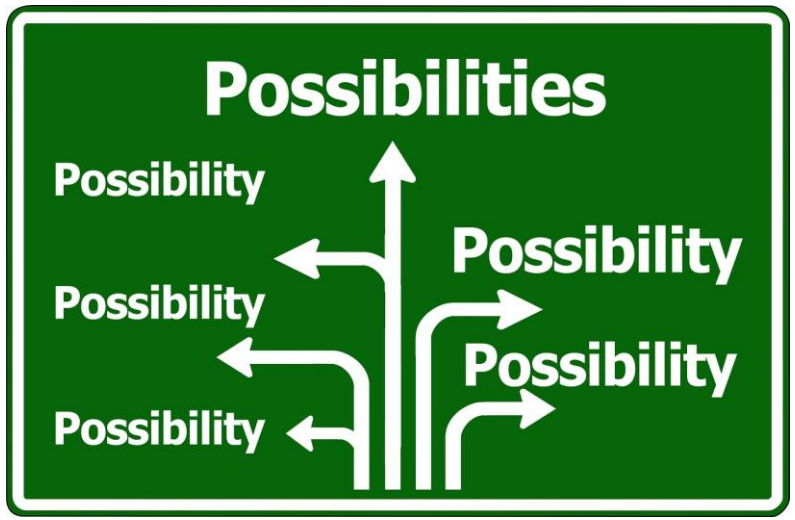


time

money



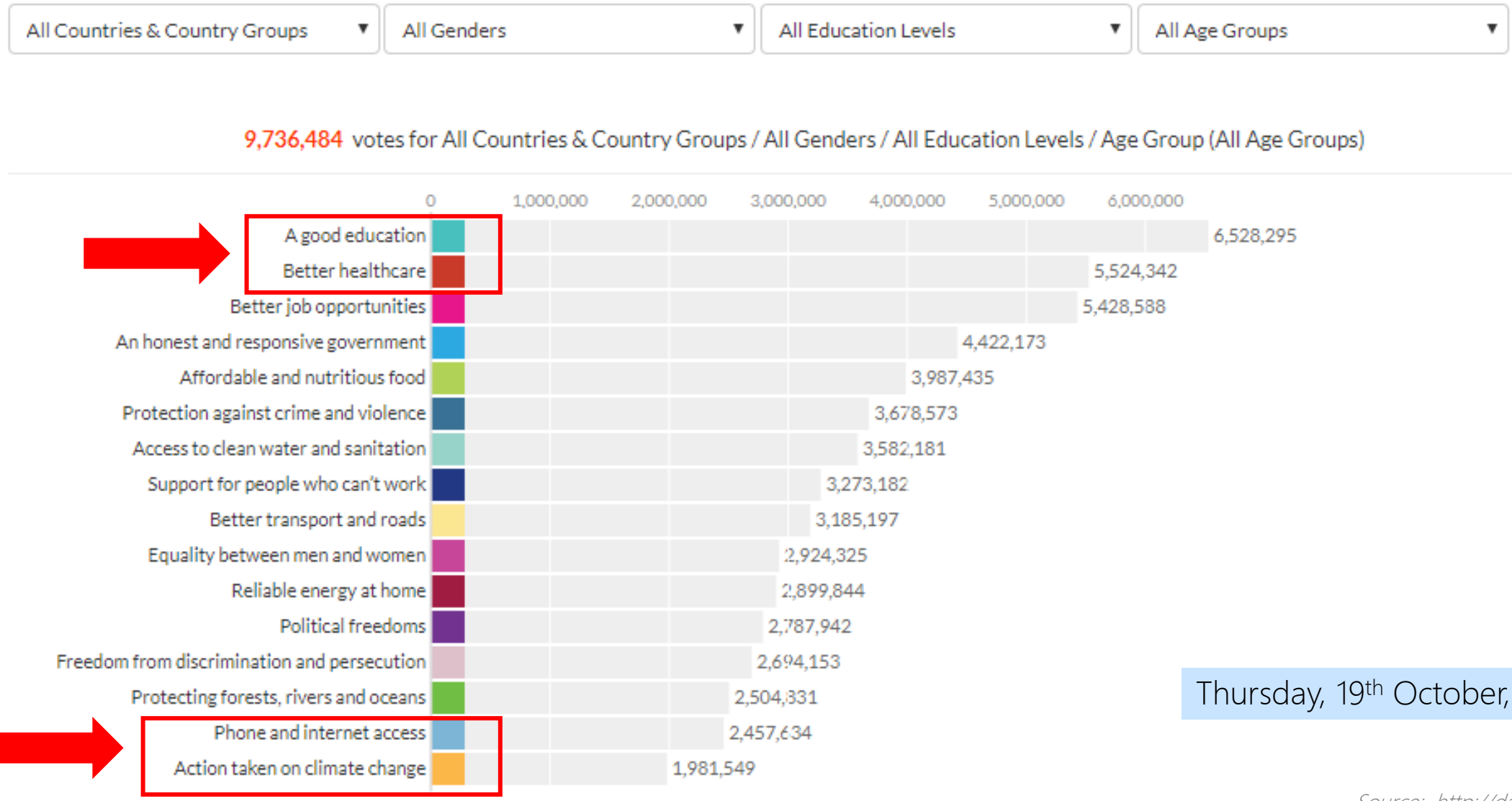
Opportunity



What drives primary energy demand?

U.N. MyWorld survey

Voters rank any 6, out of 16, in order of importance



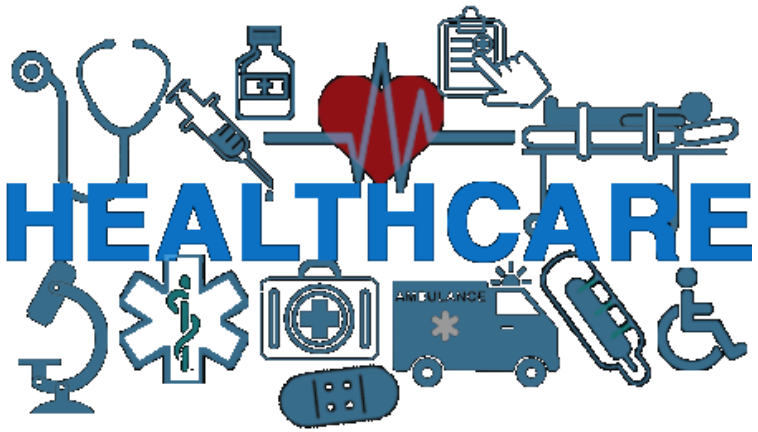
Thursday, 19th October, 2017

Source: http://data.myworld2015.org/

Education requires time

Healthcare requires

- Education
- Buildings and/or transport
- Electricity
- Refrigeration
- …etc., etc.



What drives energy demand?

Note: economic growth is both a consequence and a cause of increased energy demand.

roads

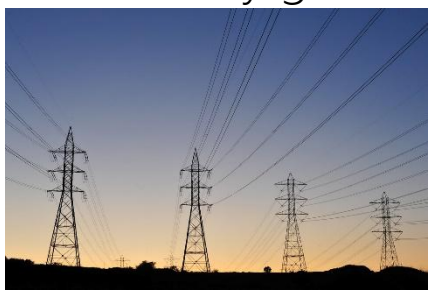
railways

ports

airports

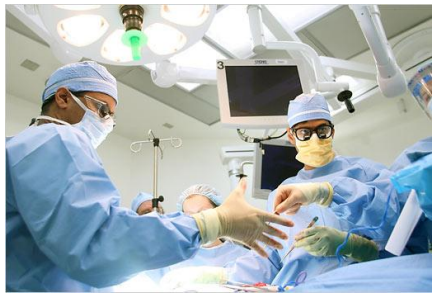
power plant

electricity grid



Phase 1 (development) consumes energy to install and expand infrastructure, e.g:

hospitals



schools

water / sewage

housing

factories

gas pipelines

What drives energy demand?

Note: economic growth is both a consequence and a cause of increased energy consumption.

Phase 1 (development) consumes energy to install and expand infrastructure.

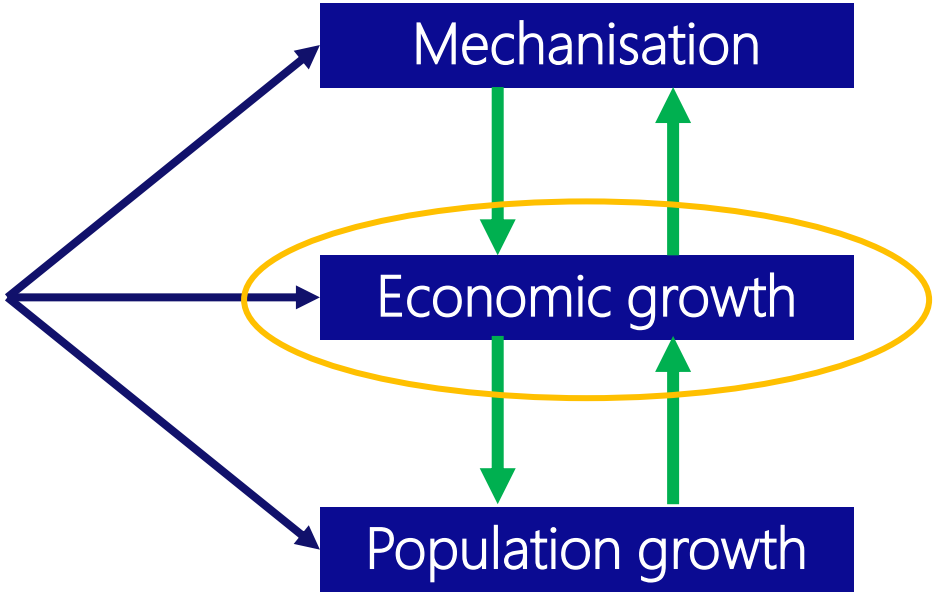
Phase 2 (maturity) consumes energy to leverage existing infrastructure, e.g:






What drives energy demand?

3 main factors drive energy demand:



a) Can we achieve economic growth using less energy?

b) Can we decouple energy consumption from greenhouse gas emissions?

Metrics of global and regional energy demand

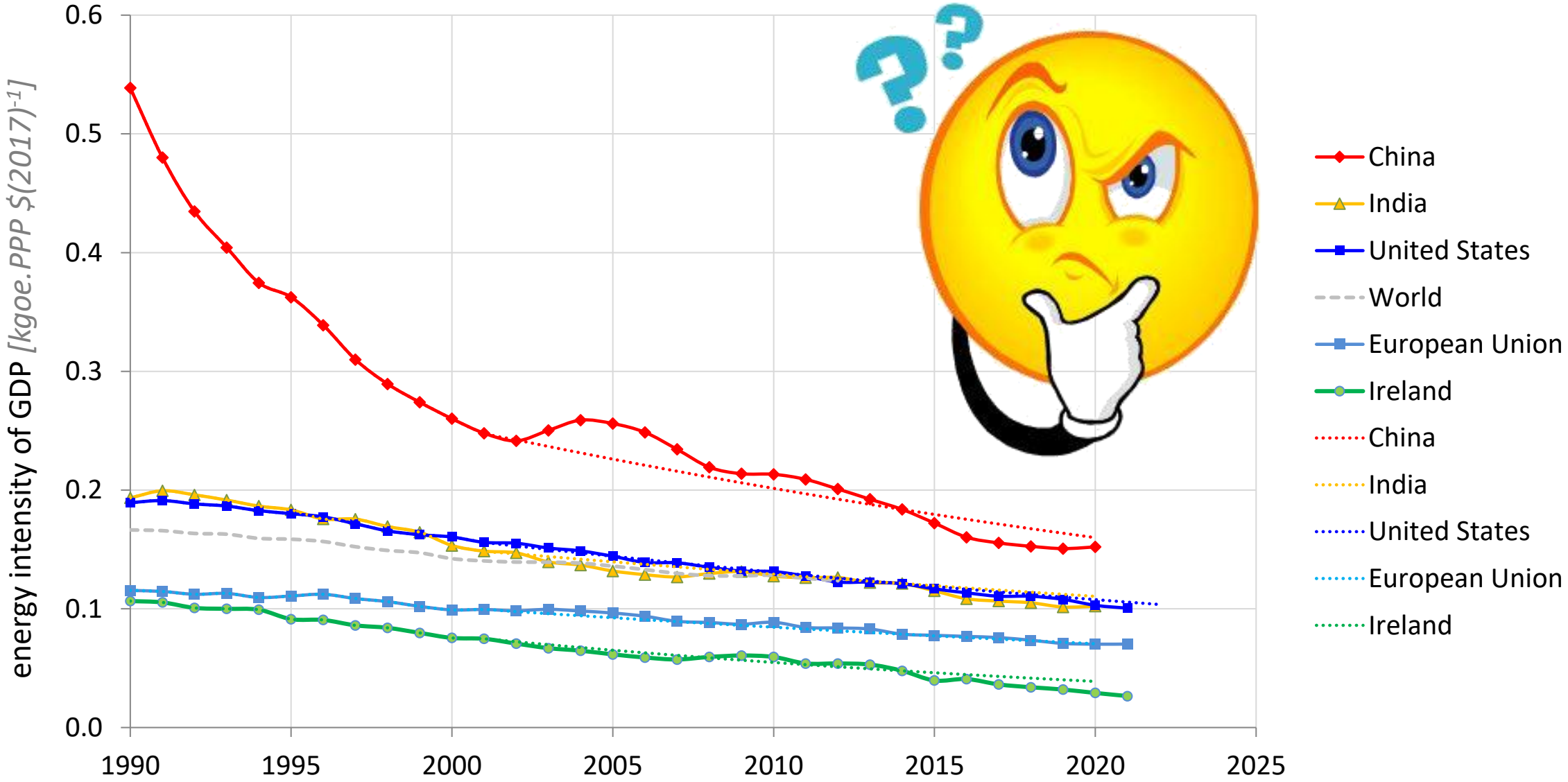
Can we achieve economic growth using less energy?

Define: energy-intensity of GDP $= \dfrac{\text{Annual energy demand}}{\text{GDP in that year}}$

Measures how much (primary?) energy was used to produce each unit of wealth.

Lower is "better".

Metrics of global and regional energy demand



Raw data: World Bank

What drives primary energy demand?

Hans Rosling: The magic washing machine

Energy for development

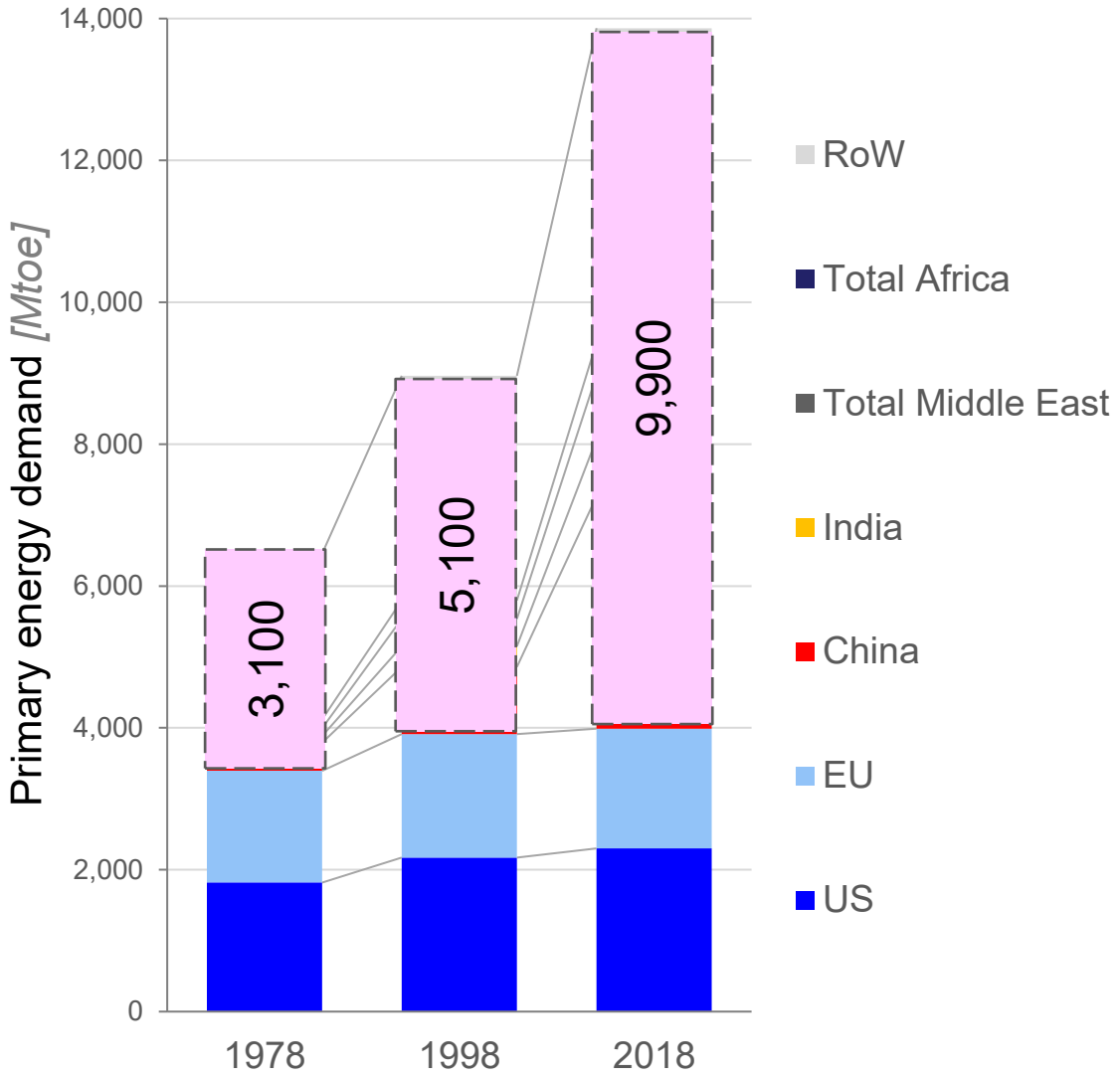
What drives primary energy demand?

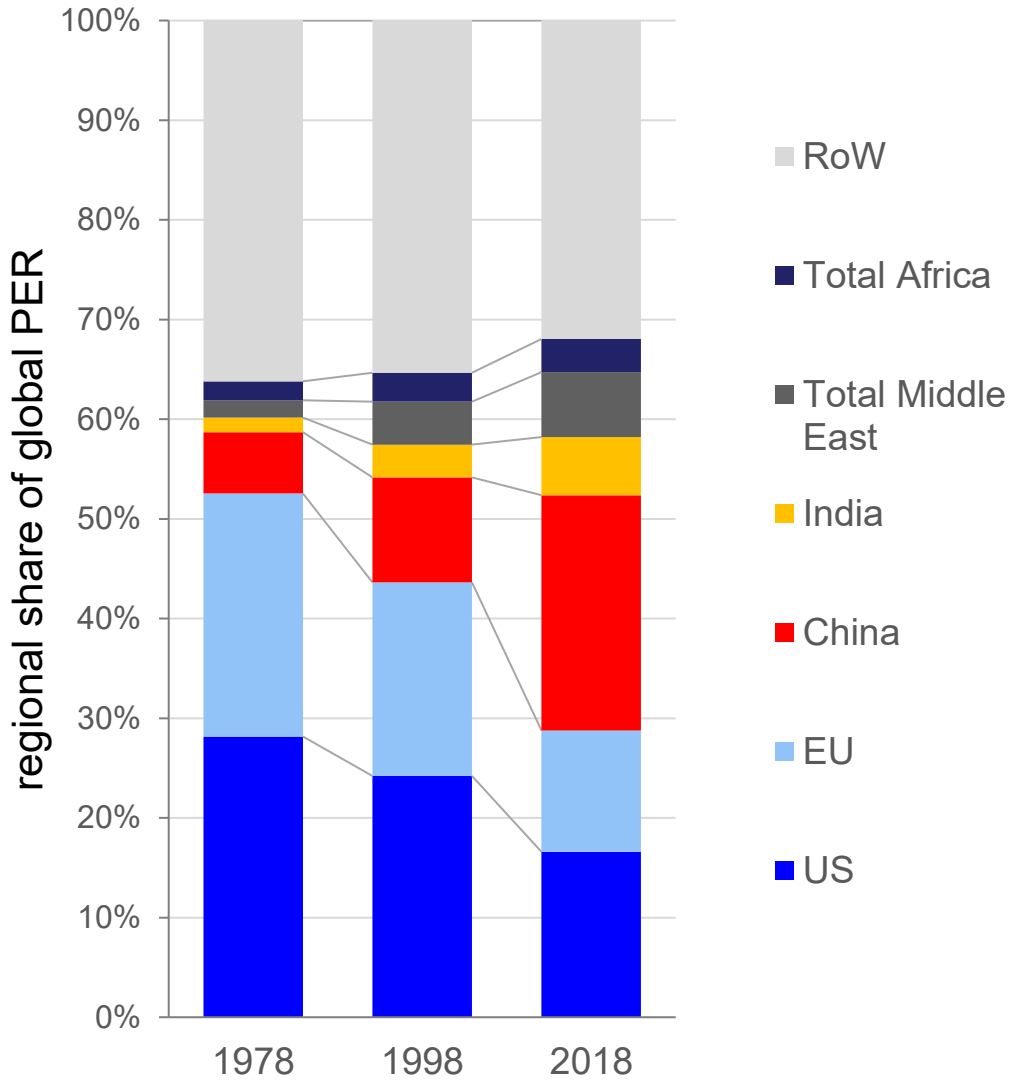
Indeed, the Wu family dislikes the light gray smog of sulfur particles and other pollutants that darkens the sky, and dulls the dark green fields of young wheat and the white blossoms of peach orchards in the distance. But they tolerate the pollution.

"Everything else is better here," Mr. Wu said. "Now we live better, we eat better."

New York Times, 11 June 2006

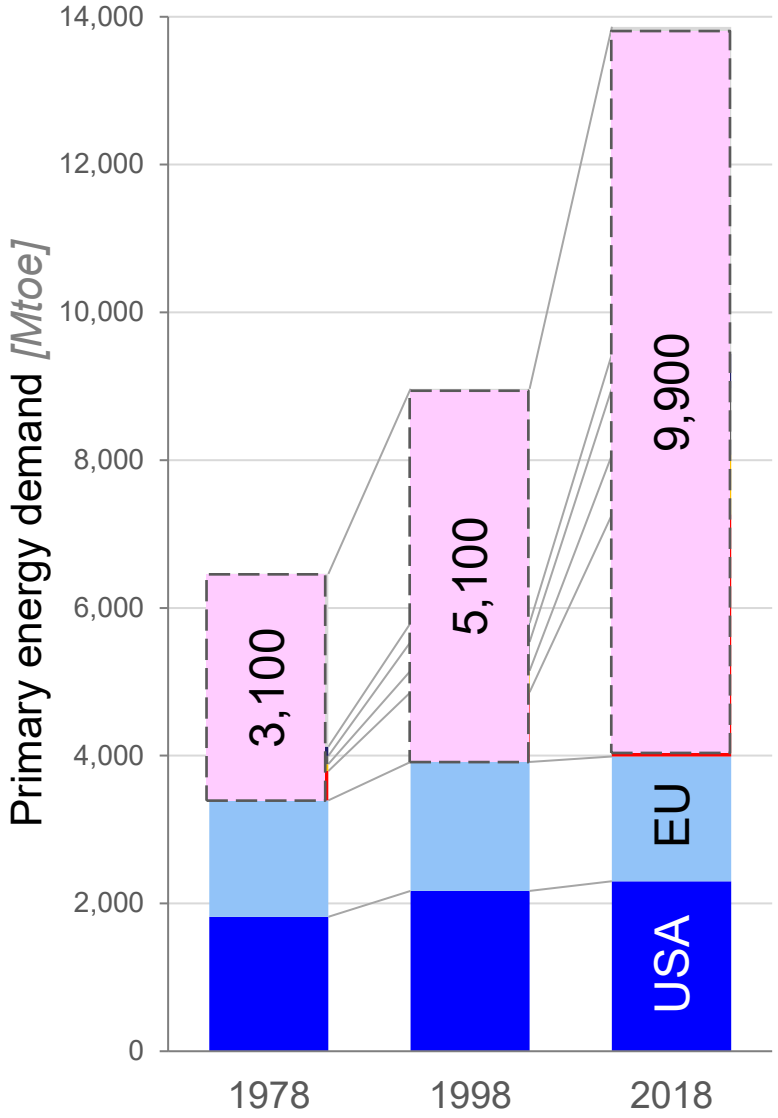
What drives energy demand?



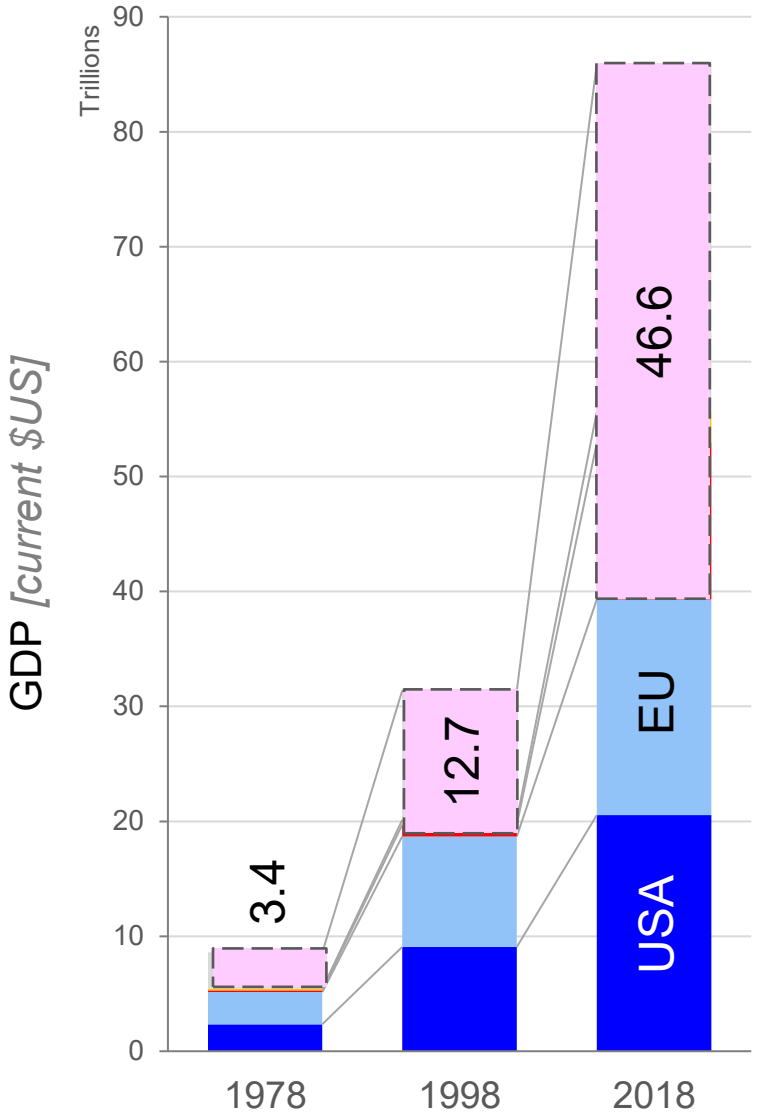


[1]*Raw data: Statistical Review of World Energy, www.energyinst.org*

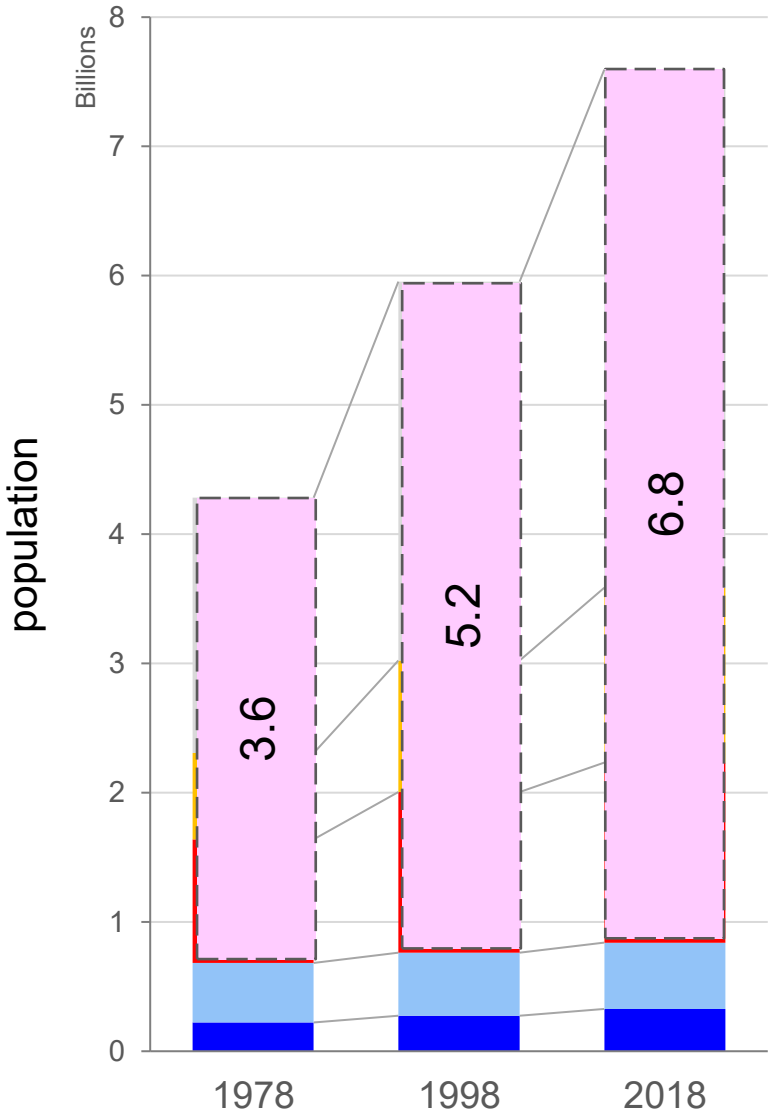
What drives energy demand?



Economic growth



Population growth



Raw data: B.P. Statistical review of world energy 2019; World Bank development Indicators

Hans Rosling: Ikea boxes

https://www.youtube.com/watch?v=fTznEIZRkLg

(10 min)

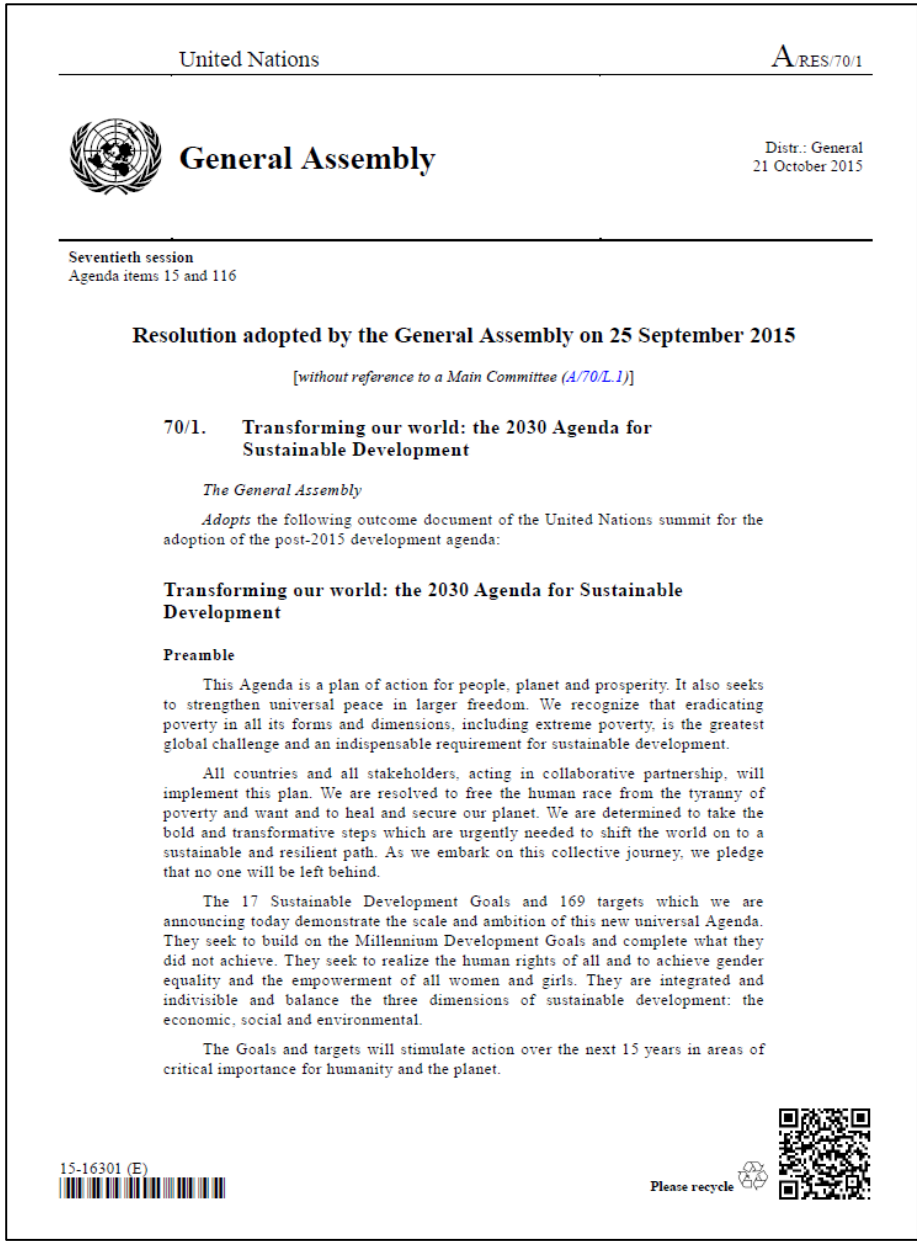
Image source: *https://sdgs.un.org/goals/*

SUSTAINABLE DEVELOPMENT GOALS

- Agreed by world Heads of State in September 2015.

  "...we are setting out a supremely ambitious and transformational vision."

- 17 Goals (SDGs) to be achieved by 2030



United Nations A/RES/70/1

General Assembly

Distr.: General
21 October 2015

Seventieth session
Agenda items 15 and 116

Resolution adopted by the General Assembly on 25 September 2015

[*without reference to a Main Committee (A/70/L.1)*]

70/1. Transforming our world: the 2030 Agenda for Sustainable Development

The General Assembly

Adopts the following outcome document of the United Nations summit for the adoption of the post-2015 development agenda:

Transforming our world: the 2030 Agenda for Sustainable Development

Preamble

This Agenda is a plan of action for people, planet and prosperity. It also seeks to strengthen universal peace in larger freedom. We recognize that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development.

All countries and all stakeholders, acting in collaborative partnership, will implement this plan. We are resolved to free the human race from the tyranny of poverty and want and to heal and secure our planet. We are determined to take the bold and transformative steps which are urgently needed to shift the world on to a sustainable and resilient path. As we embark on this collective journey, we pledge that no one will be left behind.

The 17 Sustainable Development Goals and 169 targets which we are announcing today demonstrate the scale and ambition of this new universal Agenda. They seek to build on the Millennium Development Goals and complete what they did not achieve. They seek to realize the human rights of all and to achieve gender equality and the empowerment of all women and girls. They are integrated and indivisible and balance the three dimensions of sustainable development: the economic, social and environmental.

The Goals and targets will stimulate action over the next 15 years in areas of critical importance for humanity and the planet.

15-16301 (E)

Please recycle

SUSTAINABLE DEVELOPMENT GOALS

"...a world free of poverty, hunger, disease and want"

"...a world free of fear and violence"

"...with universal literacy"

"...equitable and universal access to quality education at all levels"

"...safe drinking water and sanitation"

"...where food is sufficient, safe, affordable and nutritious"

"...where human habitats are safe, resilient and sustainable"

"...universal access to affordable, reliable and sustainable energy"

"...universal respect for human rights and human dignity"

"...a world in which every country enjoys sustained, inclusive and sustainable economic growth"

Source: *Transforming our world: the 2030 Agenda for Sustainable Development*

SUSTAINABLE DEVELOPMENT GOALS

Achieving these goals will require increased energy consumption...

Image source: *https://www.un.org/sustainabledevelopment/news/communications-material/*

SUSTAINABLE DEVELOPMENT GOALS

Ending extreme poverty is at the heart of the SDG agenda. Between 1990 and 2013 the number of people living below $1.90 a day fell by over 1 billion.

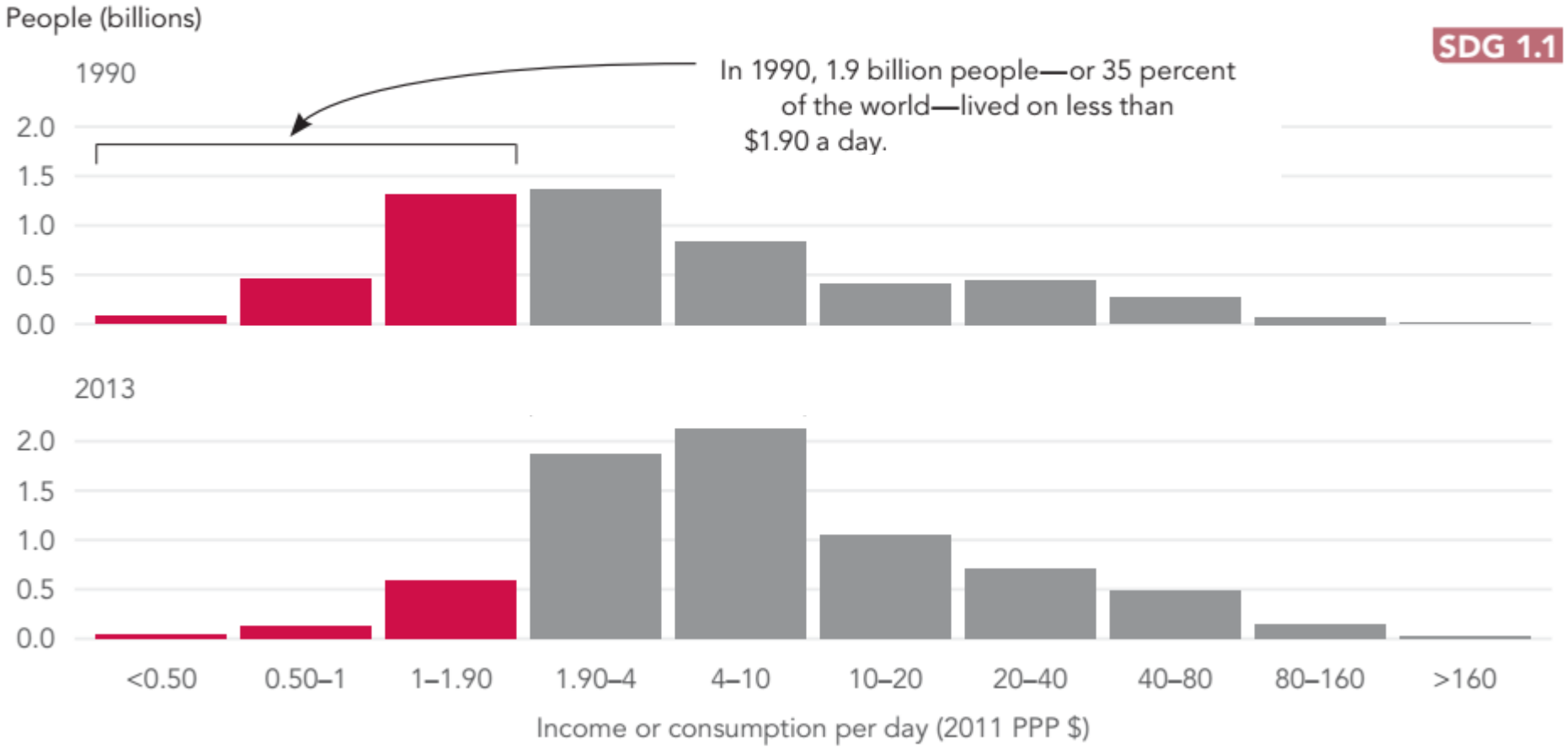
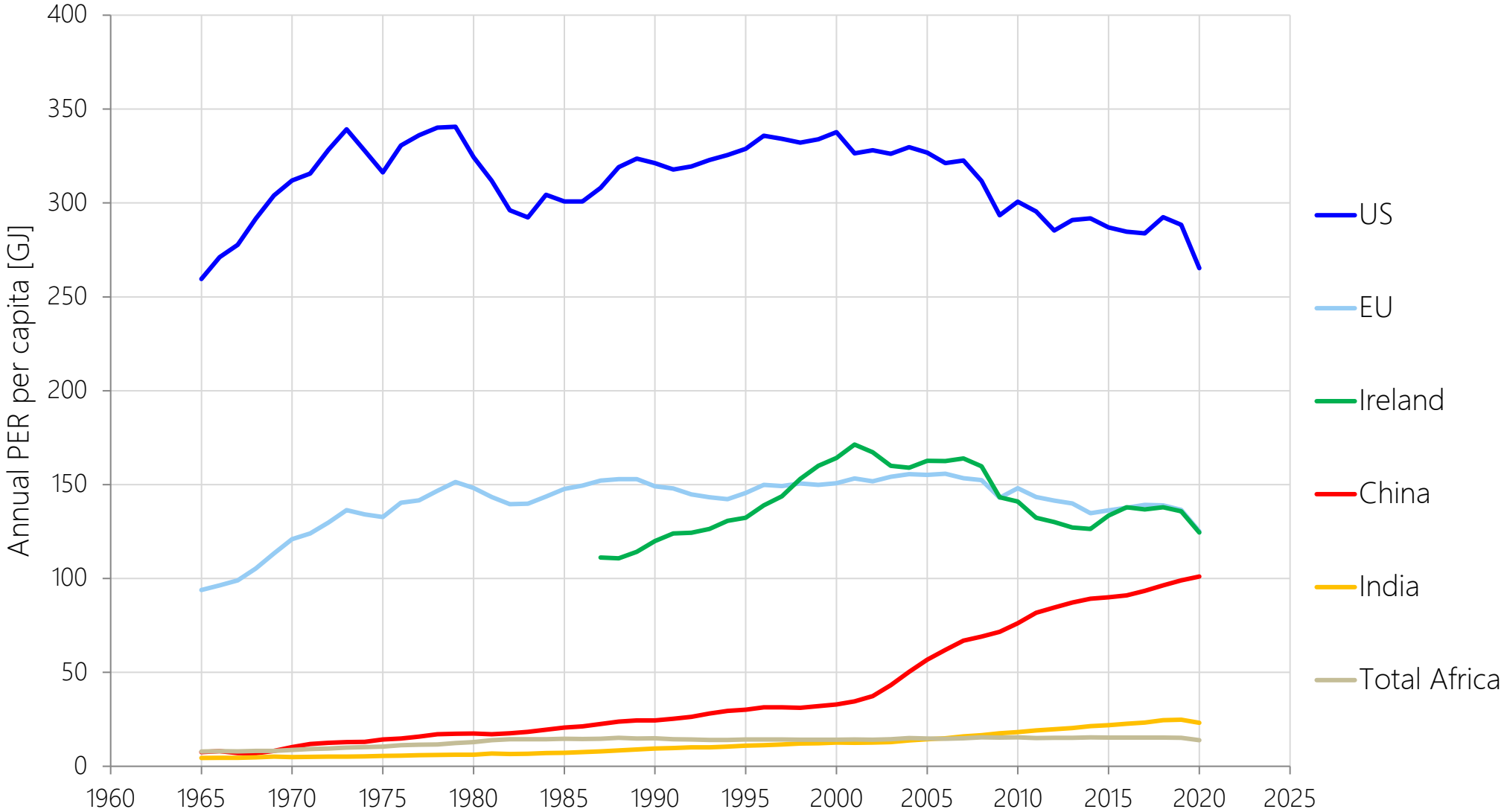


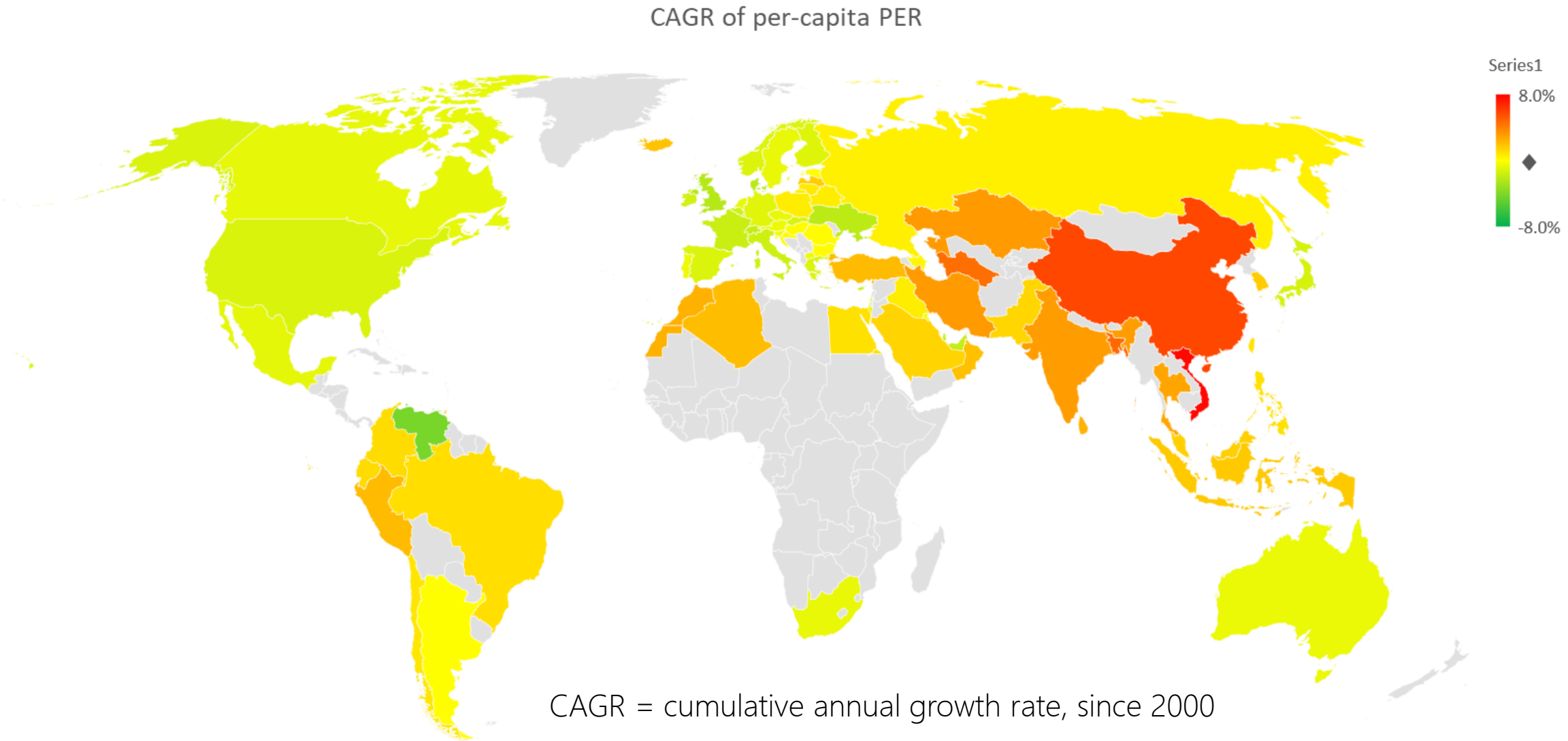
Image Source: World Bank (2018), Atlas of Sustainable Development Goals 2018, p2.

Metrics of global and regional energy demand



Raw data: *B.P. Statistical review of world energy*

Metrics of global and regional energy demand



CAGR = cumulative annual growth rate, since 2000

Raw data: B.P. Statistical review of world energy


Summary

Interim summary 2

- We're looking at energy *systems* as a whole
- The behaviour of these systems may be (probably is?) chaotic
- Data quality is variable
- Nonetheless, clear trends can be discerned in historic data

At a global scale, there seems to be a link between GDP and PER

- Strong correlation between GDP and PER for individual countries, but
- Significant differences in PER between countries of equivalent GDP
- What exogenous factors might give rise to these differences?





Energy Systems & Climate Change