Clés de lecture pour la transition énergétique: vitesse, abondance et densité

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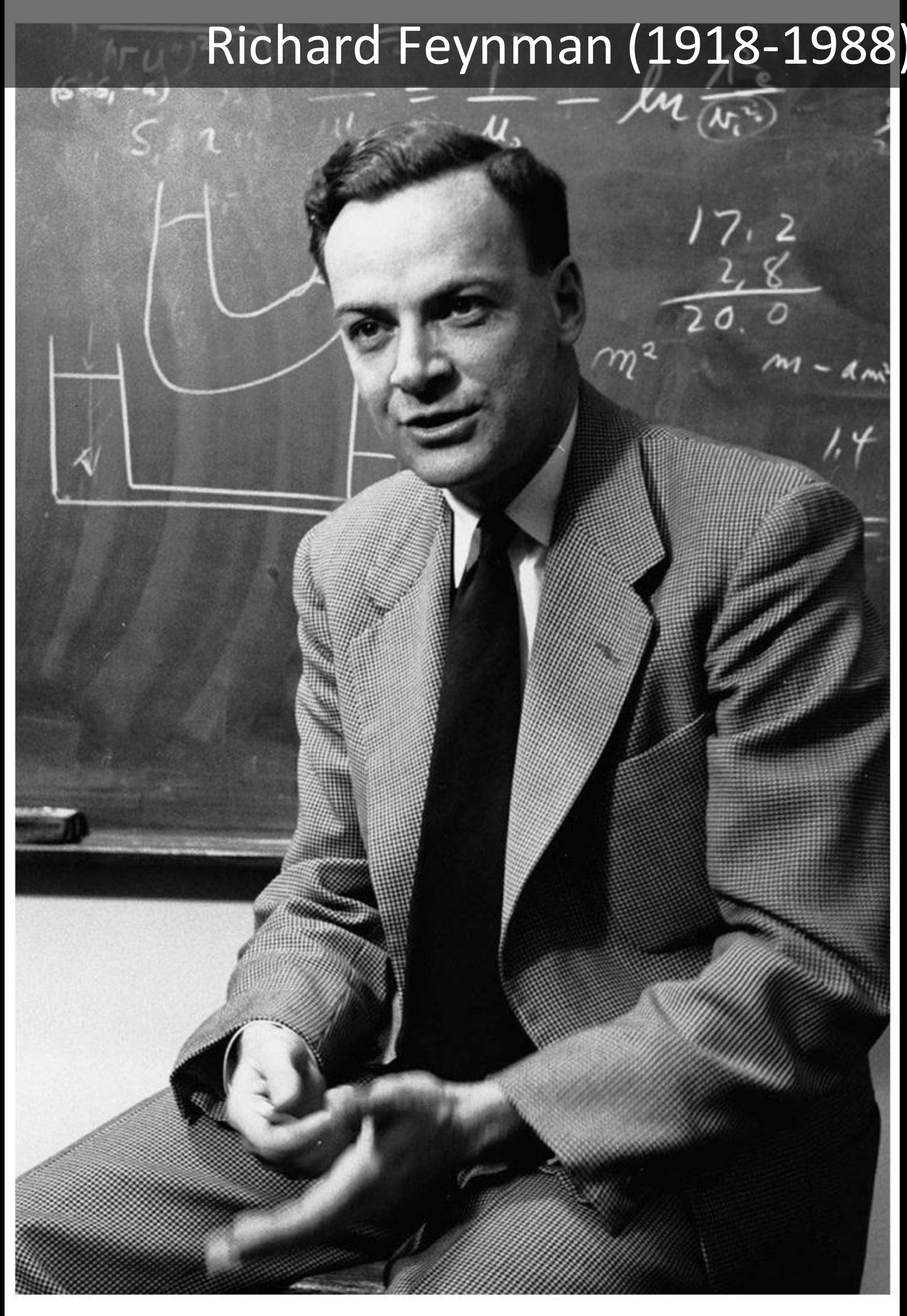
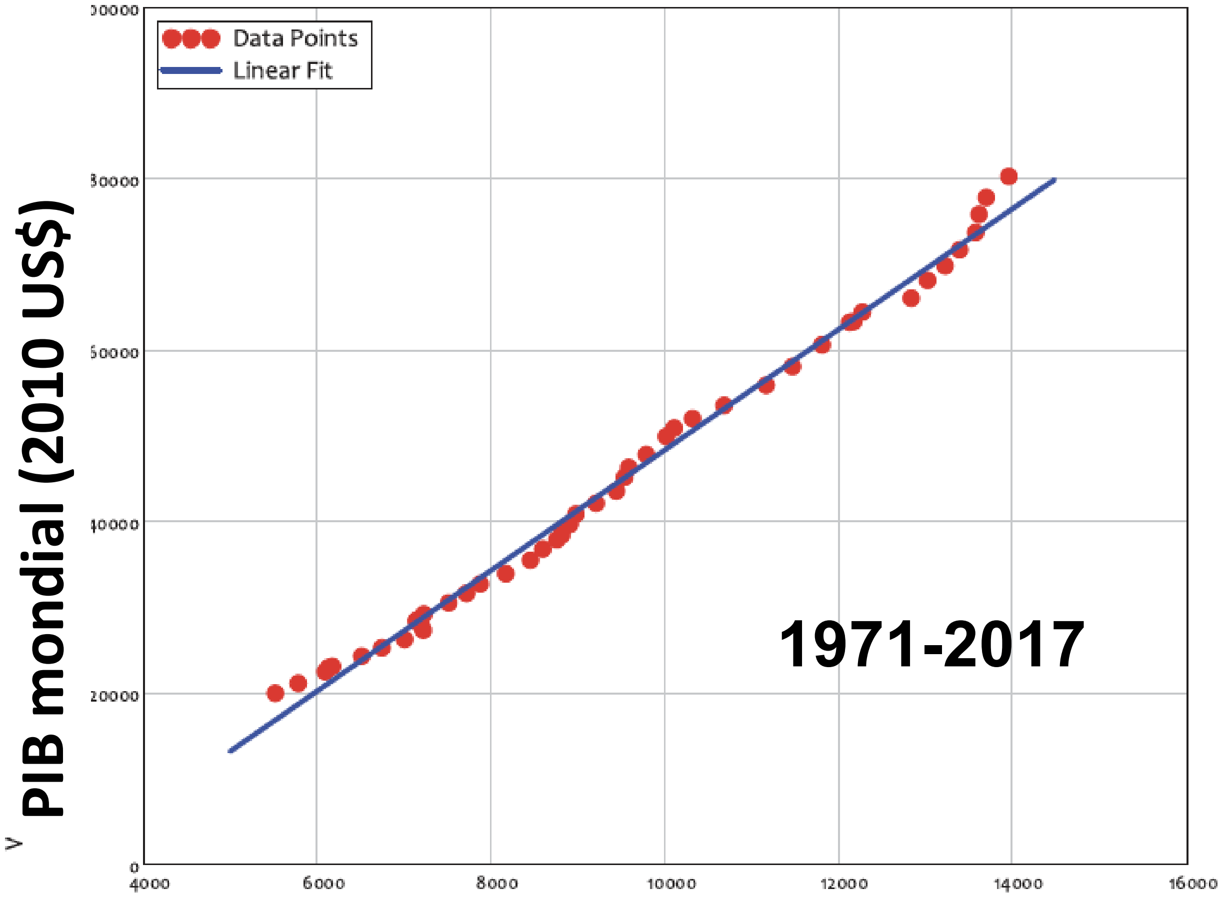
« Il est important de réaliser que dans la physique d'aujourd'hui, nous n'avons aucune connaissance de ce qu'est l'énergie. Nous n'avons pas de représentation comme quoi l'énergie viendrait en petits paquets d'une certaine quantité. Ce n'est pas ainsi. Cependant des formules permettent de calculer une certaine quantité numérique (…). C'est une chose abstraite en cela qu'elle ne nous donne pas le mécanisme ou les raisons des diverses formules. »

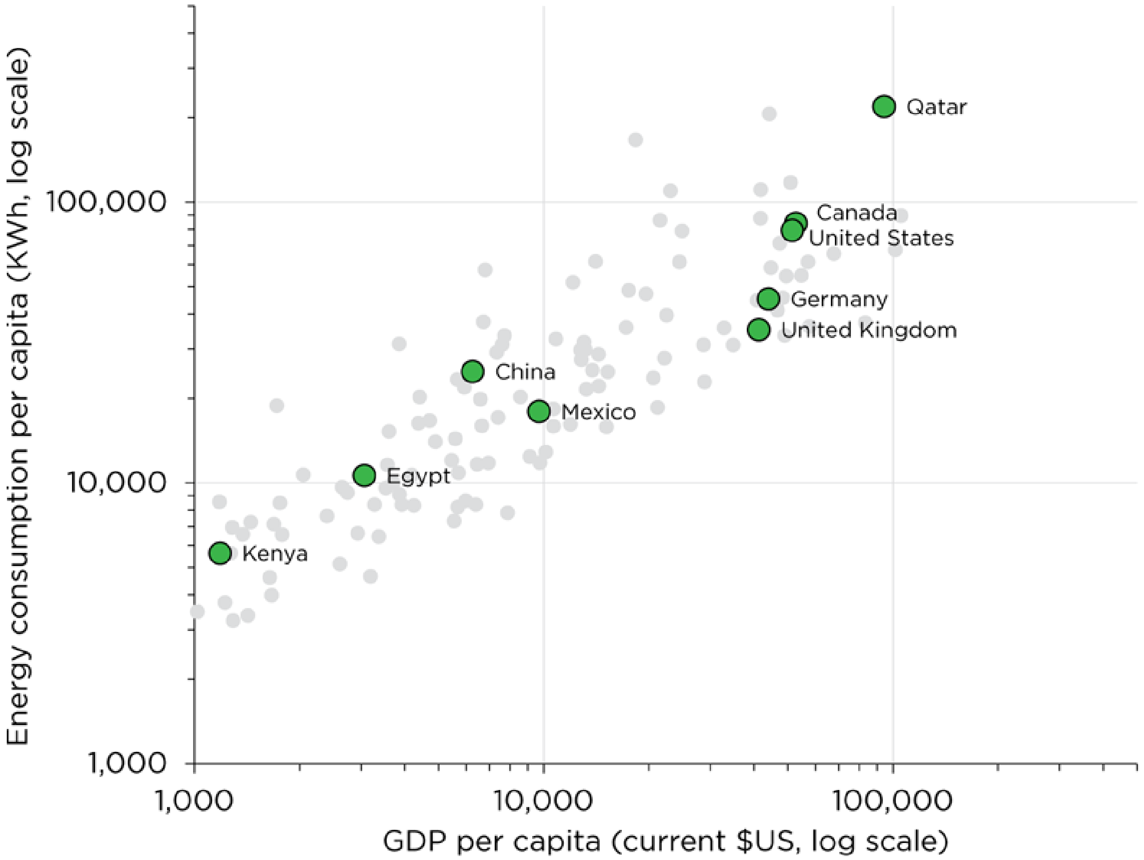


Plus d'énergie=plus de PIB

✧ **L'énergie (fossile) est ce qui a permis le développement économique actuel**

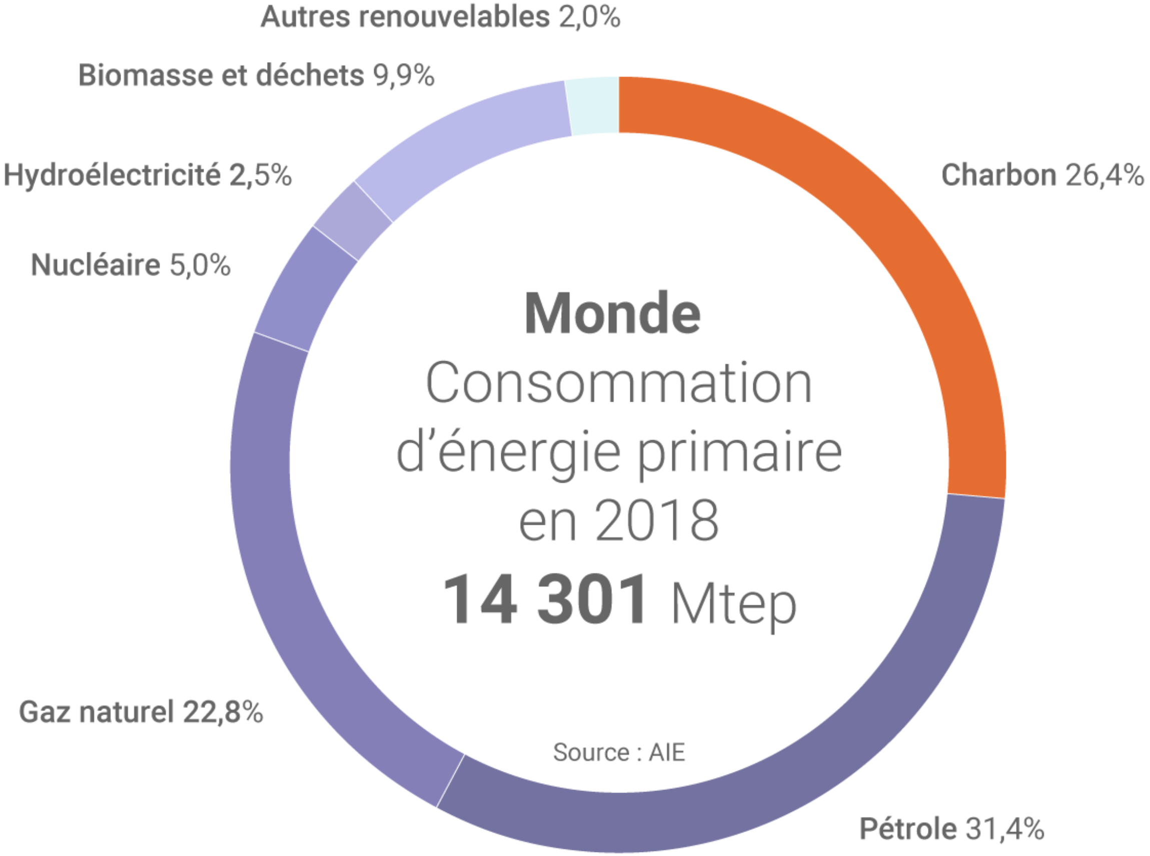


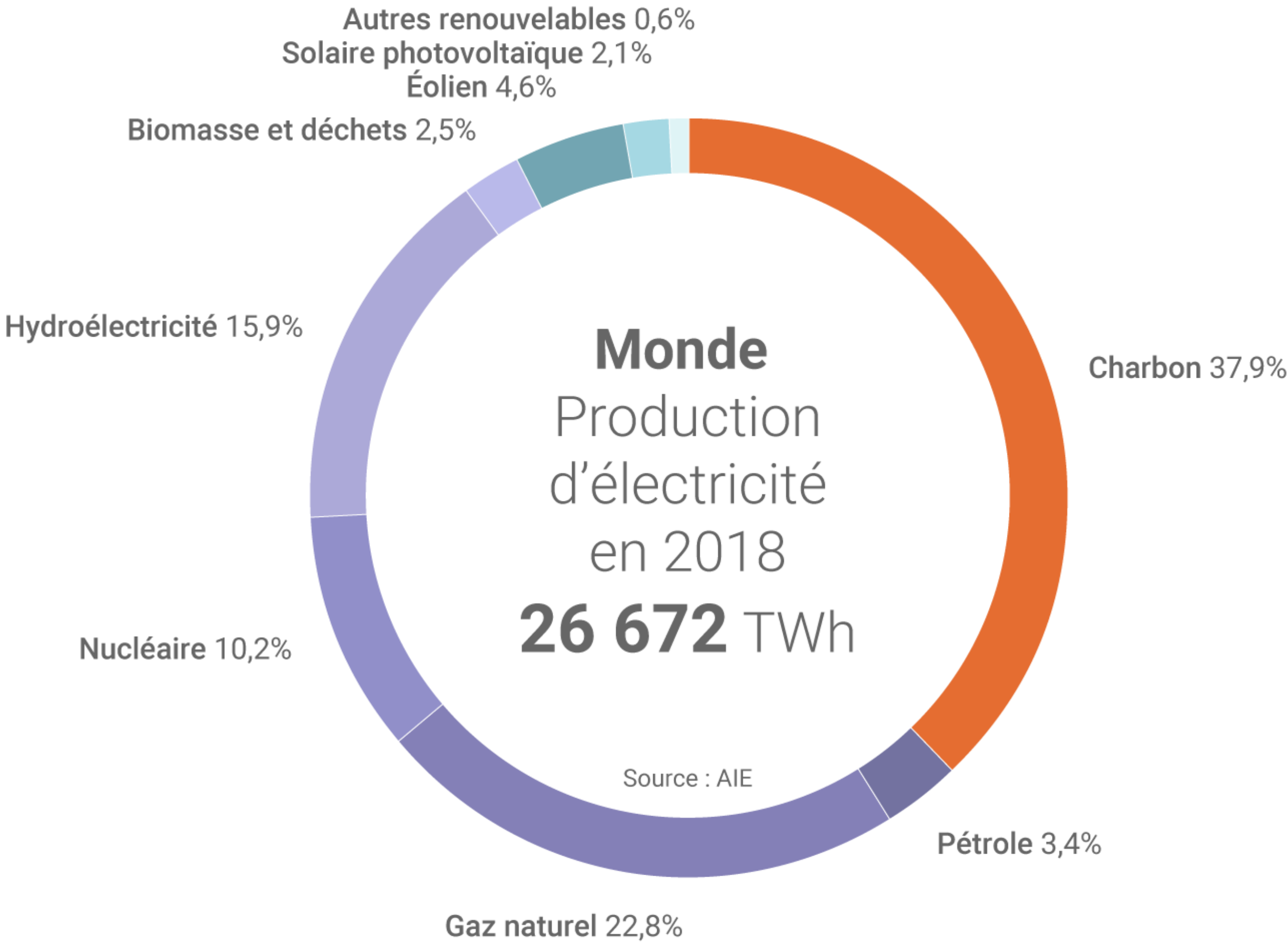
Energie mondiale Mtoe



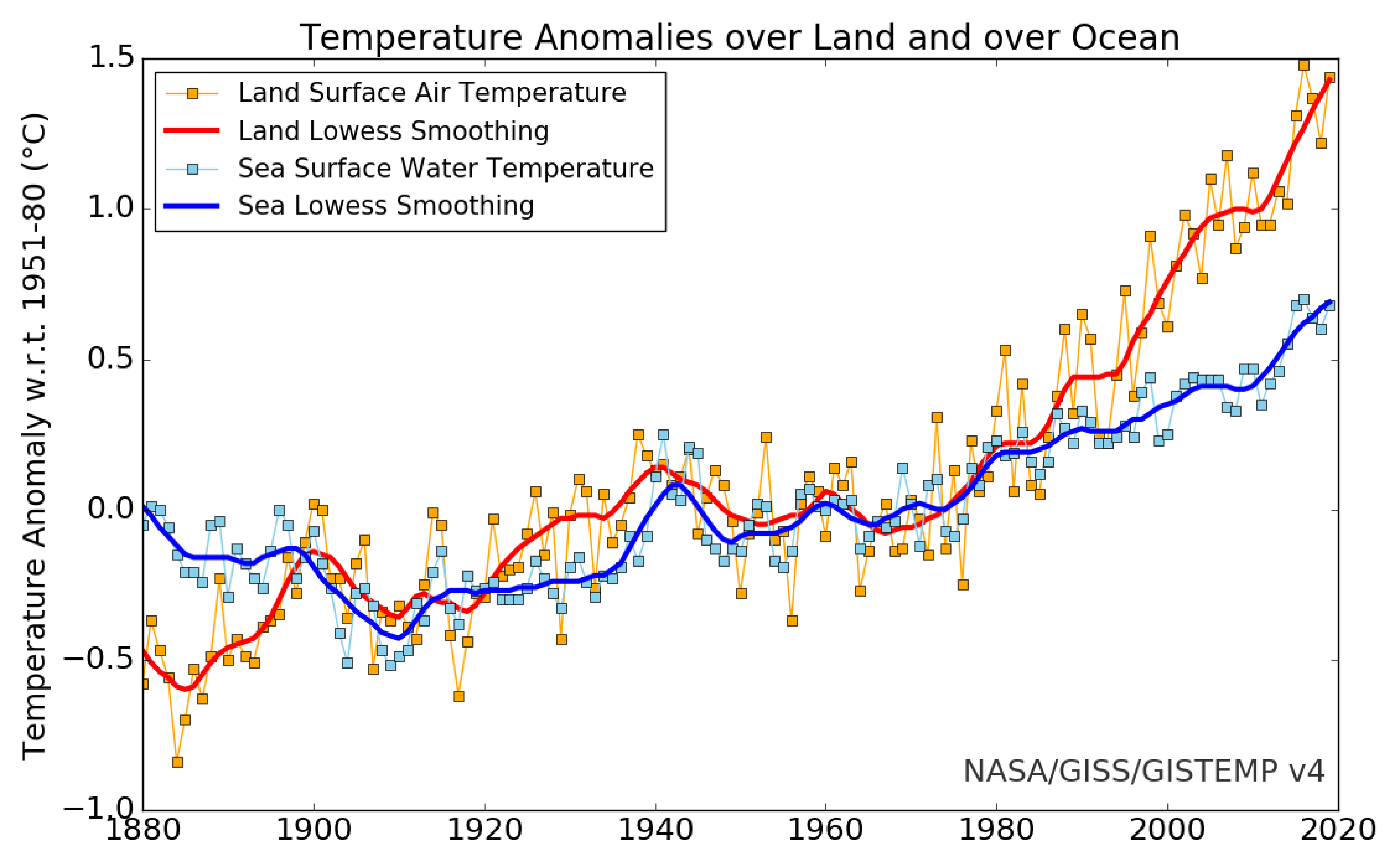
R. Heinberg, Our Renewable Future, 2018

G. Tverberg, Ourfiniteworld.com; S. Keen, Globalizations 2020
J.M. Jancovici, Cours Mines 2019

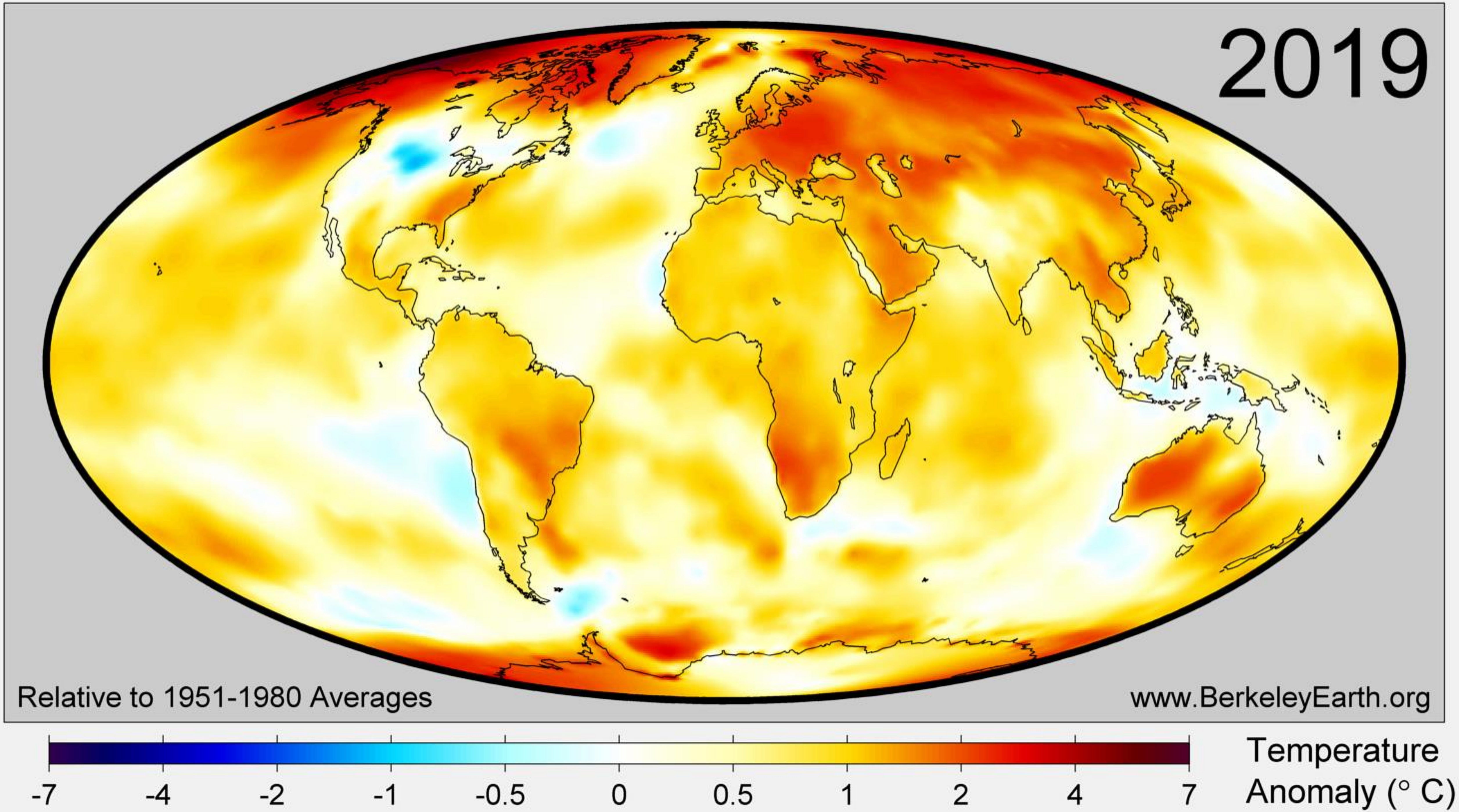


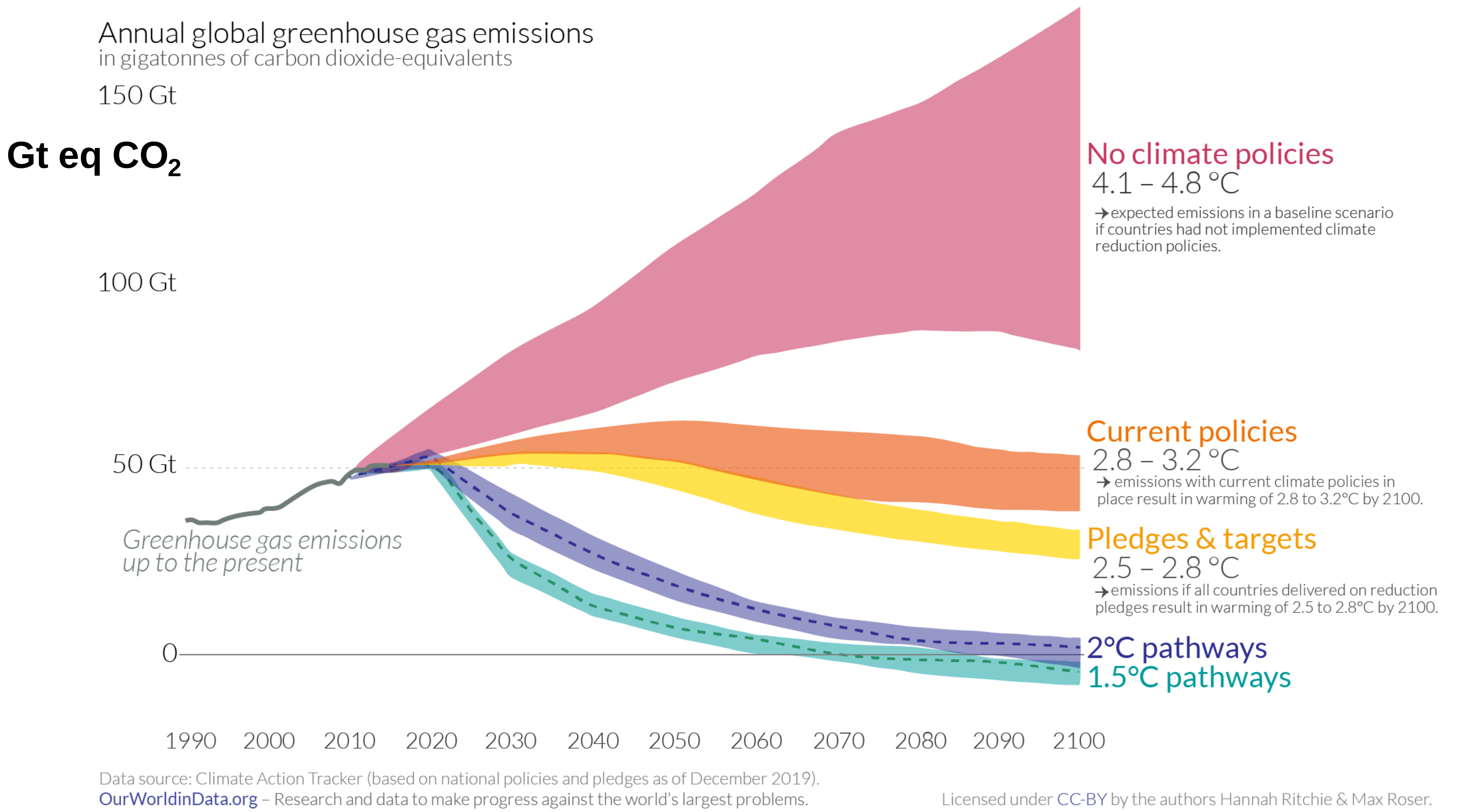


Connaissances des énergies, d'après AIE 2018

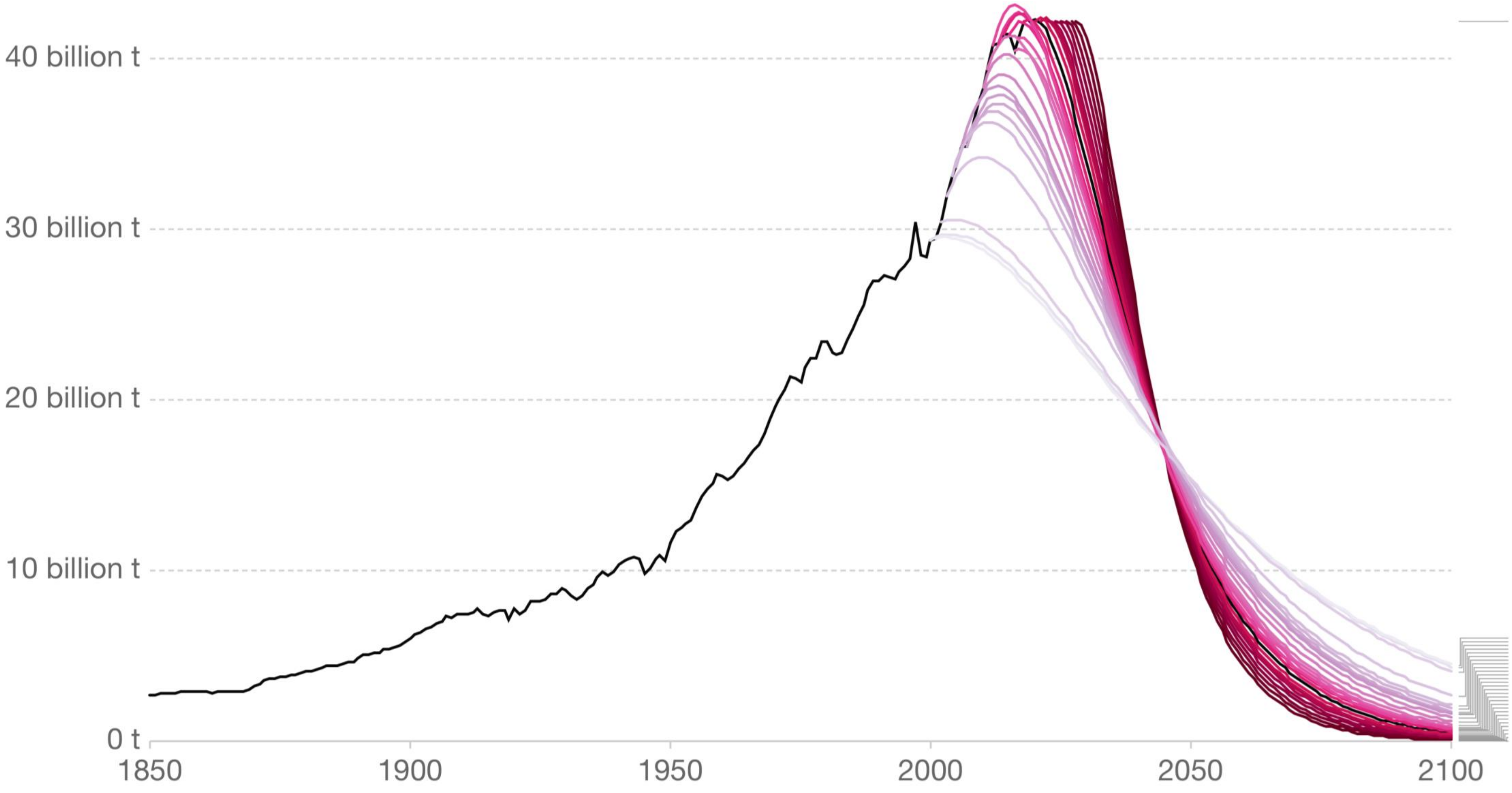


Temperature Anomalies over Land and over Ocean
Land Surface Air Temperature
Land Lowess Smoothing
Sea Surface Water Temperature
Sea Lowess Smoothing
Temperature Anomaly w.r.t. 1951-80 (°C)
1.5
1.0
0.5
0.0
−0.5
−1.0
1880
1900
1920
1940
1960
1980
2000
2020
NASA/GISS/GISTEMP v4


2019
Relative to 1951-1980 Averages
www.BerkeleyEarth.org
-7
-4
-2
-1
-0.5
0
0.5
1
2
4
7
Temperature
Anomaly (° C)

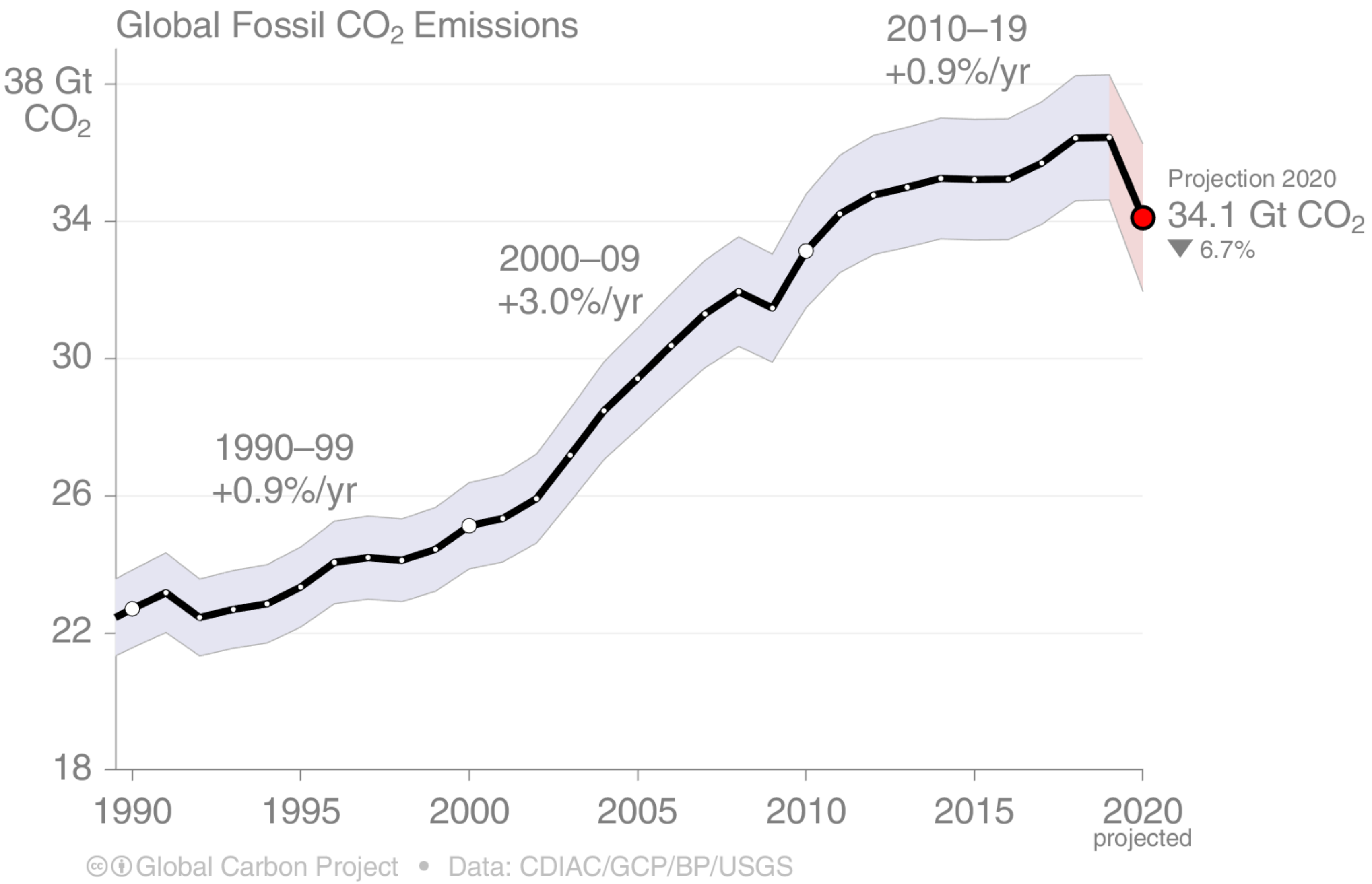

Annual global greenhouse gas emissions
in gigatonnes of carbon dioxide-equivalents
Gt eq CO_2
150 Gt
100 Gt
50 Gt
0
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Greenhouse gas emissions up to the present
No climate policies
4.1 – 4.8 °C
→ expected emissions in a baseline scenario if countries had not implemented climate reduction policies.
Current policies
2.8 – 3.2 °C
→ emissions with current climate policies in place result in warming of 2.8 to 3.2°C by 2100.
Pledges & targets
2.5 – 2.8 °C
→ emissions if all countries delivered on reduction pledges result in warming of 2.5 to 2.8°C by 2100.
2°C pathways
1.5°C pathways
Data source: Climate Action Tracker (based on national policies and pledges as of December 2019).
OurWorldinData.org – Research and data to make progress against the world's largest problems.
Licensed under CC-BY by the authors Hannah Ritchie & Max Roser.

Urgent de ne pas attendre



Source: Robbie Andrews (2019); based on Global Carbon Project & IPPC SR15
Note: Carbon budgets are based on a >66% chance of staying below 2°C from the IPCC's SR15 Report.

7% de reductions d'émissions en 2020

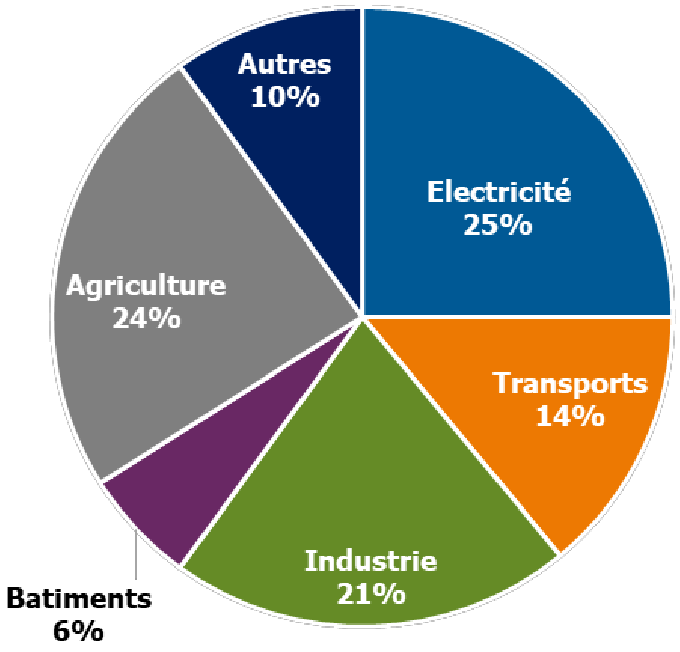


Source: www.carbonbrief.org, Octobre 2020

The 2020 projection is based on preliminary data and modelling, and is the median of the four studies.
Source: CDIAC; Friedlingstein et al 2020; Global Carbon Budget 2020

Sources d'émissions

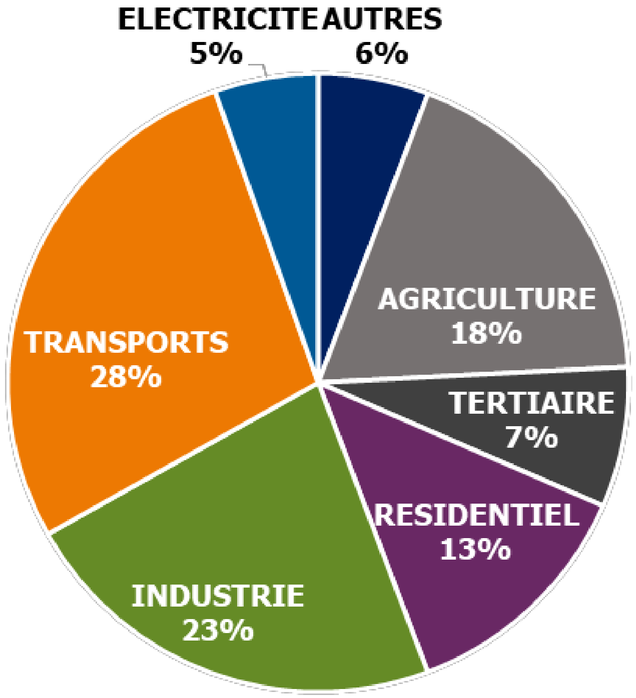
MONDE



Émissions de GES mondiales
par secteur économique en 2010
50Gt CO2eq

Source: GIEC

FRANCE



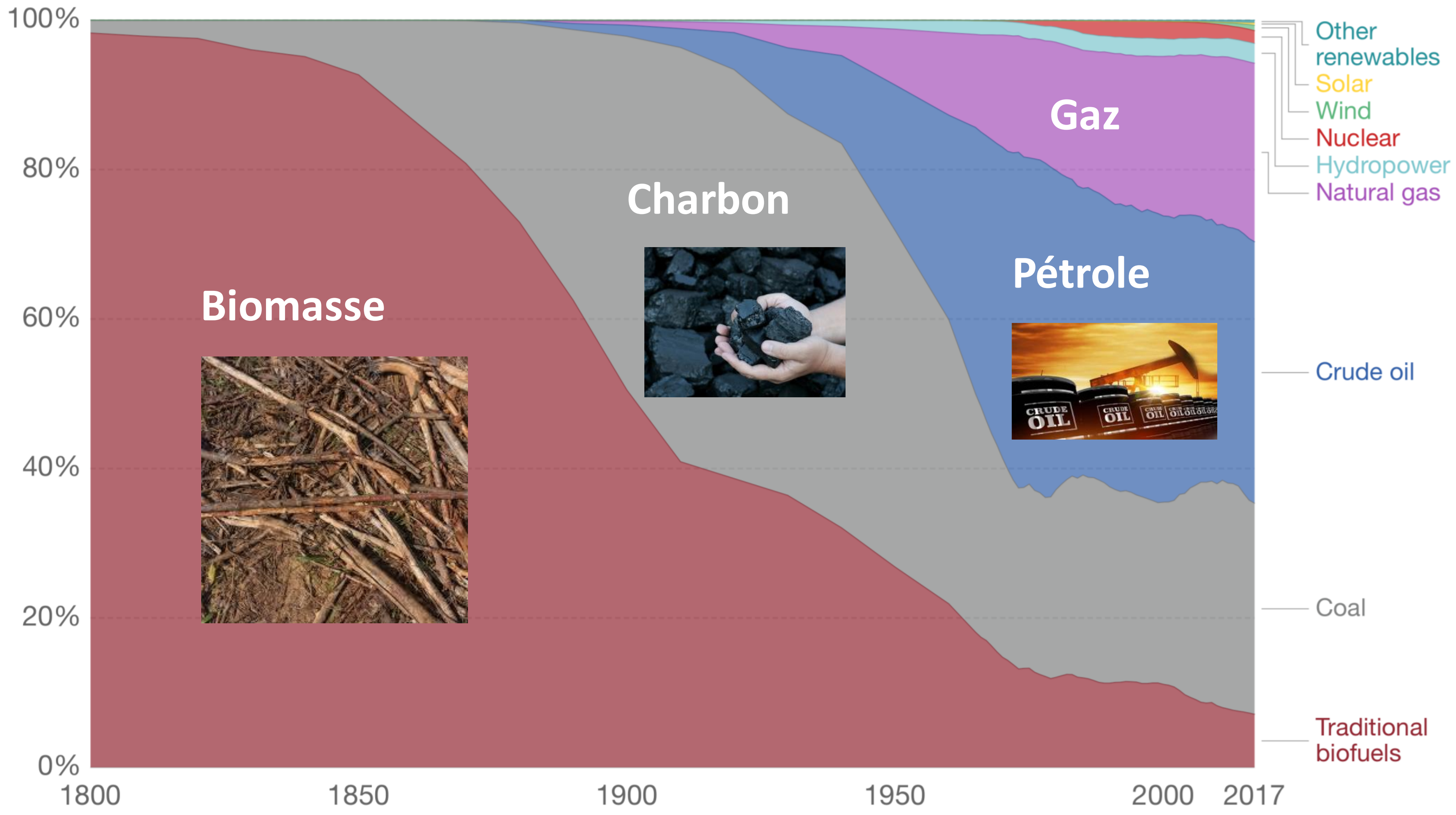
Émissions de GES
par secteur économique
en France 2012

Source: CITEPA (2014)

Emissions 2019: 12Gt eqC

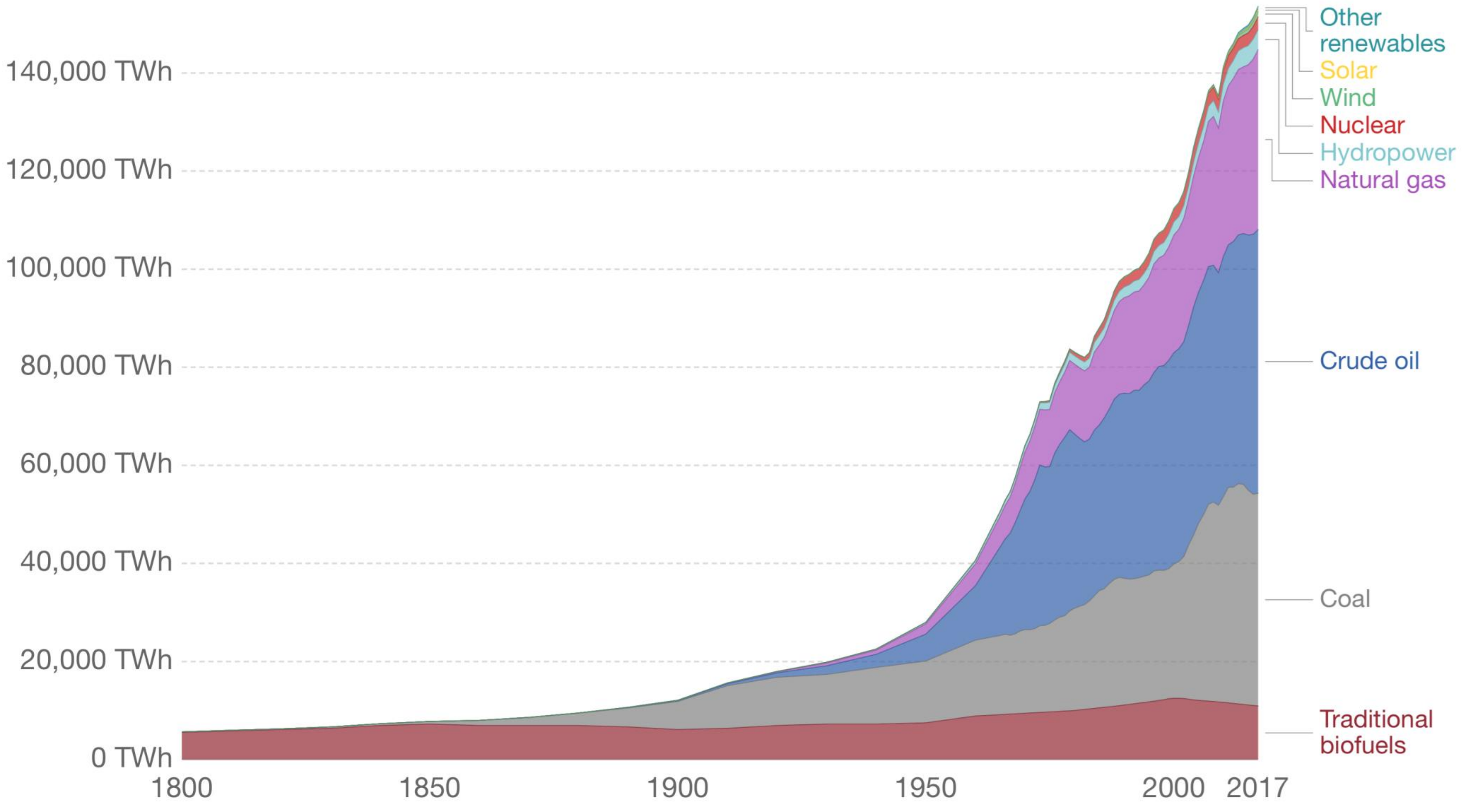
1.35 millions par seconde!!!

3 transitions énergétiques…



Source: Vaclav Smil (2017) and BP Statistical Review of World Energy

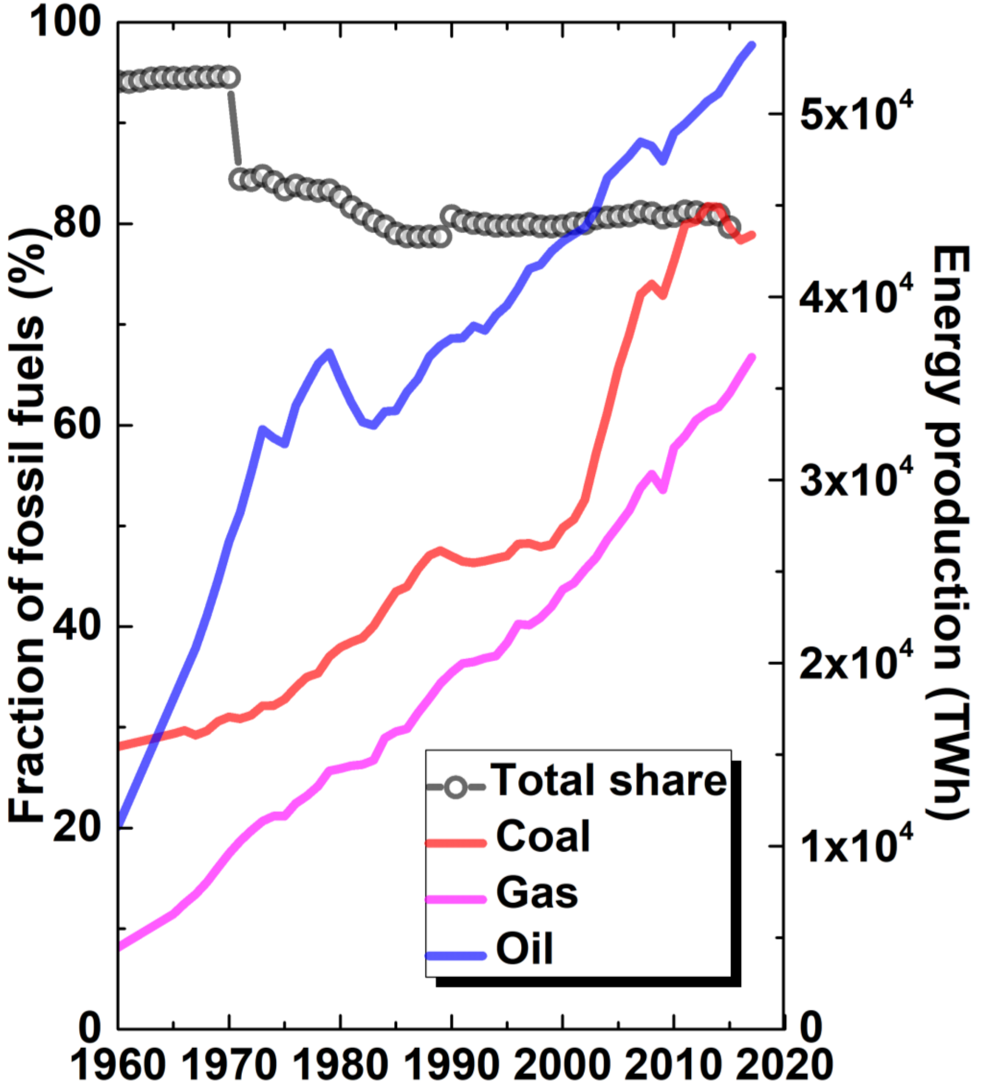
3 transitions énergétiques…ou pas



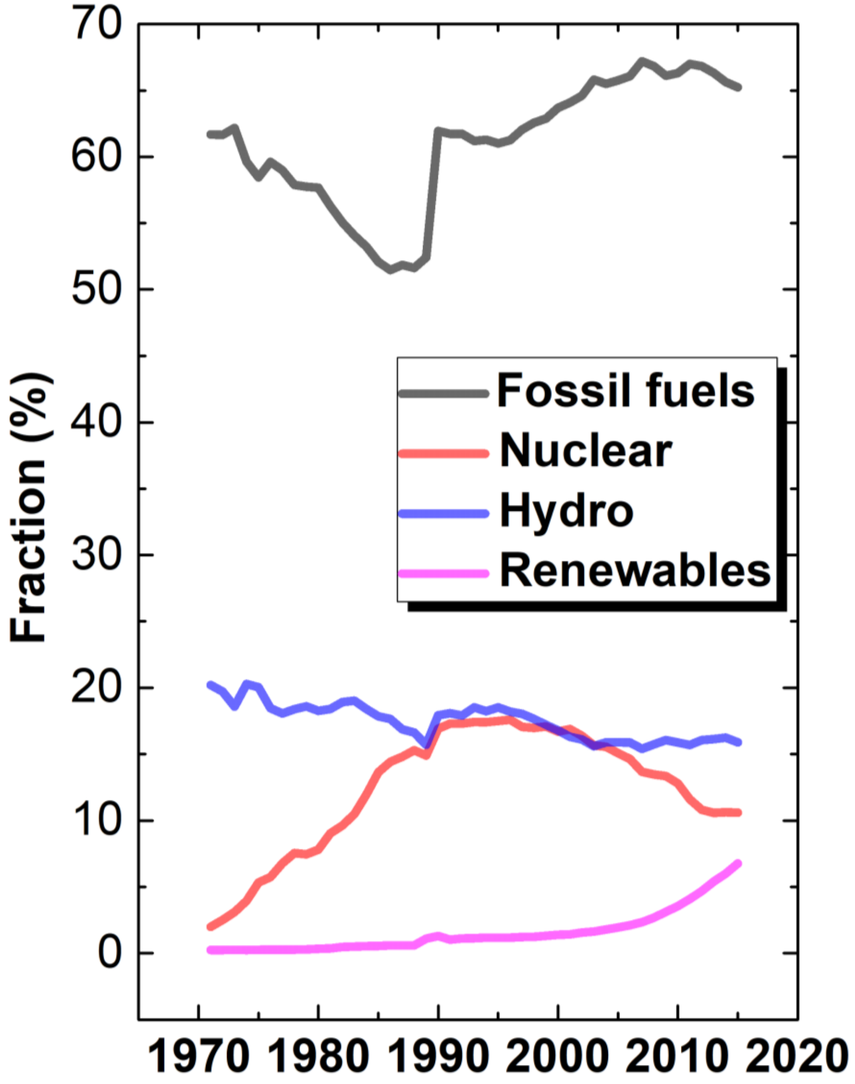
Source: Vaclav Smil (2017) and BP Statistical Review of World Energy

Décarbonner ? ...

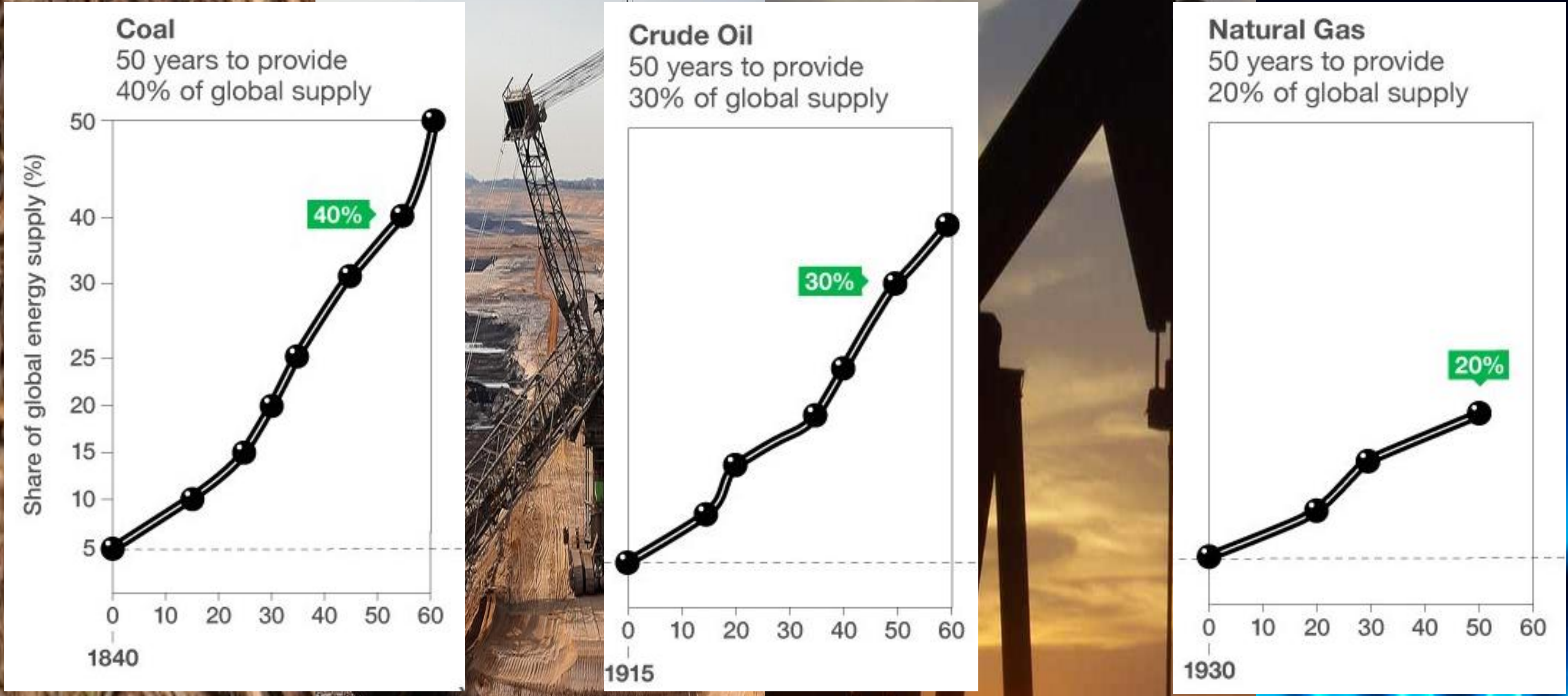
Energie primaire



Electricité

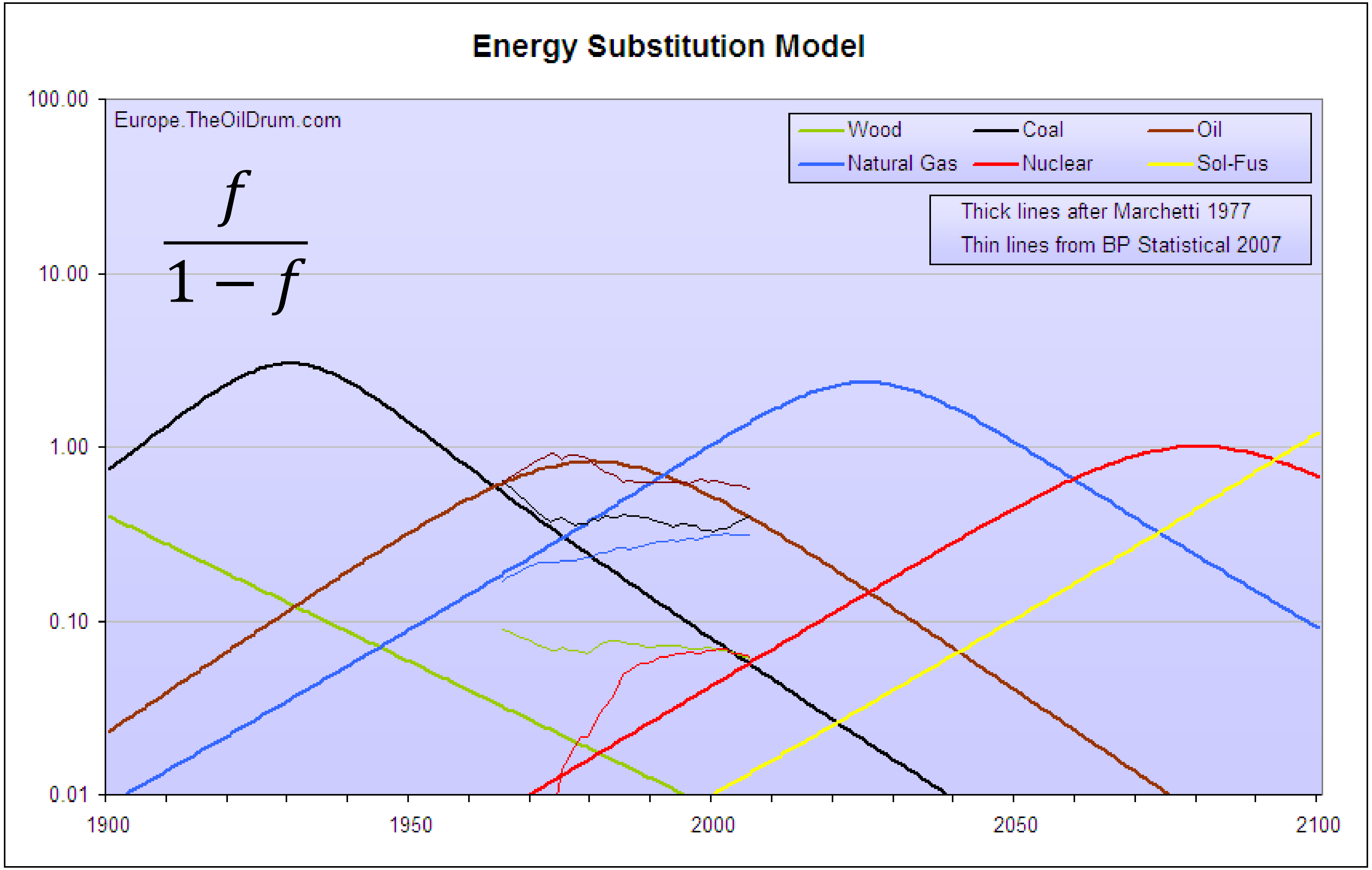


Replotted with data from Worldbank, 2019



V. Smil, Energy Transitions: Global and national perspectives

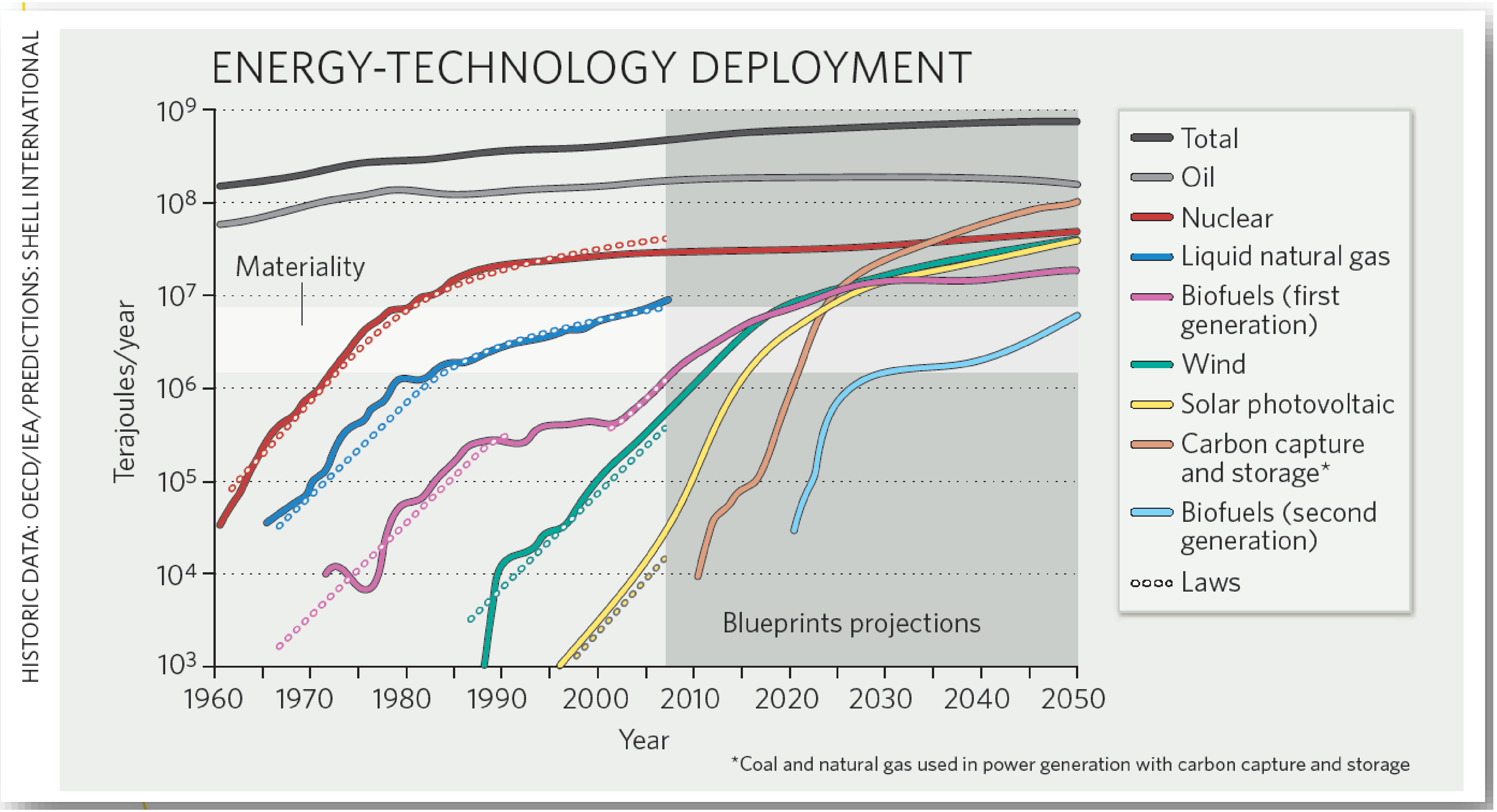
Prédire la transition?



C. Marchetti; Technology Forecasting and societal change, 10 (1977)

‘Pas de transition rapide…’

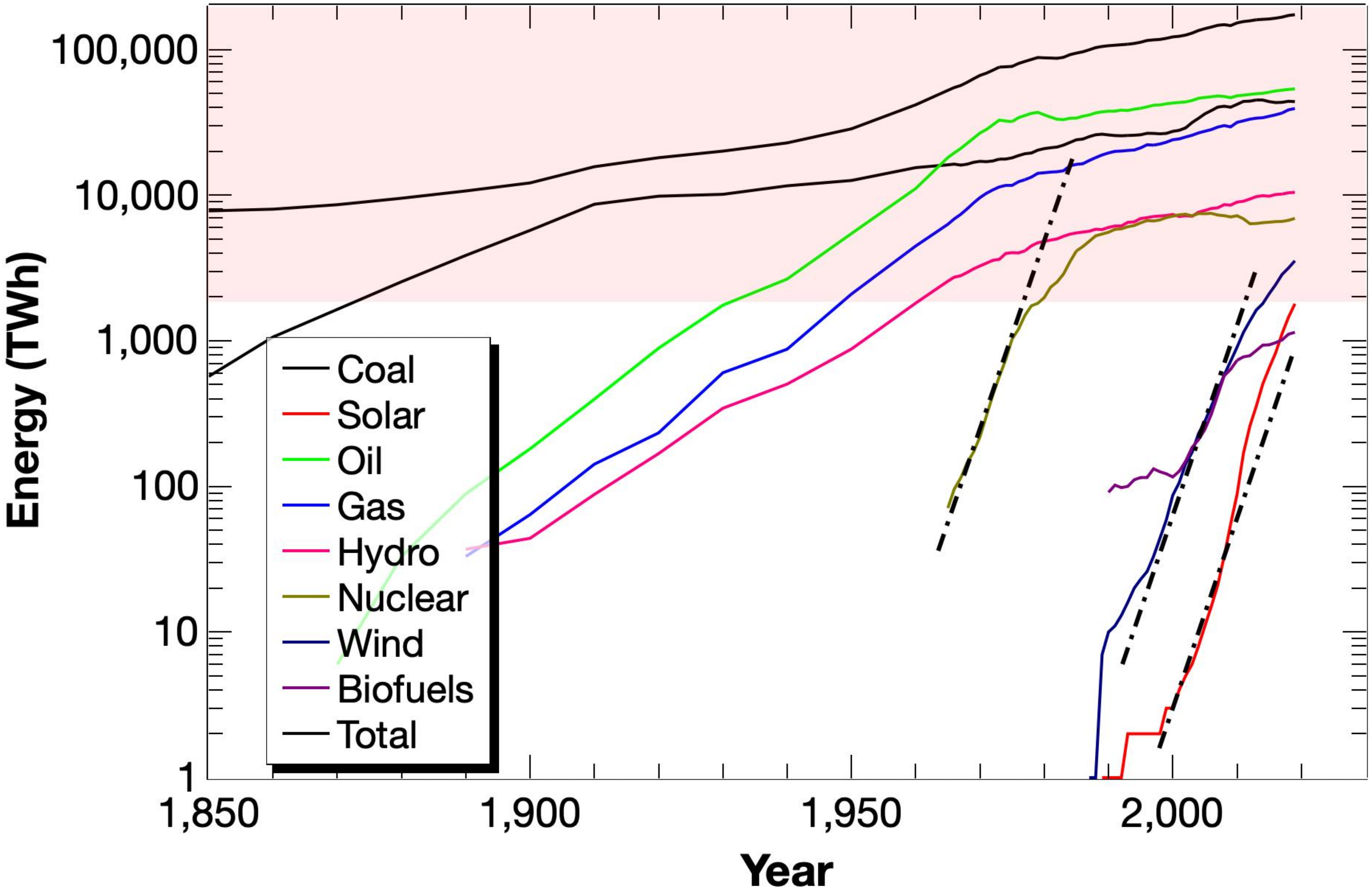
✧ **Les 2 lois du déploiement**



G.J. Kramer, M. Haigh, Nature, 462, 568 (2009)

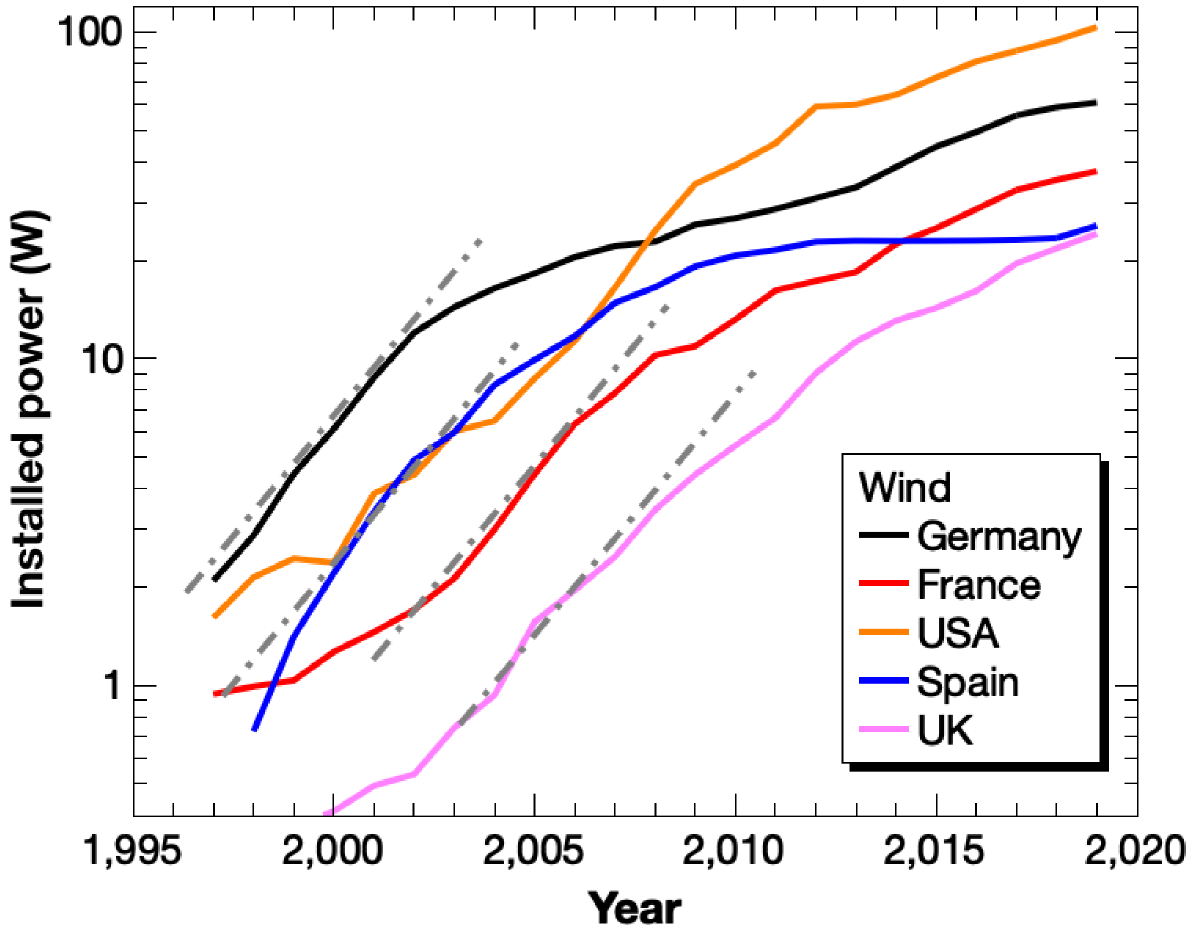
‘Pas de transition rapide…’

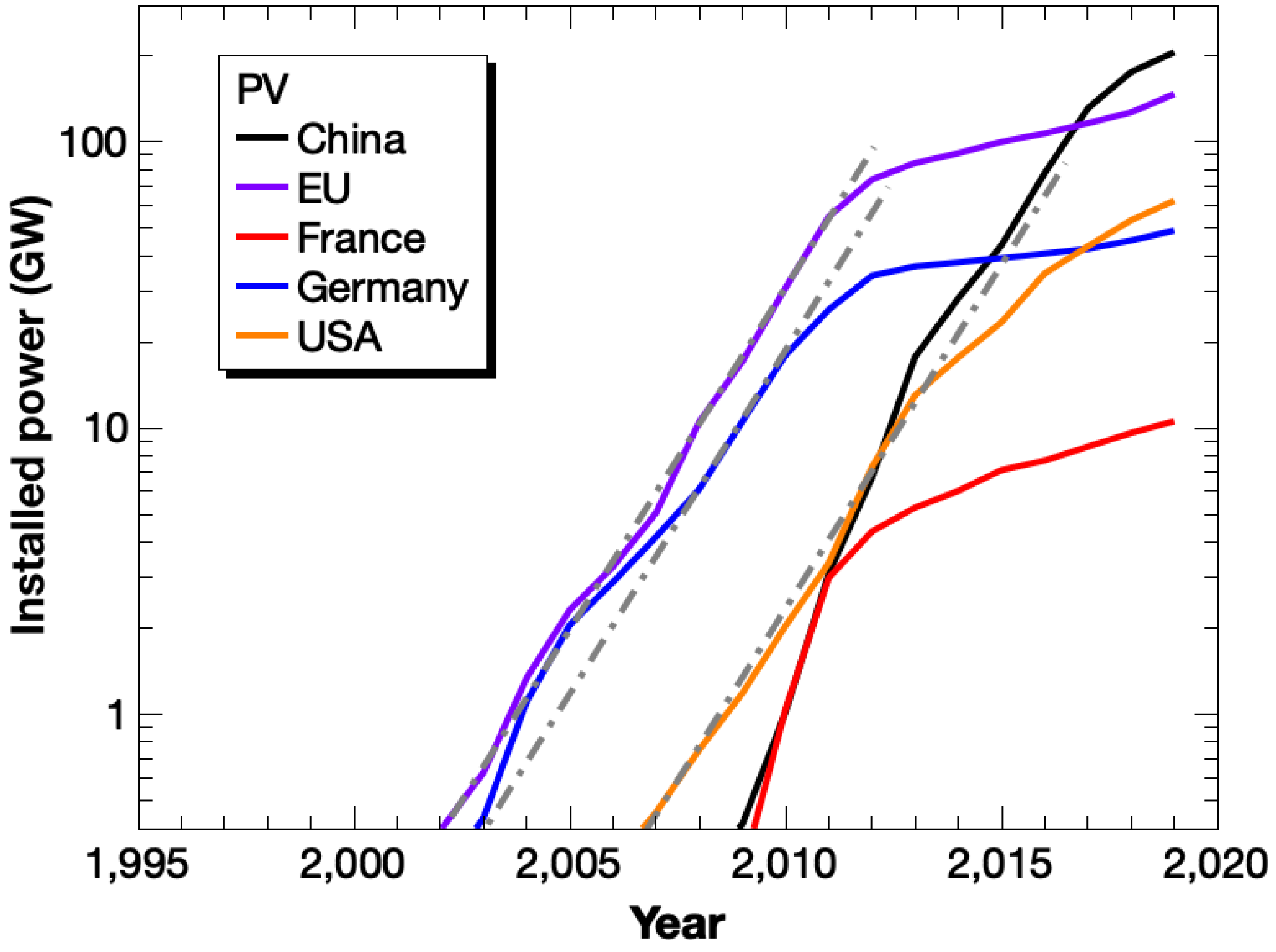
✧ **Mise à jour avec données 2019**



Des taux de déploiement en baisse…

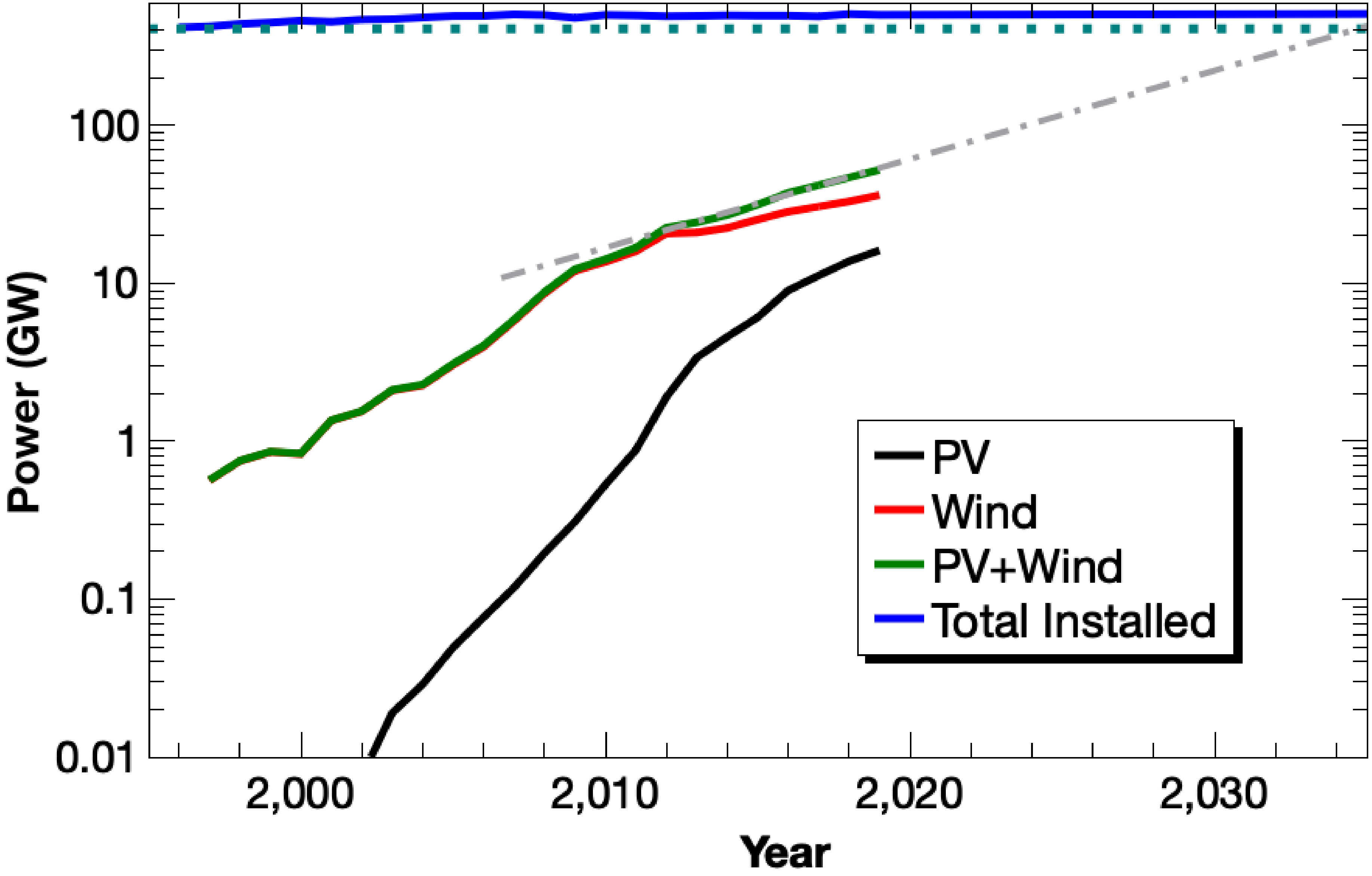
✧ **Beaucoup de pays semblent connaître des baisses de régimes**



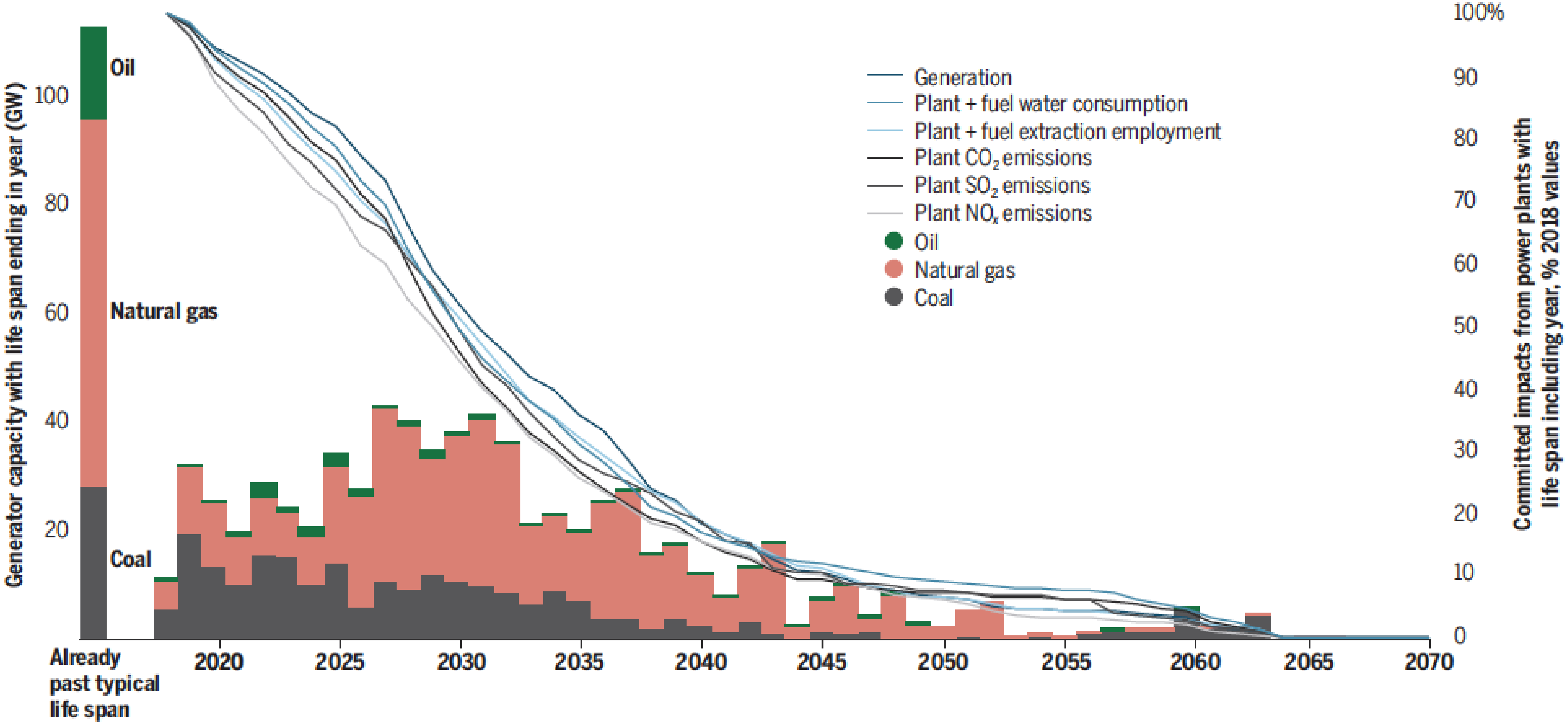


J. Biden et la décarbonation

✧ **Ambition d'une éléctricité décarbonnée en 2035**

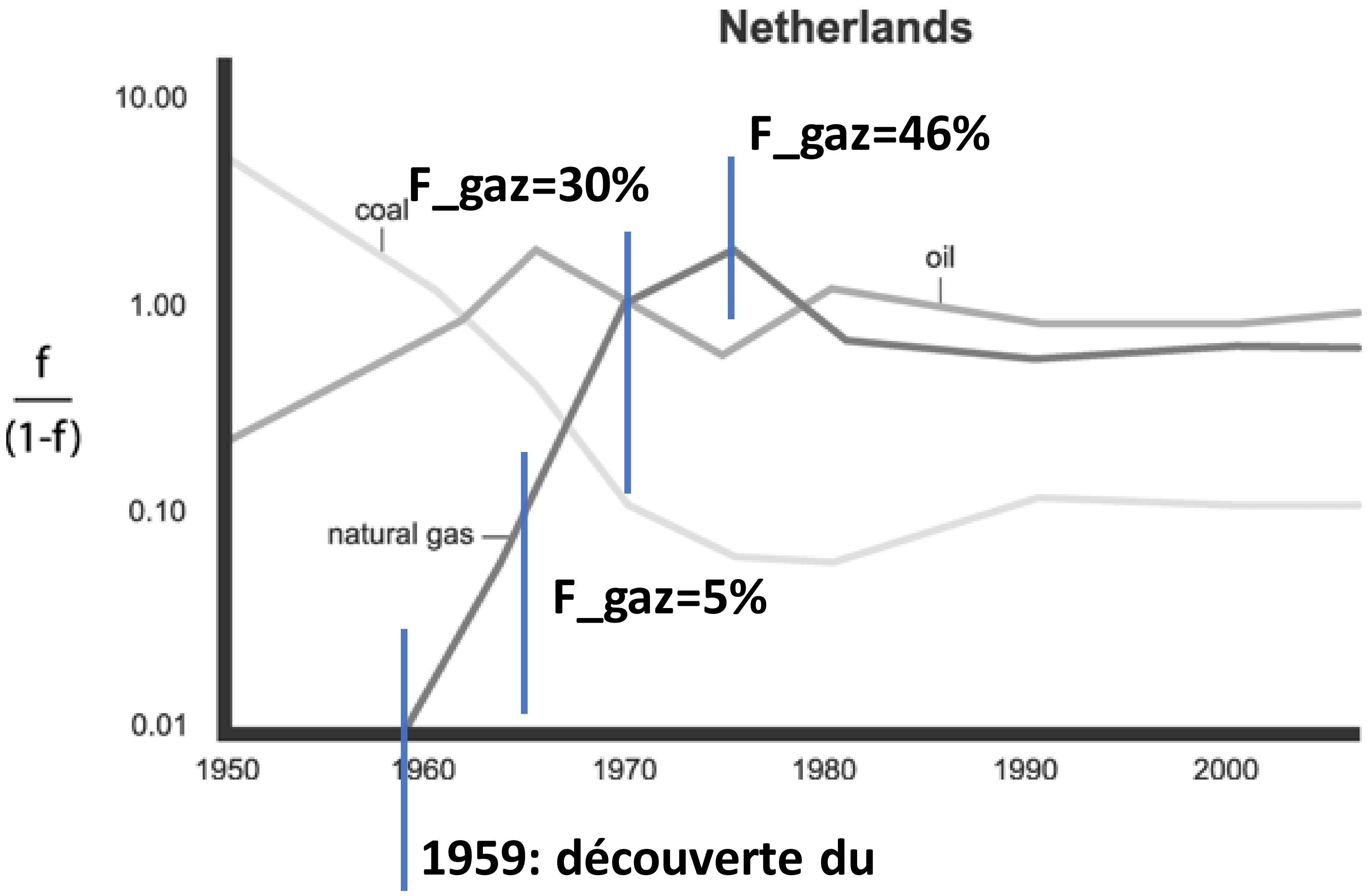


Décarbonner=fermer



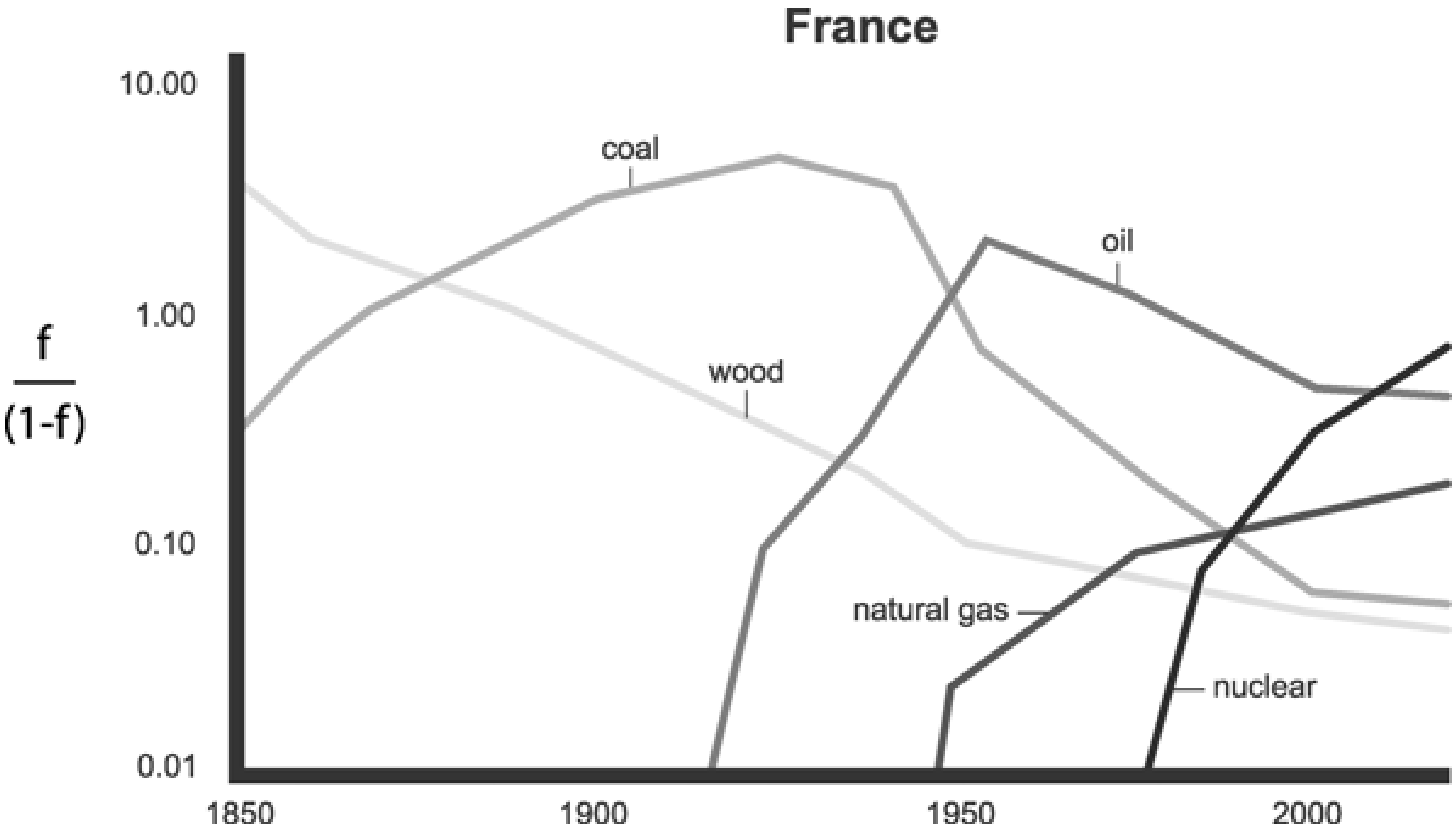
E. Grubert, Science, 2020

Des transitions rapides à l'échelle locale



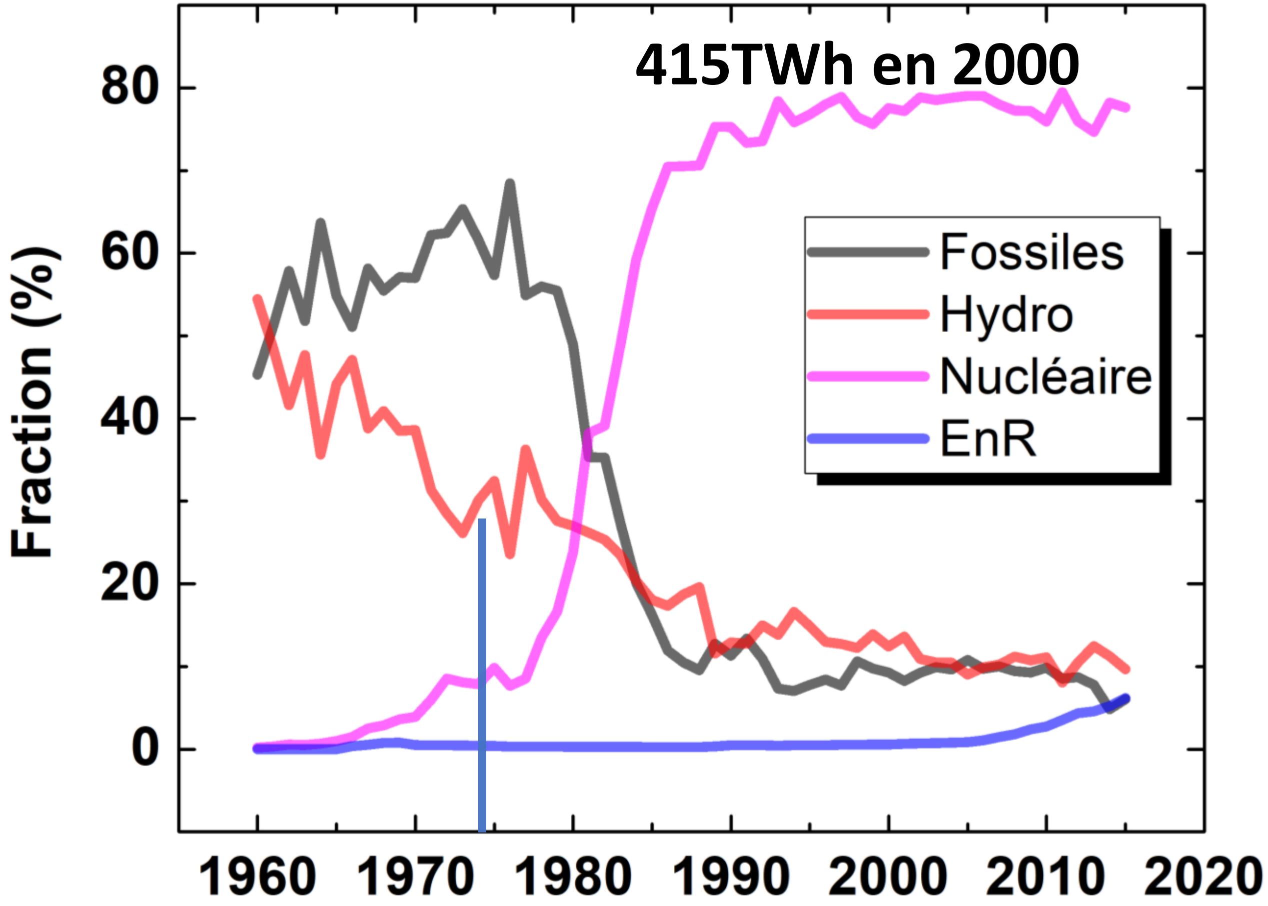
1959: découverte du superchamp géant de Groningen

L'exemple francais (1/2)

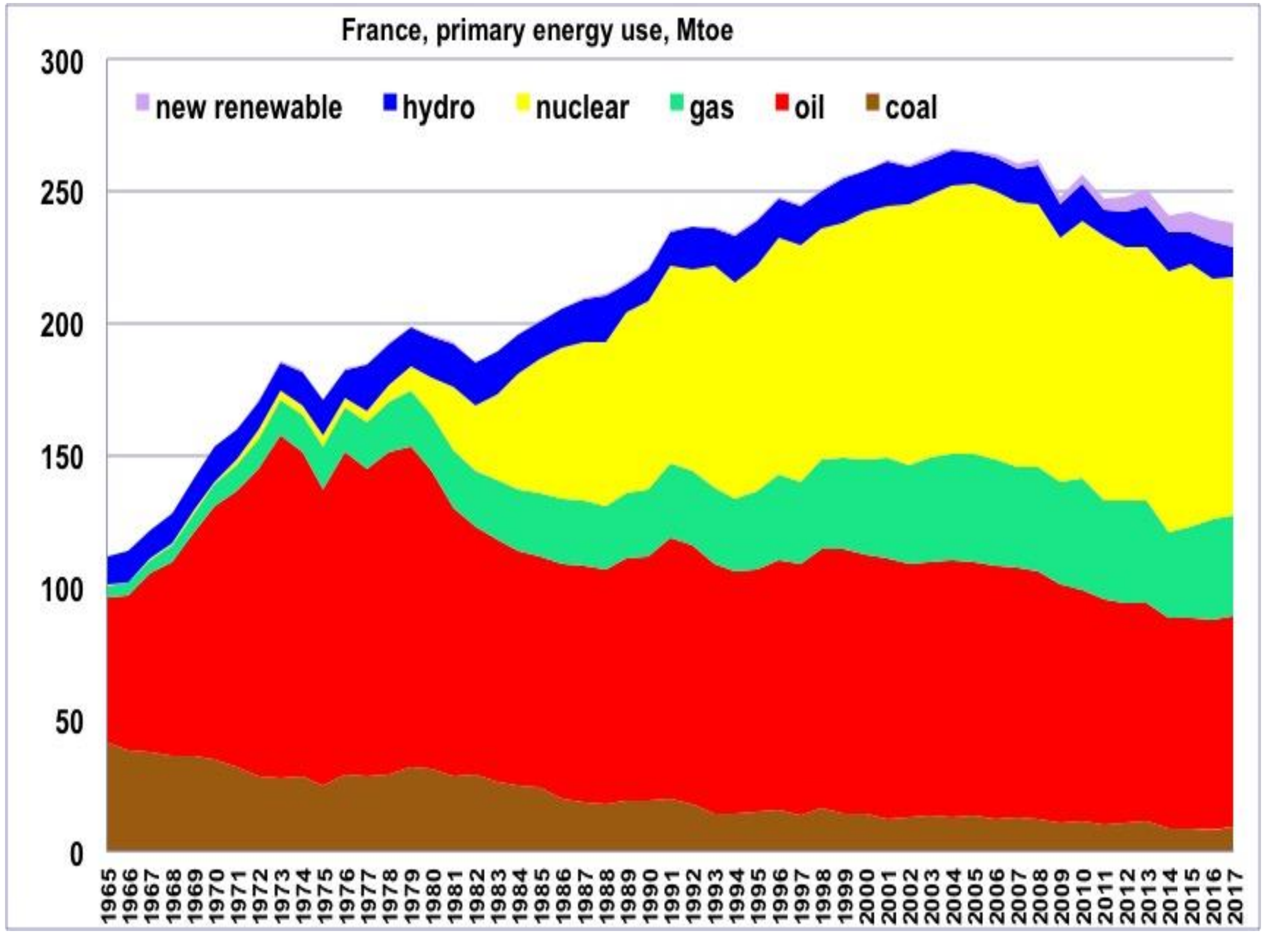


L'exemple francais (2/2)

Electricité



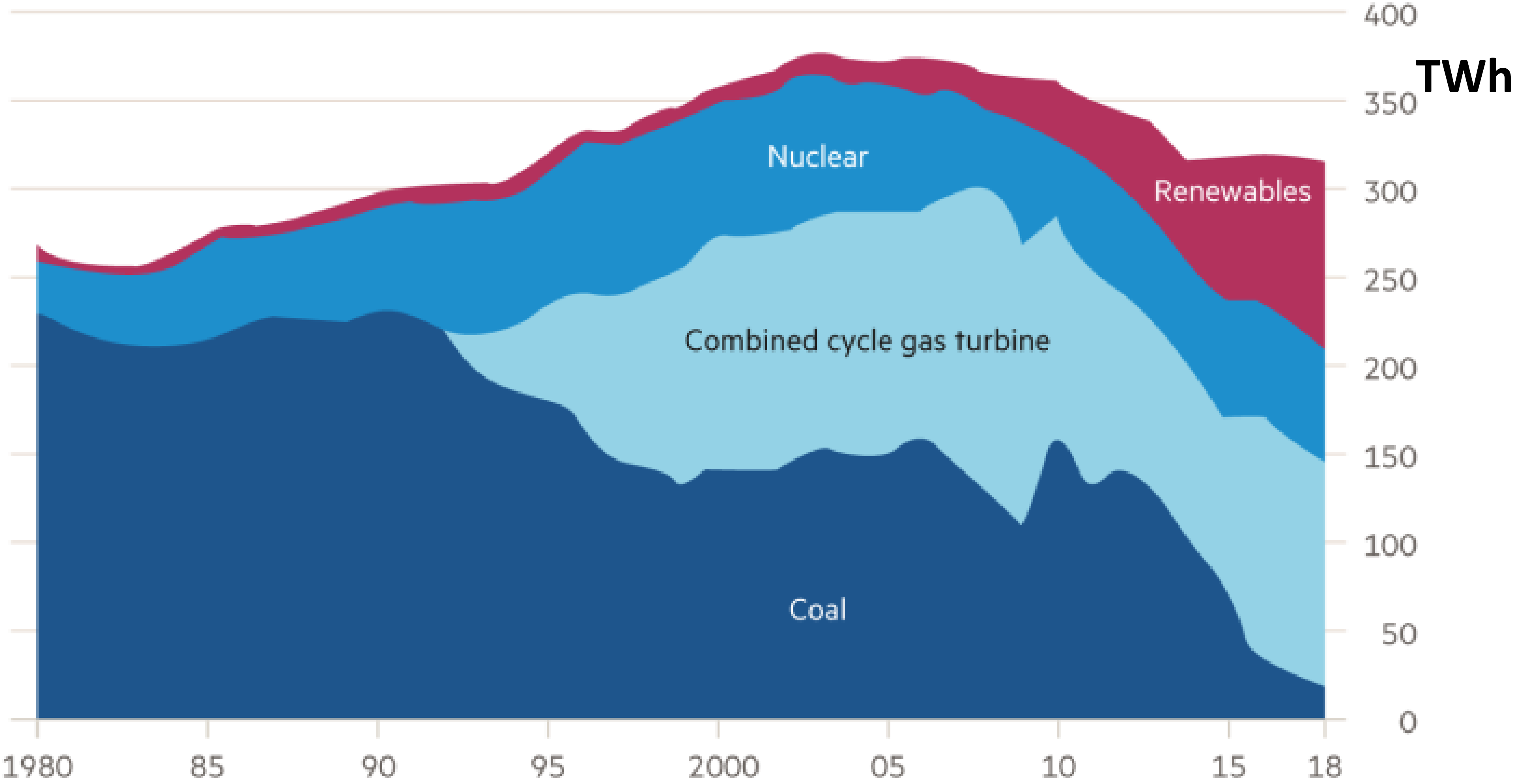
Energie primaire



1974: lancement du programme nucléaire (14TWh)

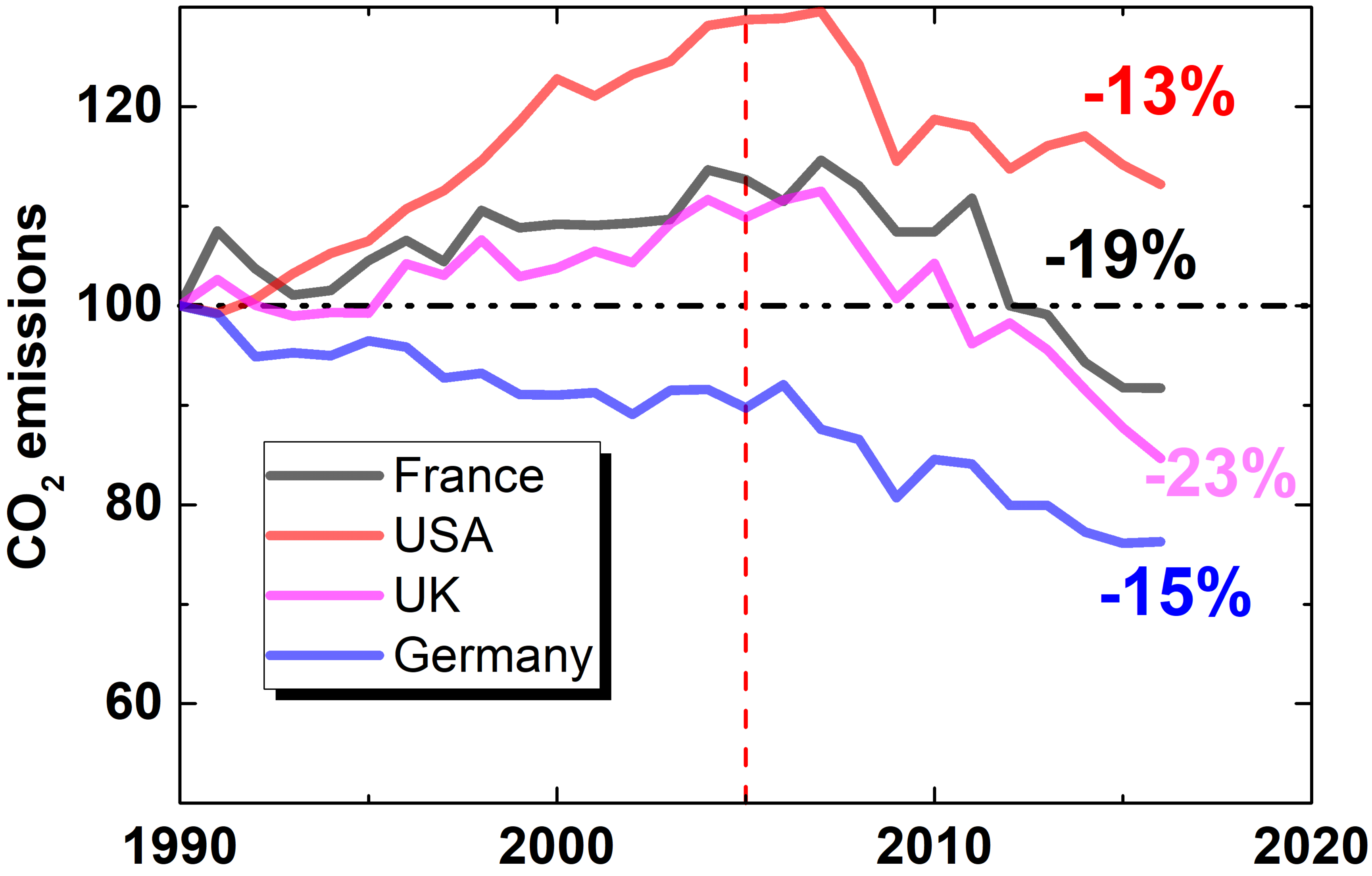
UK: l'autre pays du Rugby

Electricité

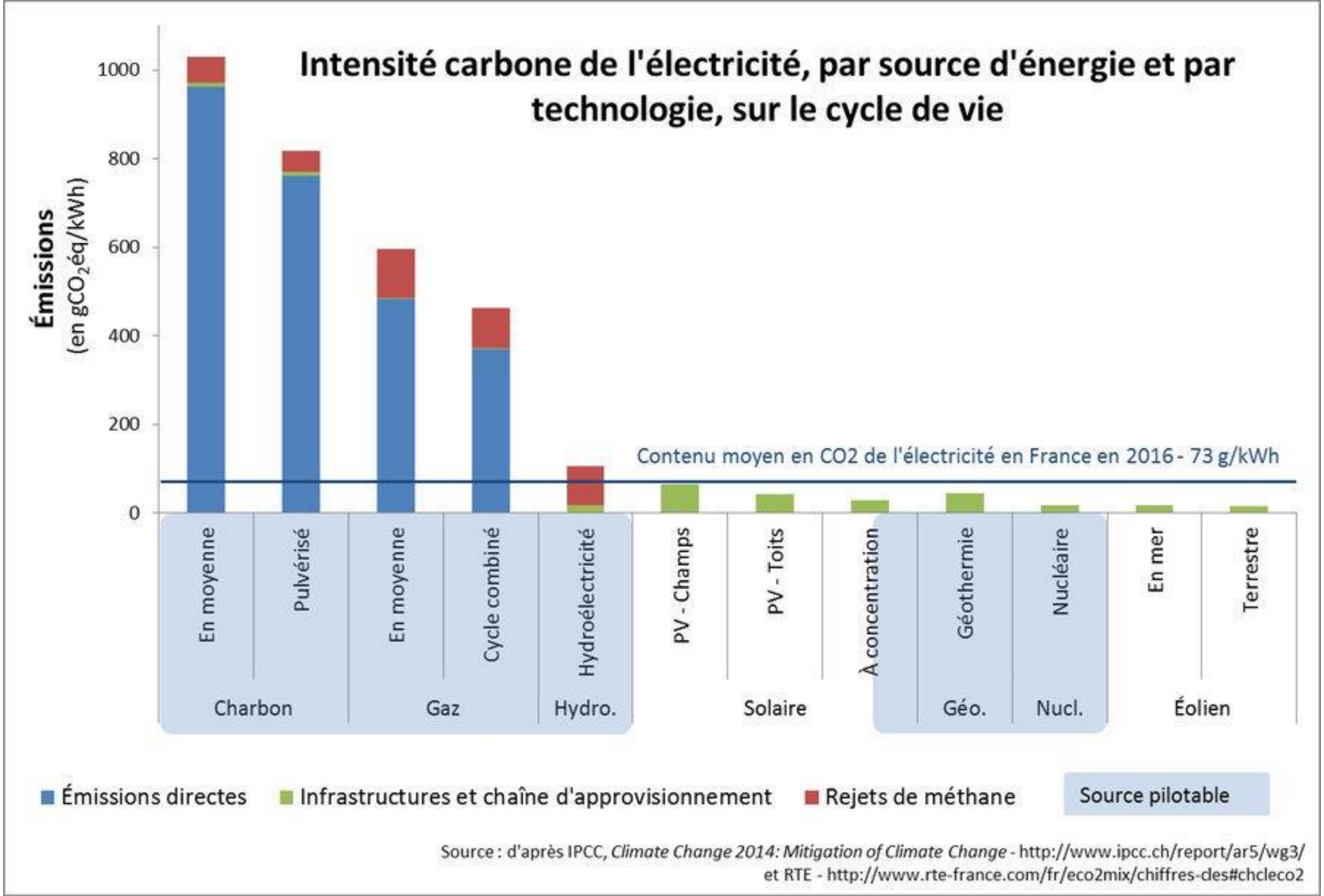


Sources: Aurora Energy Research; BEIS

Des résultats contrastés



Source: OurWorldinData 2020

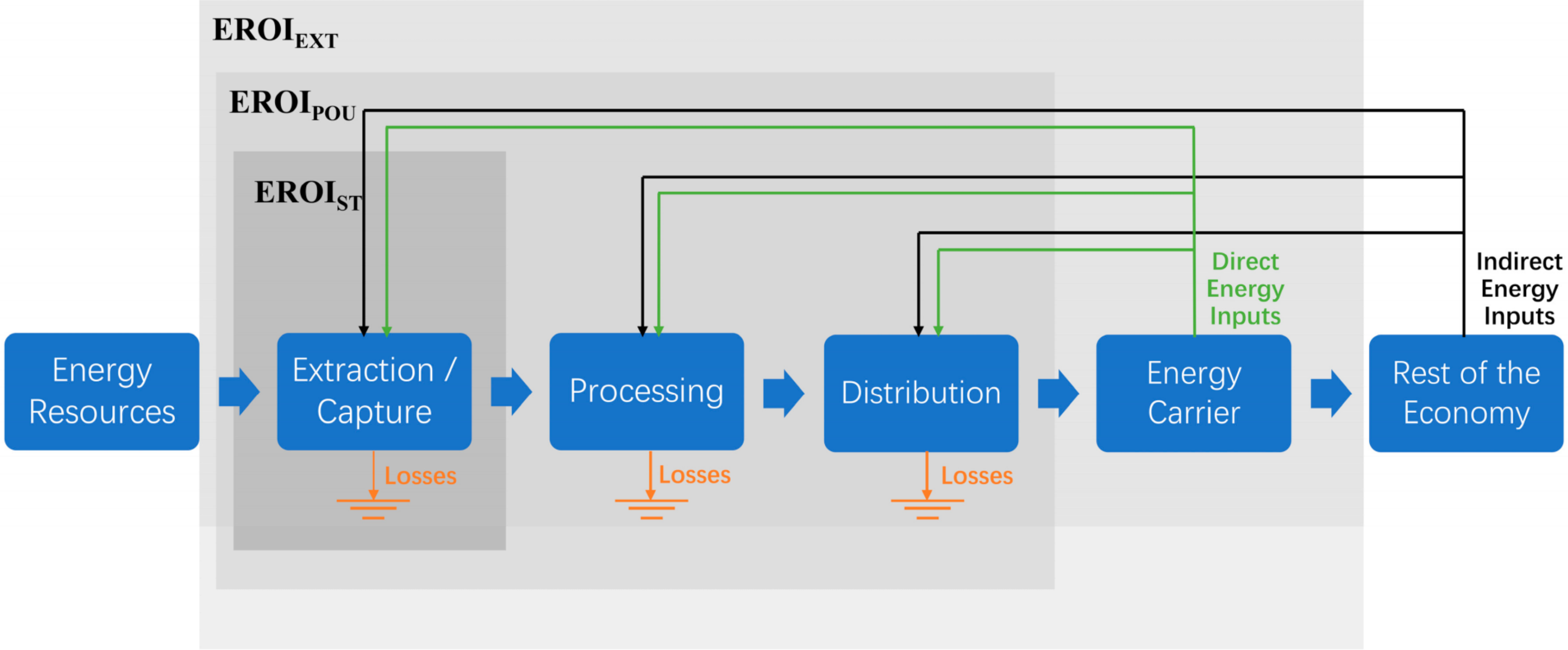


Intensité carbone de l'électricité, par source d'énergie et par technologie, sur le cycle de vie
Émissions
(en $gCO_2éq/kWh$)
1000
800
600
400
200
0
Contenu moyen en CO2 de l'électricité en France en 2016 - 73 g/kWh
En moyenne
Pulvérisé
En moyenne
Cycle combiné
Hydroélectricité
PV - Champs
PV - Toits
À concentration
Géothermie
Nucléaire
En mer
Terrestre
Charbon
Gaz
Hydro.
Solaire
Géo.
Nucl.
Éolien
Émissions directes
Infrastructures et chaîne d'approvisionnement
Rejets de méthane
Source pilotable
Source : d'après IPCC, *Climate Change 2014: Mitigation of Climate Change* - http://www.ipcc.ch/report/ar5/wg3/
et RTE - http://www.rte-france.com/fr/eco2mix/chiffres-cles#chcleco2

Taux de retour énergétique

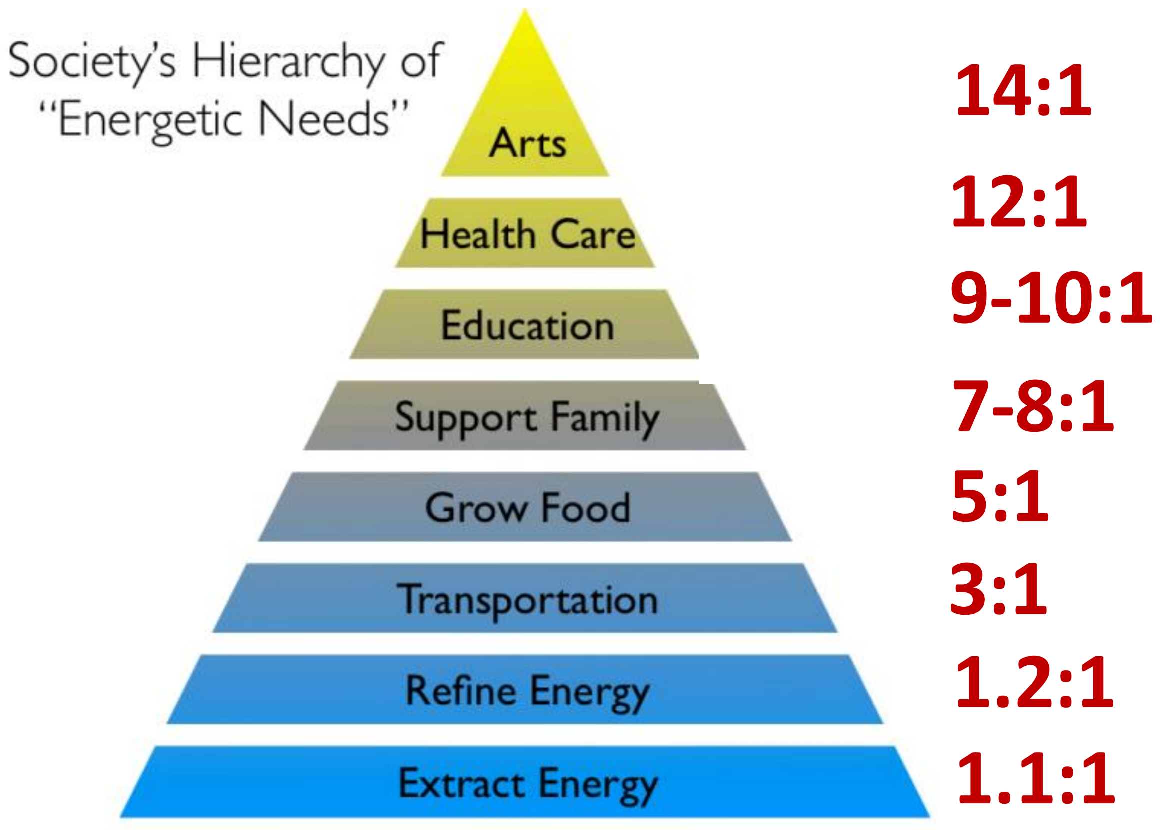
$$TRE = \frac{Energie\ effectivement\ apportée\ à\ la\ société}{Energie\ investie\ pour\ obtenir\ cette\ énergie}$$

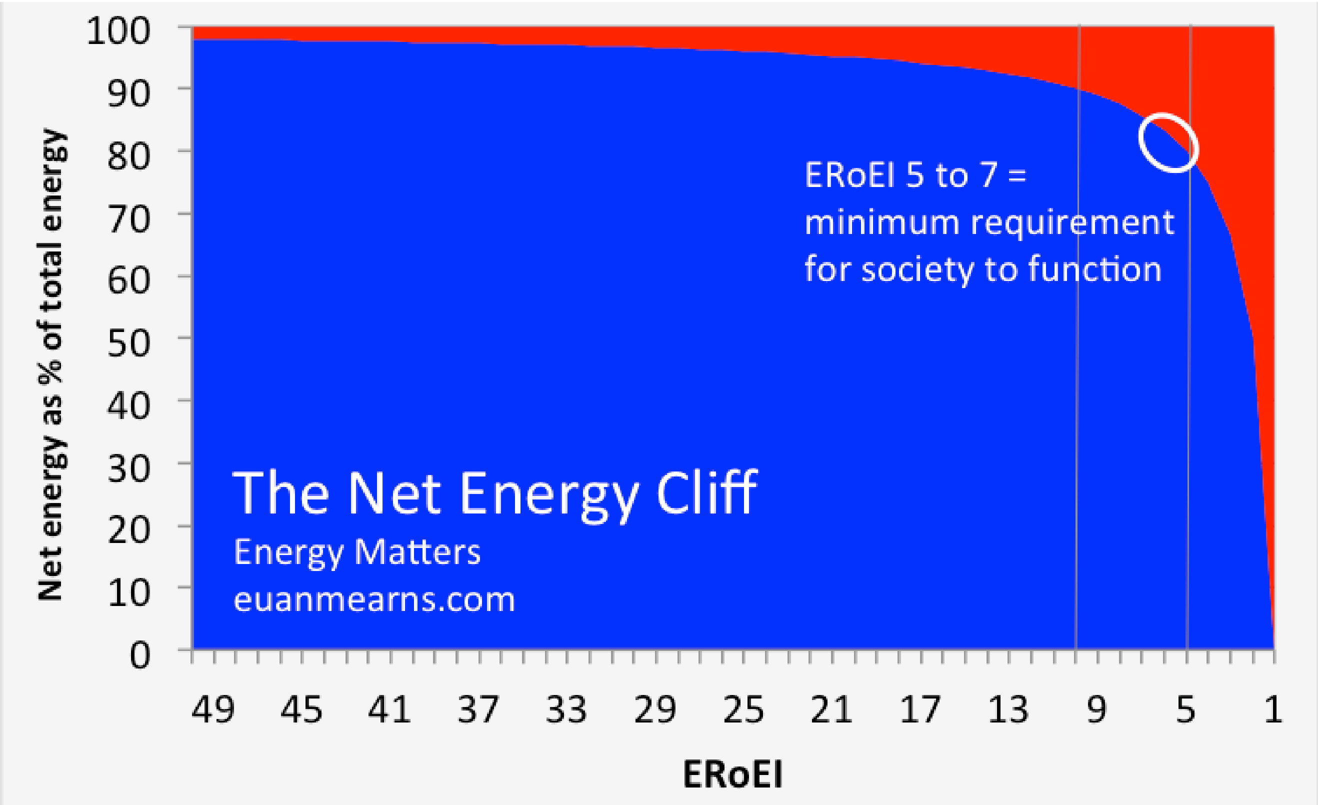
- **Le TRE définit l'abondance énergétique**
- **Différents TRE selon le champ couvert**



J. G. Lambert et al, EROI of global energy ressources (2013)

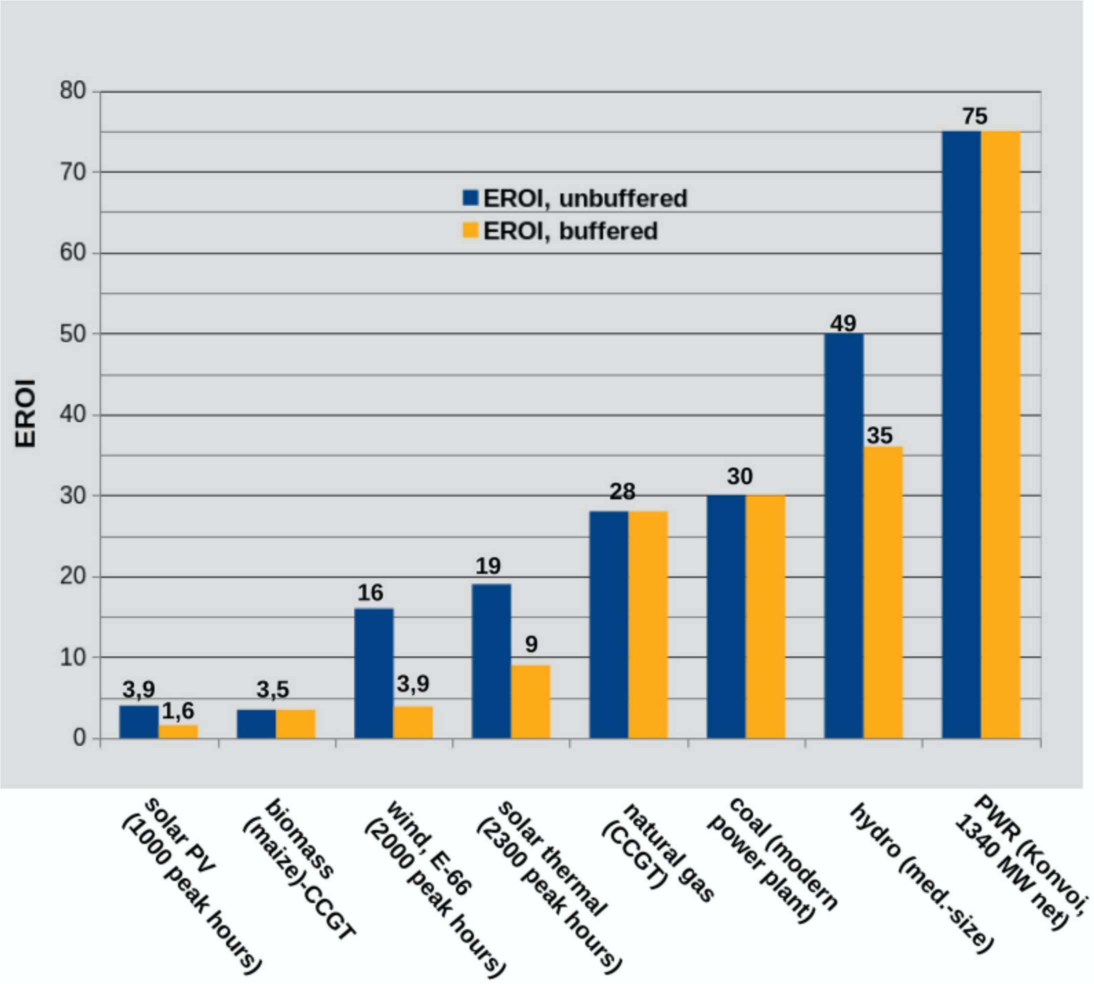
TRE et société



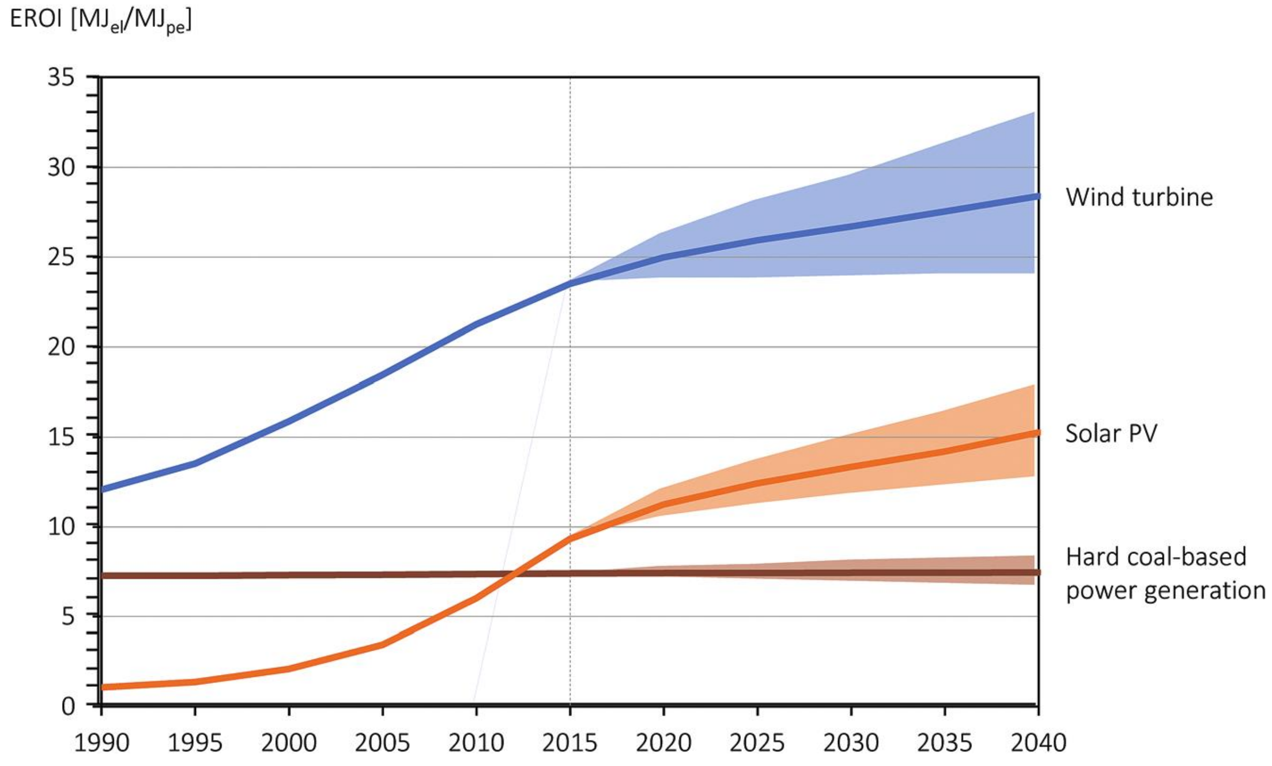


C. Hall, PPPL Colloquium, 2018

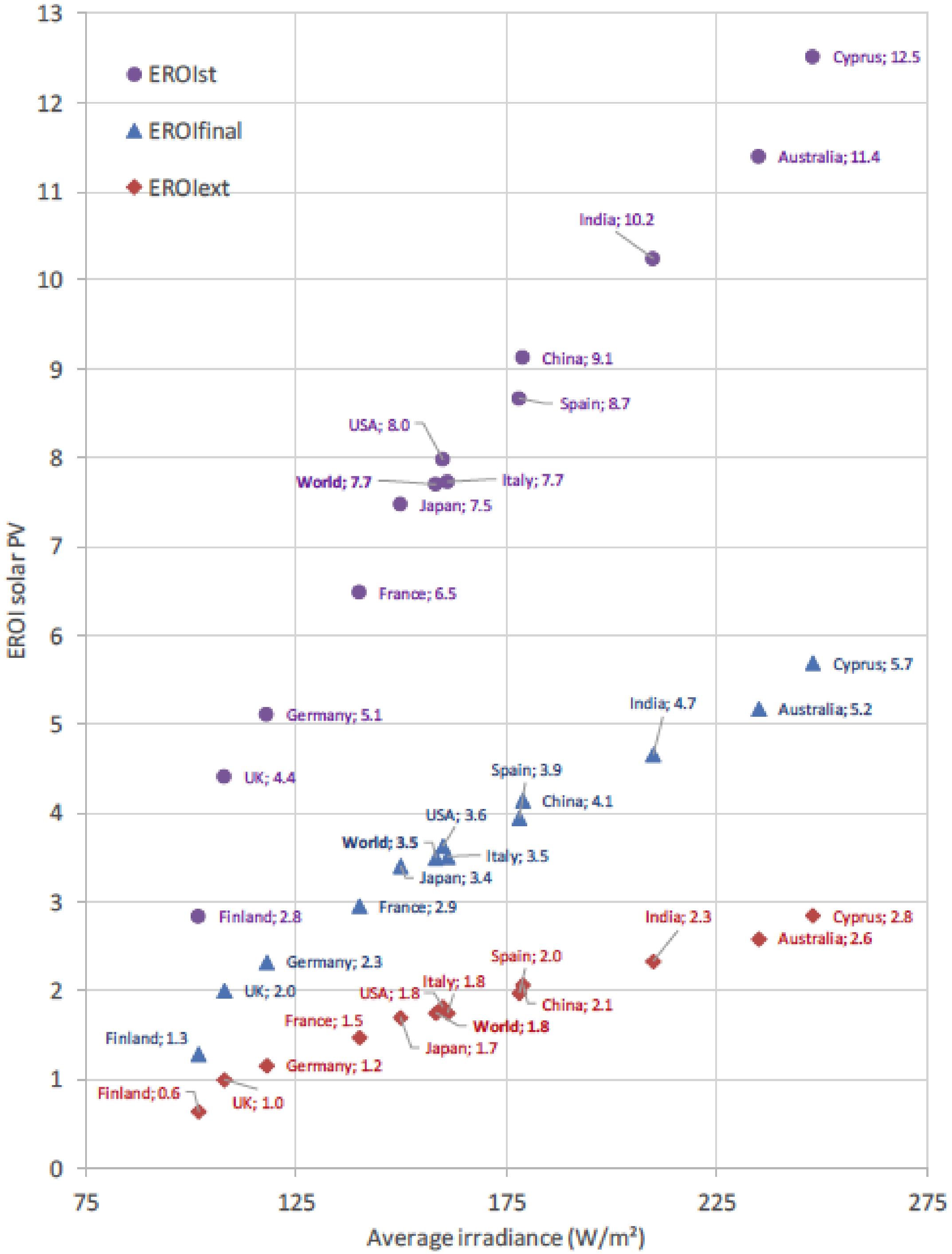
Des TRE très différents



D. Weissbach et al, EPJ Web of Conferences, 189 (2018)



B. Steffen, Energy Environ. Sci., 11, 3524, 2018

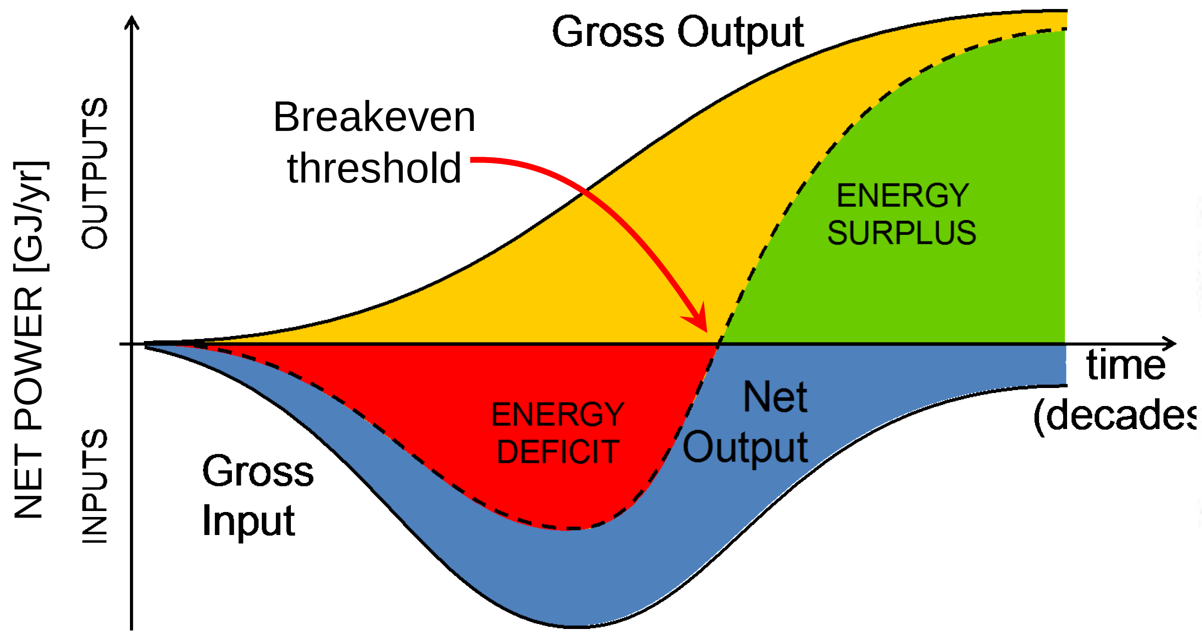


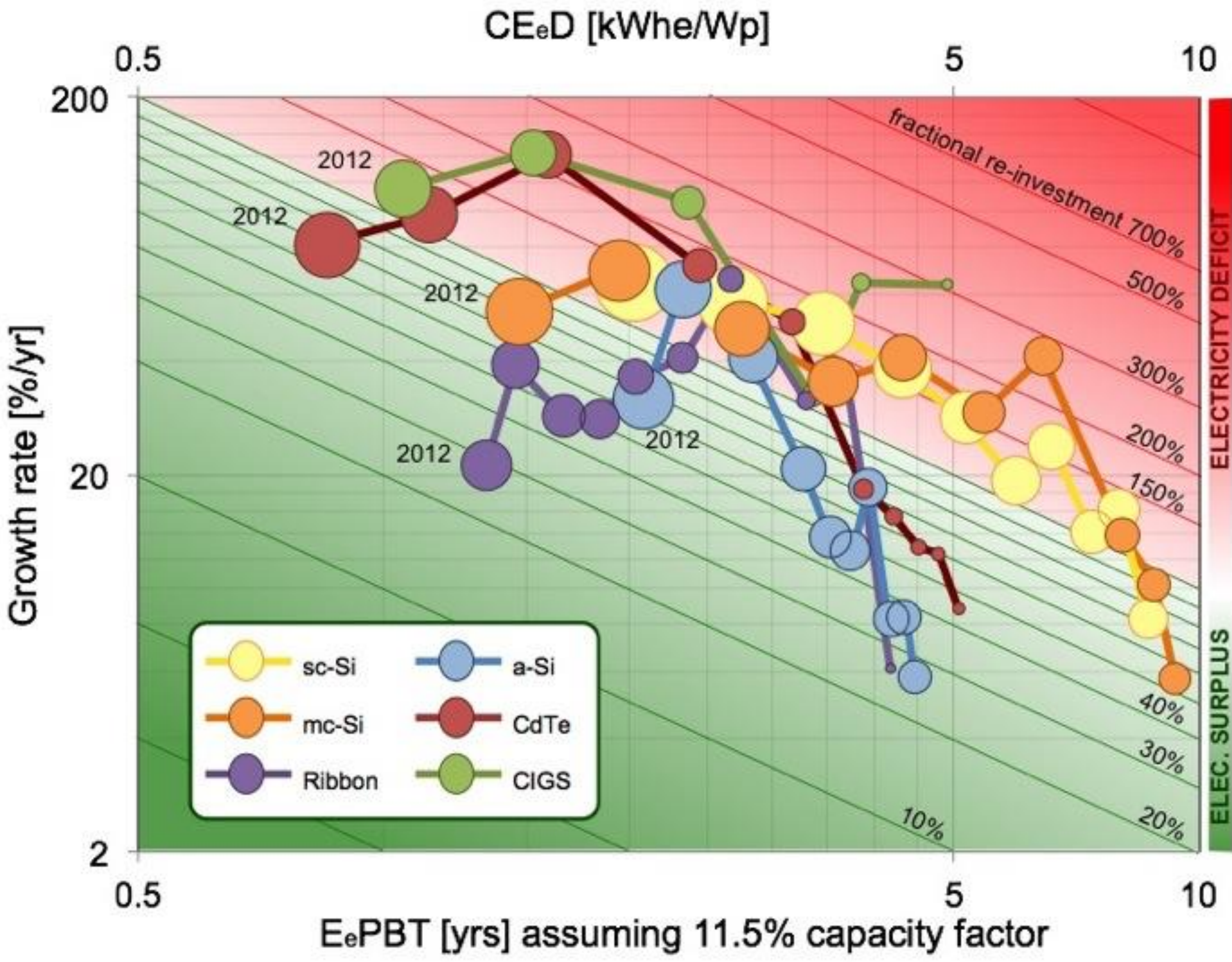
Technologies	$EROI_{st}$ This Work	$EROI_{st}$ Literature Range	Reference Literature Range Meta-Analysis and Individual Studies
Large hydro	28.4	10–105	Dale [108]; n = 16
		11.2–267	Schoenberg and Hall [109]; n = 7
		5.9–49.6 (24.7)	Kis et al. [74] (min-max)(base)
Wind onshore	13.2	12.5–66.7	Carbajales-Dale [34] (n = 42; power rating >500 kW)
		4.7–125.8	Kubiszewski et al. [20]; n > 40
		8.9	Dupont et al. [94]
		8.1–34.5 (12.6)	Kis et al. [74] (min-max)(base)
Wind offshore	8.7	5.4–66.7	Carbajales-Dale [34]; n = 37
		14.8–51.3	Kubiszewski et al., [20]; n > 4
		12	Dupont et al. [94]
		6.9–19.1 (13.5)	Kis et al. [74] (min-max)(base)
Solar PV	7.8	8.7–34.2	Bhandari et al., [14]; n = 23
		7.2	Dupont et al. [94] (present)
		2.7–7.5 (4.8)	Kis et al. [74] (min-max)(base)
CSP	2.6	5.2–6.7	Dupont et al. [94] (present)
		5.4–17.9 (9.8)	Kis et al. [74] (min-max)(base)
		9.6–67.6	de Castro and Capellán-Pérez [25] n = 13

C. De Castro, I. Capellan Perez, Energies (2020)

TRE et transition

✧ **Cumulative Energy Demand (CED): combien d'énergie est necessaire pour déployer et opérer une technologie**

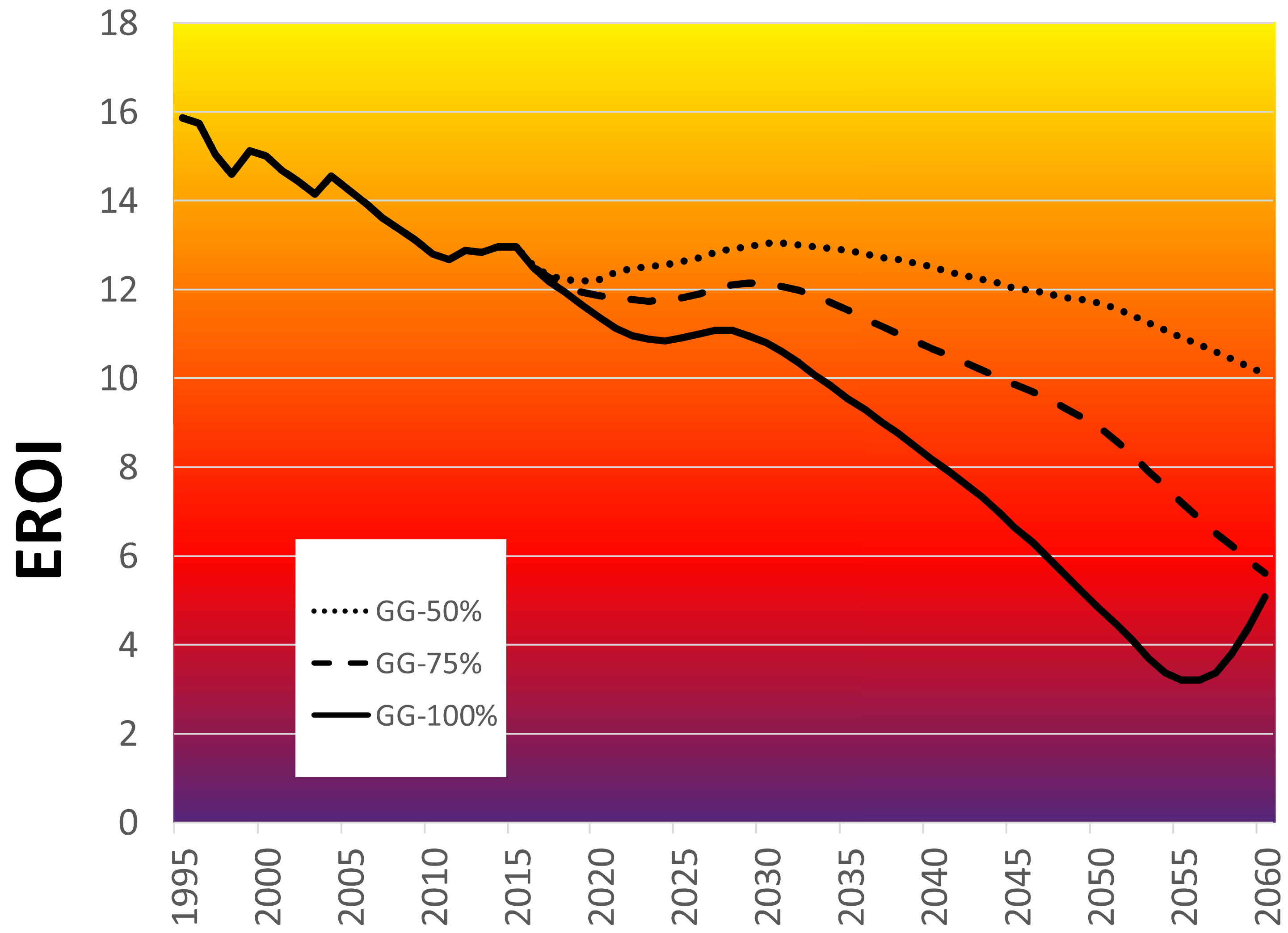




Important de considérer l'énergie nette et de minimiser la phase de déficit

M. Carbajales-Dale, GCEP workshop on Net Energy Analysis (2

TRE et transition



3 scenarios pour 2060

- **50% EnR**
- **75%EnR**
- **100% EnR**

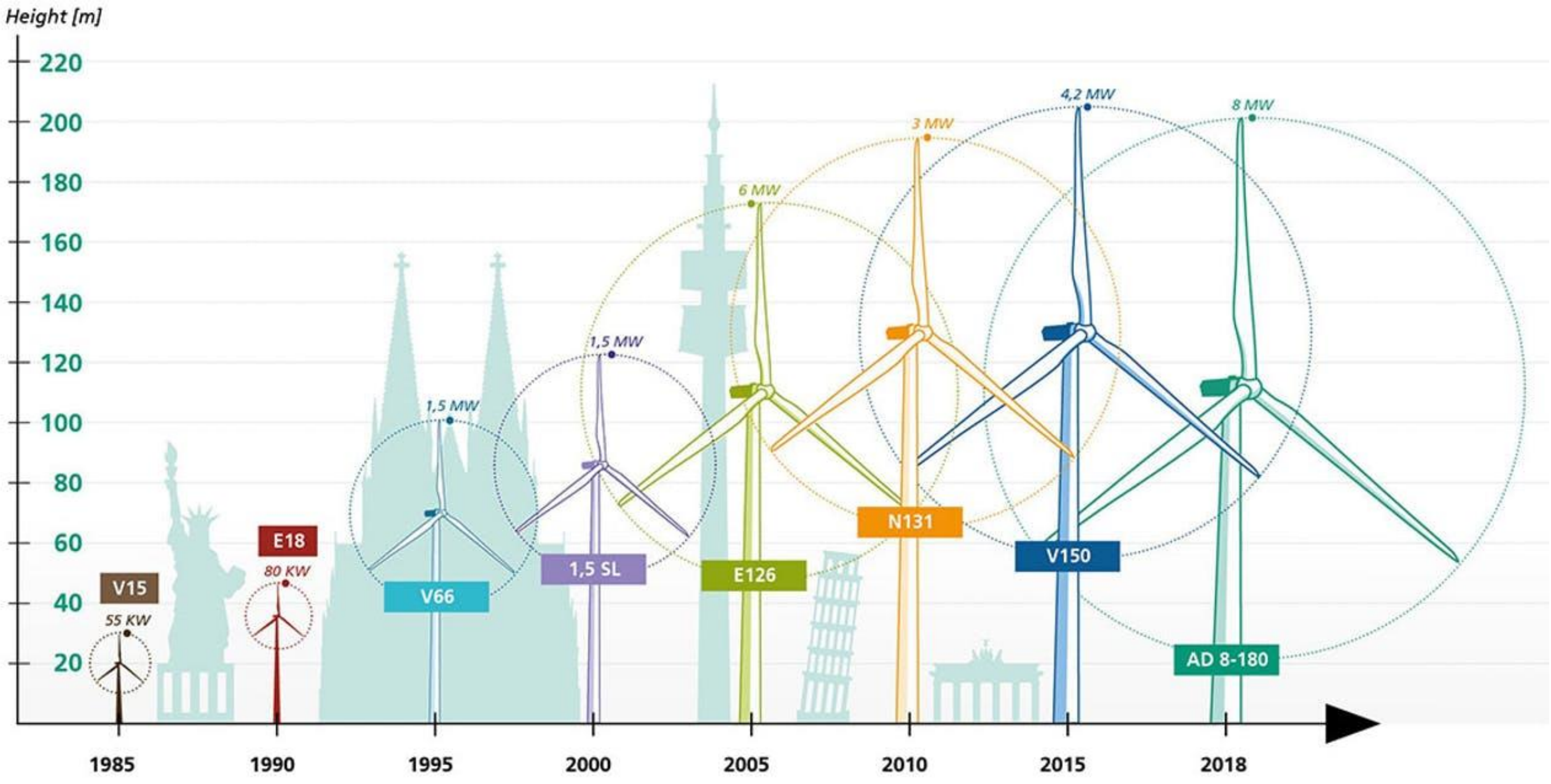
(électricité)

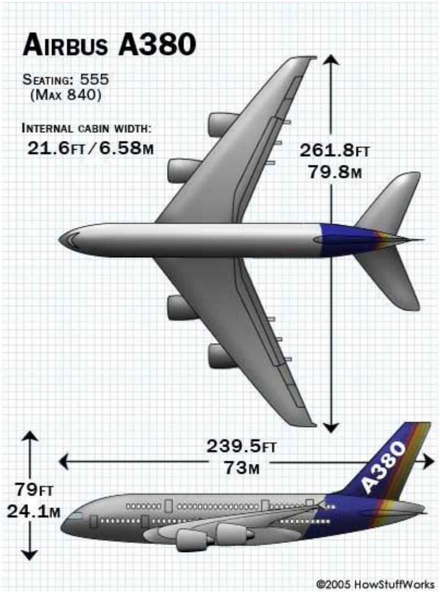
I. Capellan-Perez et al, Energy Strategy Reviews, (2019)

Densité de puissance

✧ **Puissance produite (consommée) par unité de surface horizontale requise pour l'infrastructure de production (consommation)**

V. Smil, « Power density: key to understanding Energy sources and uses », 2016



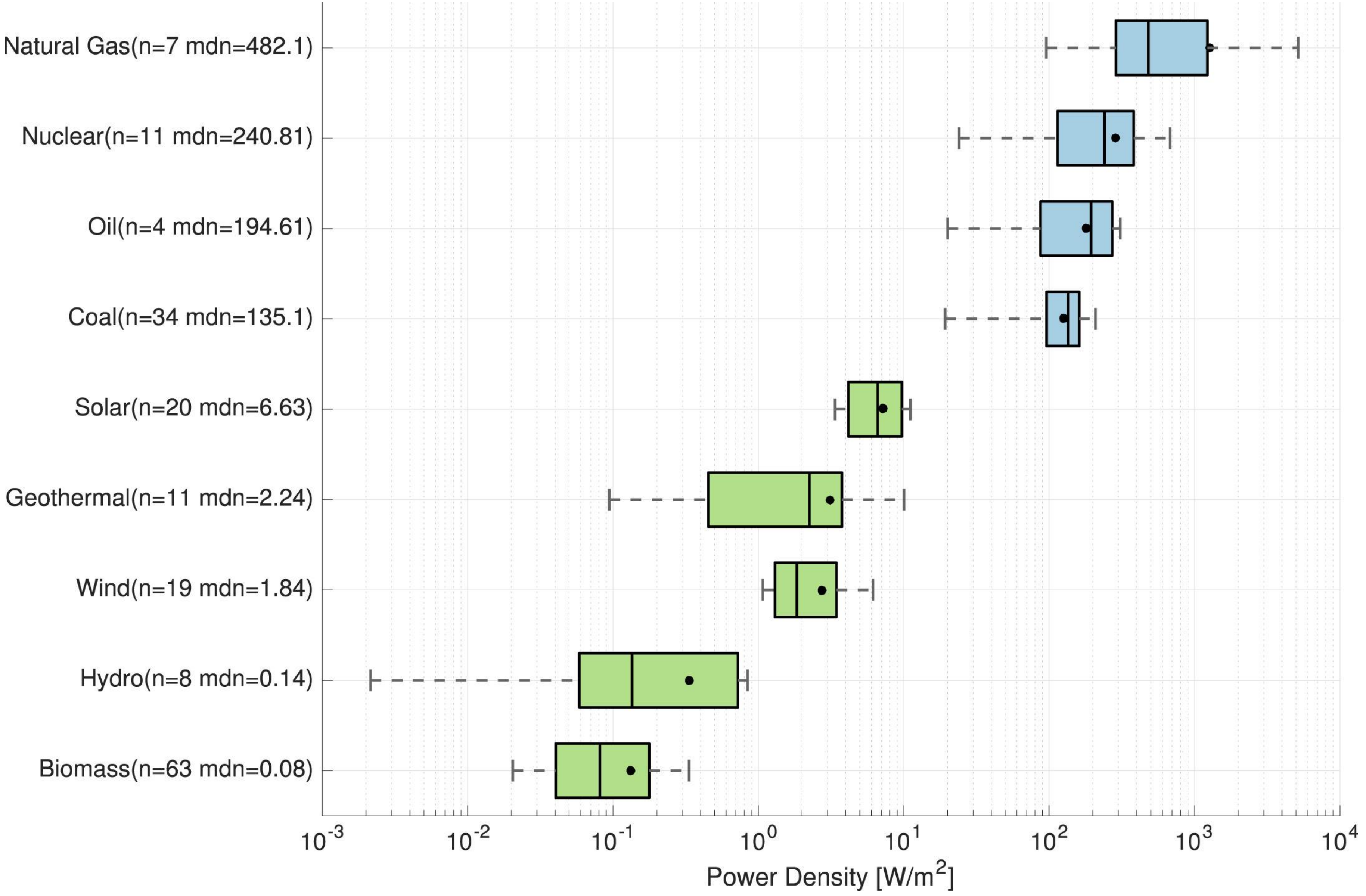


Distance entre 2 éoliennes: 5-7 fois le diameter

Densité: 1 W/m2

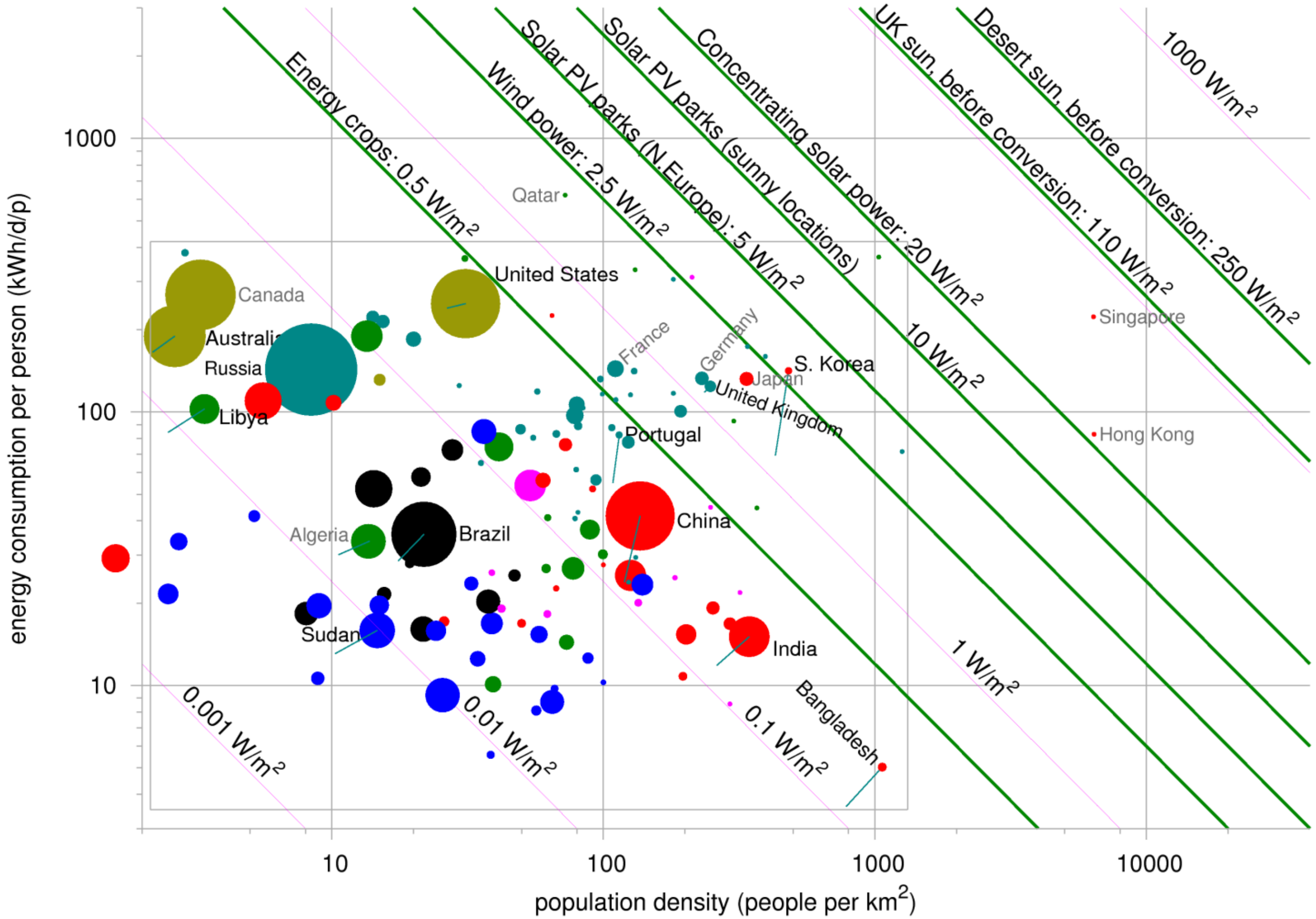
https://www.inverse.com/article/58486-future-wind-turbines-will-be-bigger-more-powerful-and-probably-cheaper

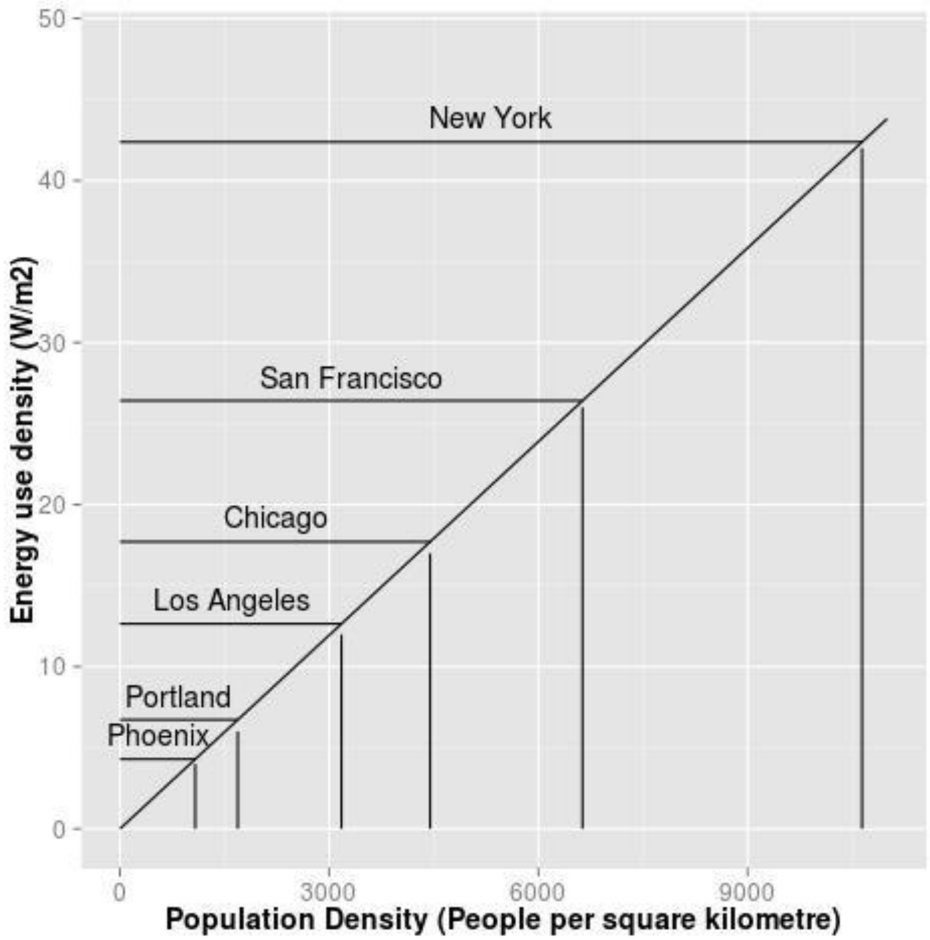
Des densités très variées



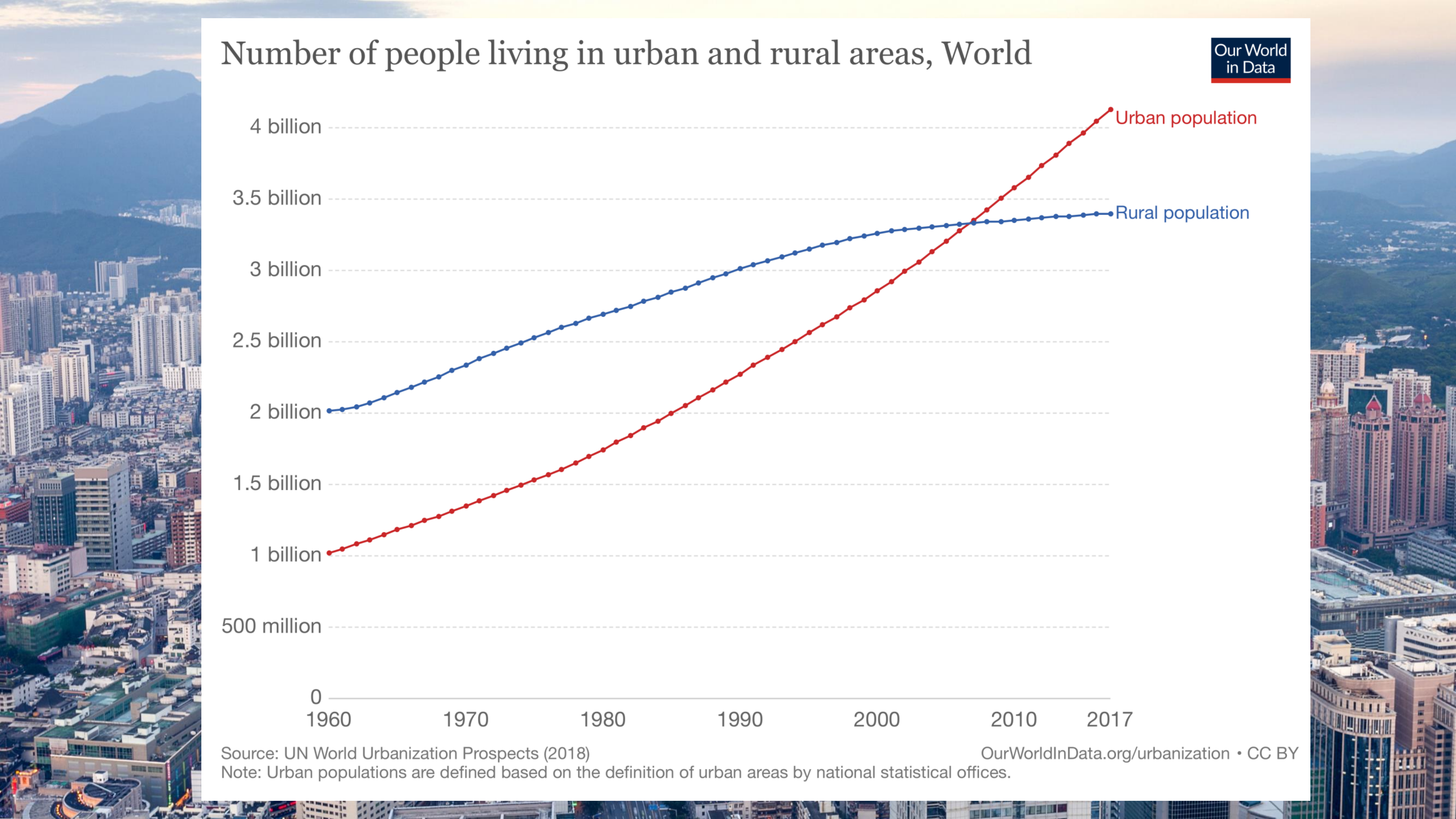
J. Van Zalk, Energy Policy, 123 (2018)

De l'espace!!

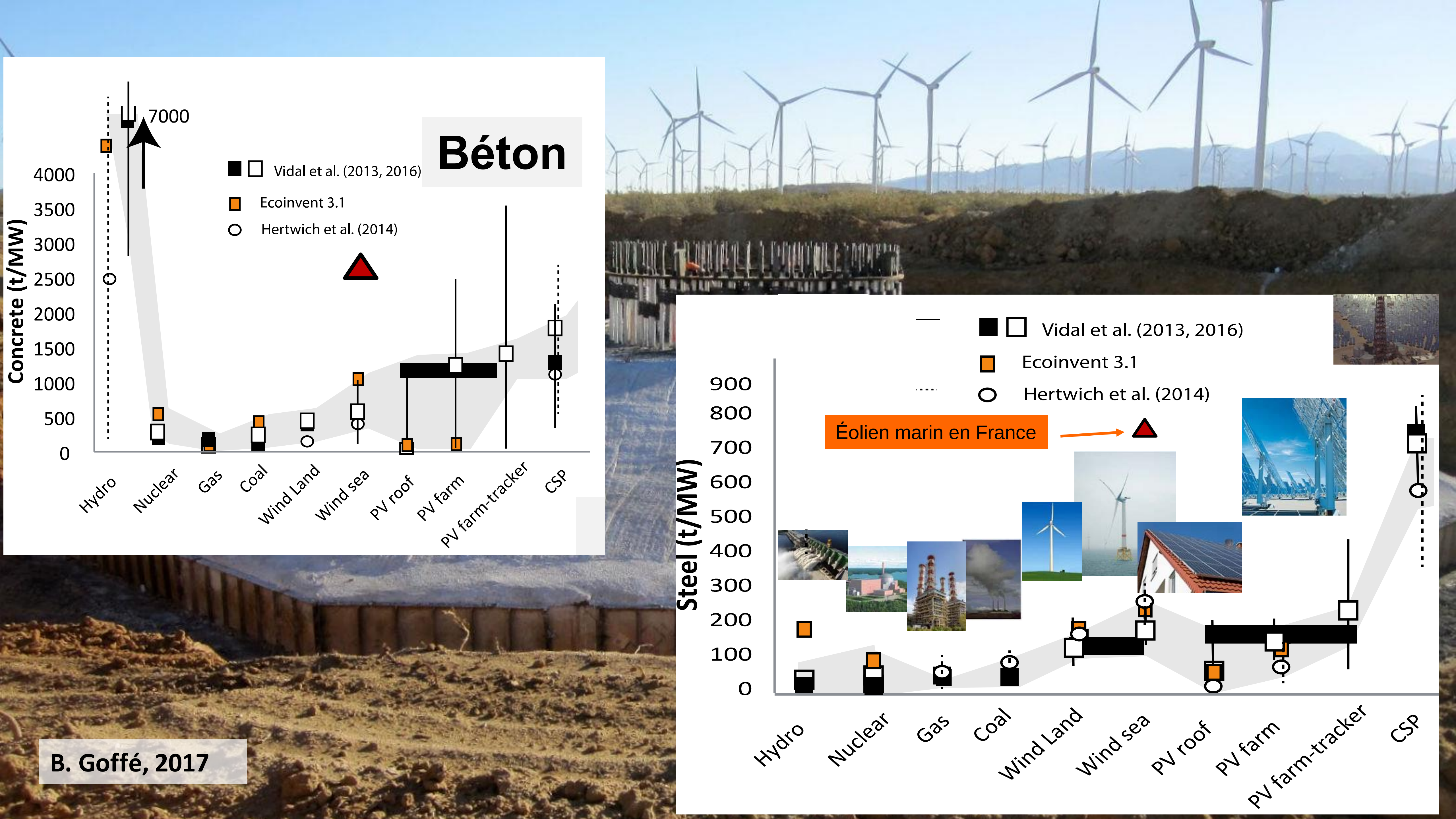




D. McKay, « Without the hot air »

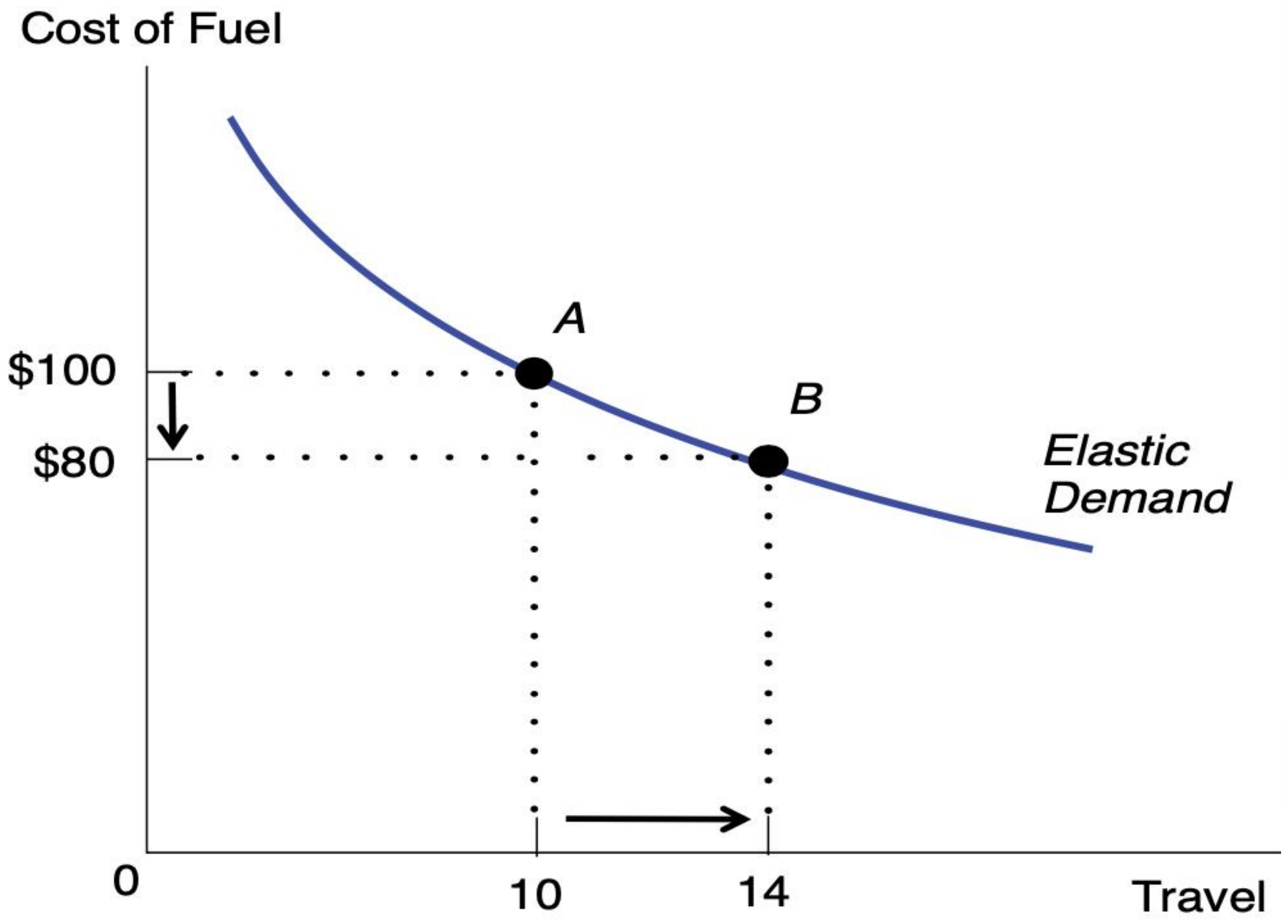


Number of people living in urban and rural areas, World
Our World in Data
Urban population
Rural population
4 billion
3.5 billion
3 billion
2.5 billion
2 billion
1.5 billion
1 billion
500 million
0
1960
1970
1980
1990
2000
2010
2017
Source: UN World Urbanization Prospects (2018)
OurWorldInData.org/urbanization • CC BY
Note: Urban populations are defined based on the definition of urban areas by national statistical offices.


Béton
7000
Vidal et al. (2013, 2016)
Ecoinvent 3.1
Hertwich et al. (2014)
Concrete (t/MW)
4000
3500
3000
2500
2000
1500
1000
500
0
Hydro
Nuclear
Gas
Coal
Wind Land
Wind sea
PV roof
PV farm
PV farm-tracker
CSP
Vidal et al. (2013, 2016)
Ecoinvent 3.1
Hertwich et al. (2014)
Éolien marin en France
Steel (t/MW)
900
800
700
600
500
400
300
200
100
0
Hydro
Nuclear
Gas
Coal
Wind Land
Wind sea
PV roof
PV farm
PV farm-tracker
CSP
B. Goffé, 2017

" It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth."

William Stanley Jevon
The Coal Question; An Inquiry Concerning the Progress of the Nation, and the Probable Exhaustion of Our Coal Mines, 1865



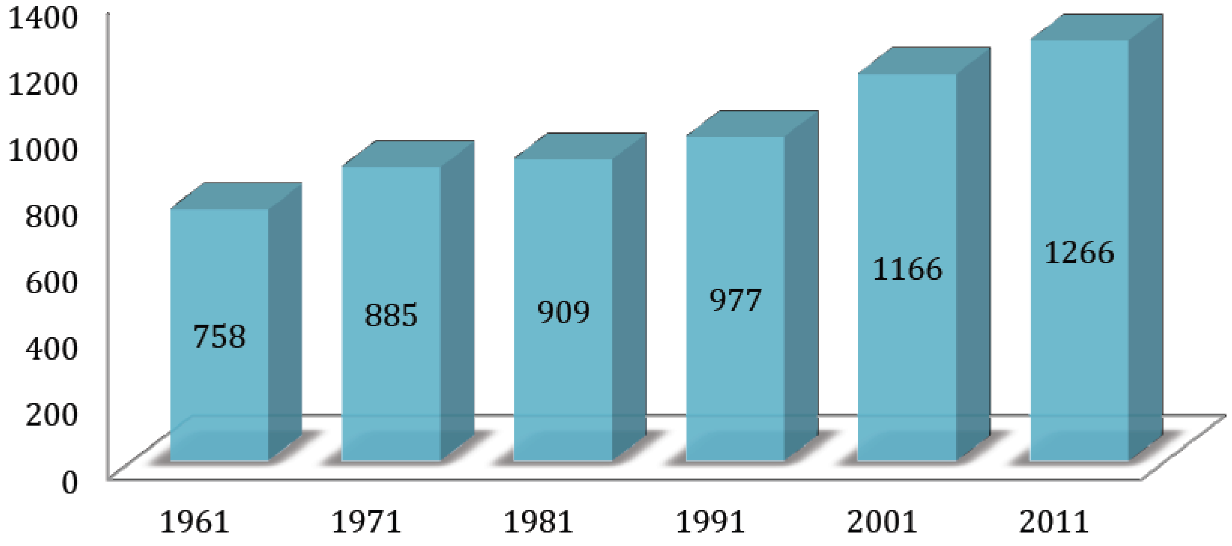
Cost of Fuel
$100
$80
A
B
Elastic Demand
0
10
14
Travel

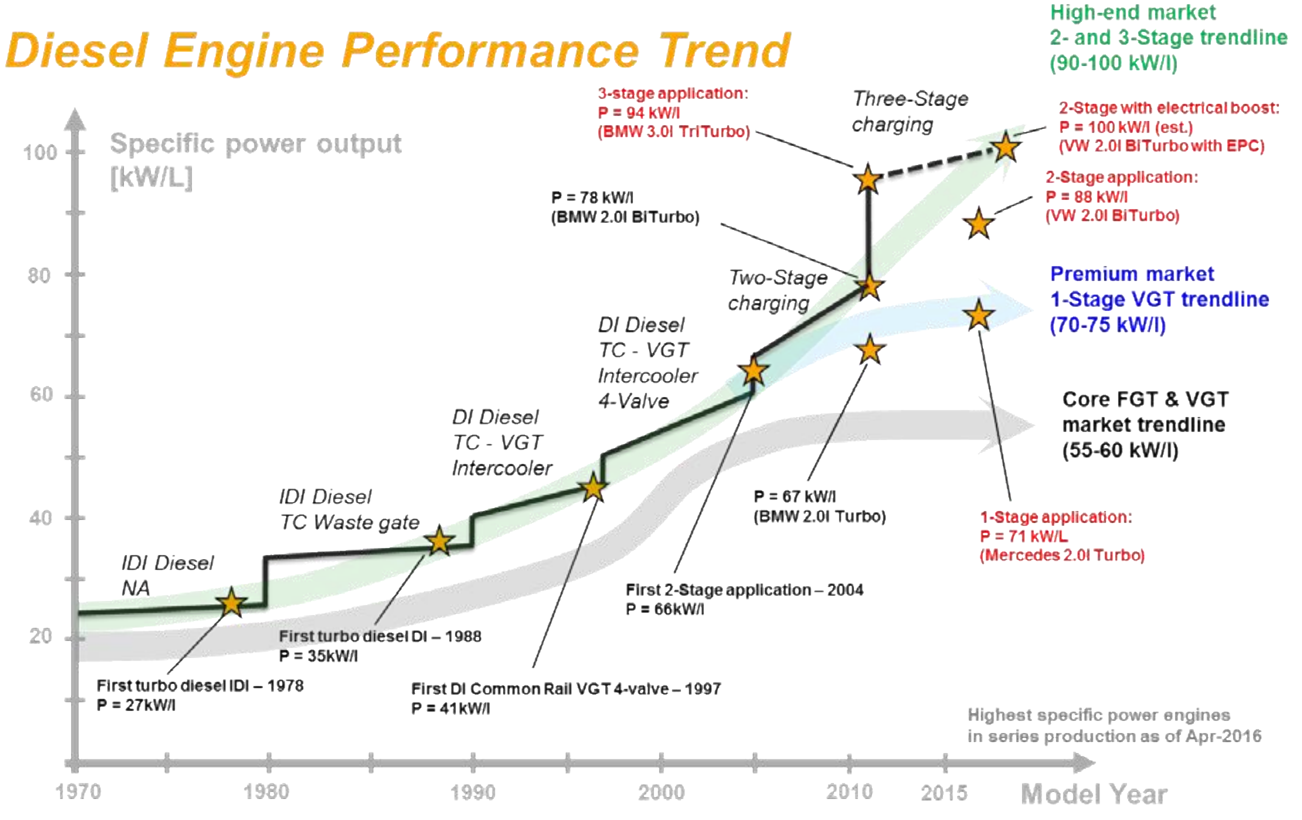
Efficacité oui mais…

✧ **Des moteurs de plus en plus performants…**

✧ **Mais des voitures de plus en plus lourdes…**

Poids moyen véhicule particulier France (kg)





F.C. Pesce et al, 25th Aachen Colloquium Automobile and Engine technology, 2016

Le cas de l'aviation…

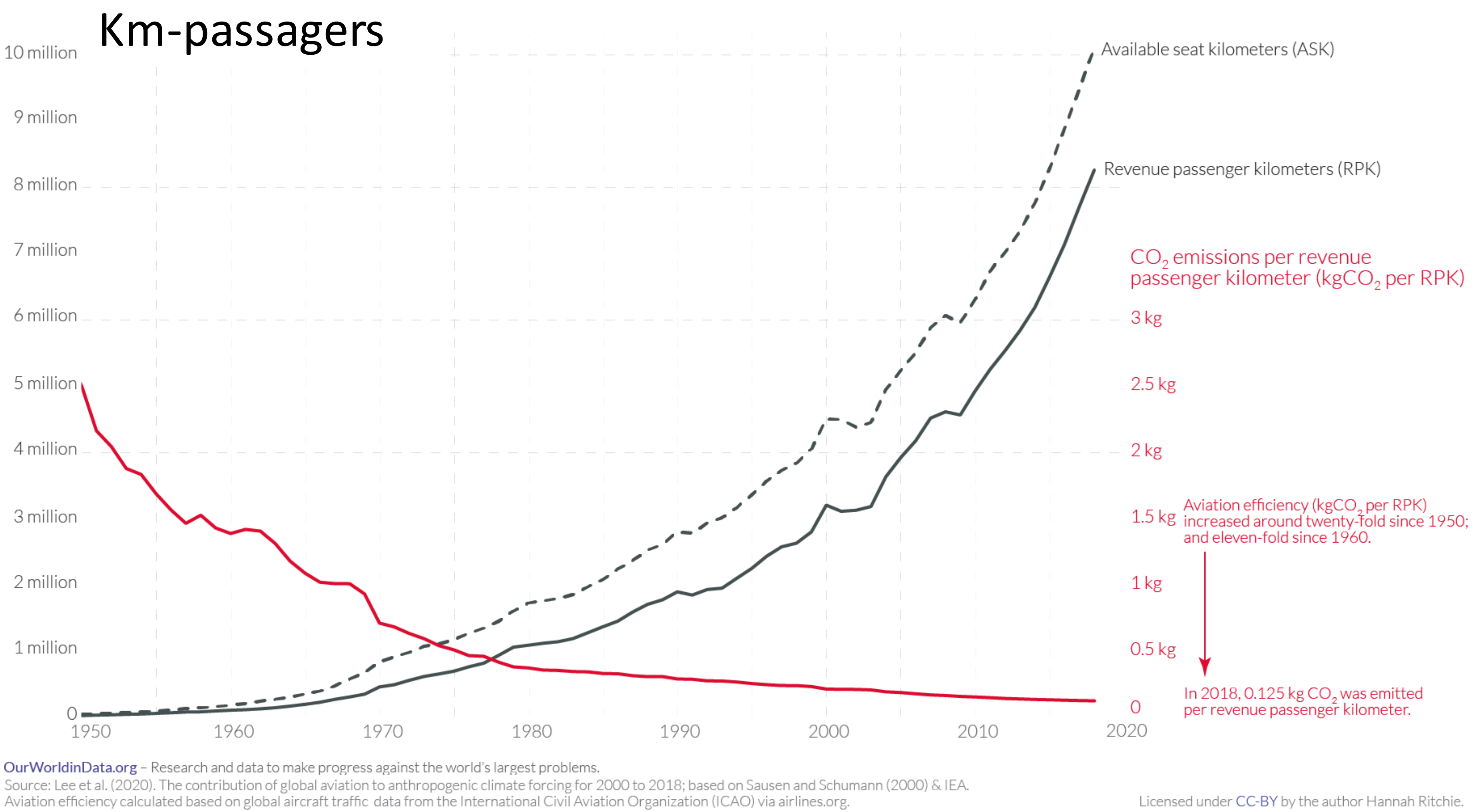
1960-2015

consommation p.km

÷11↓

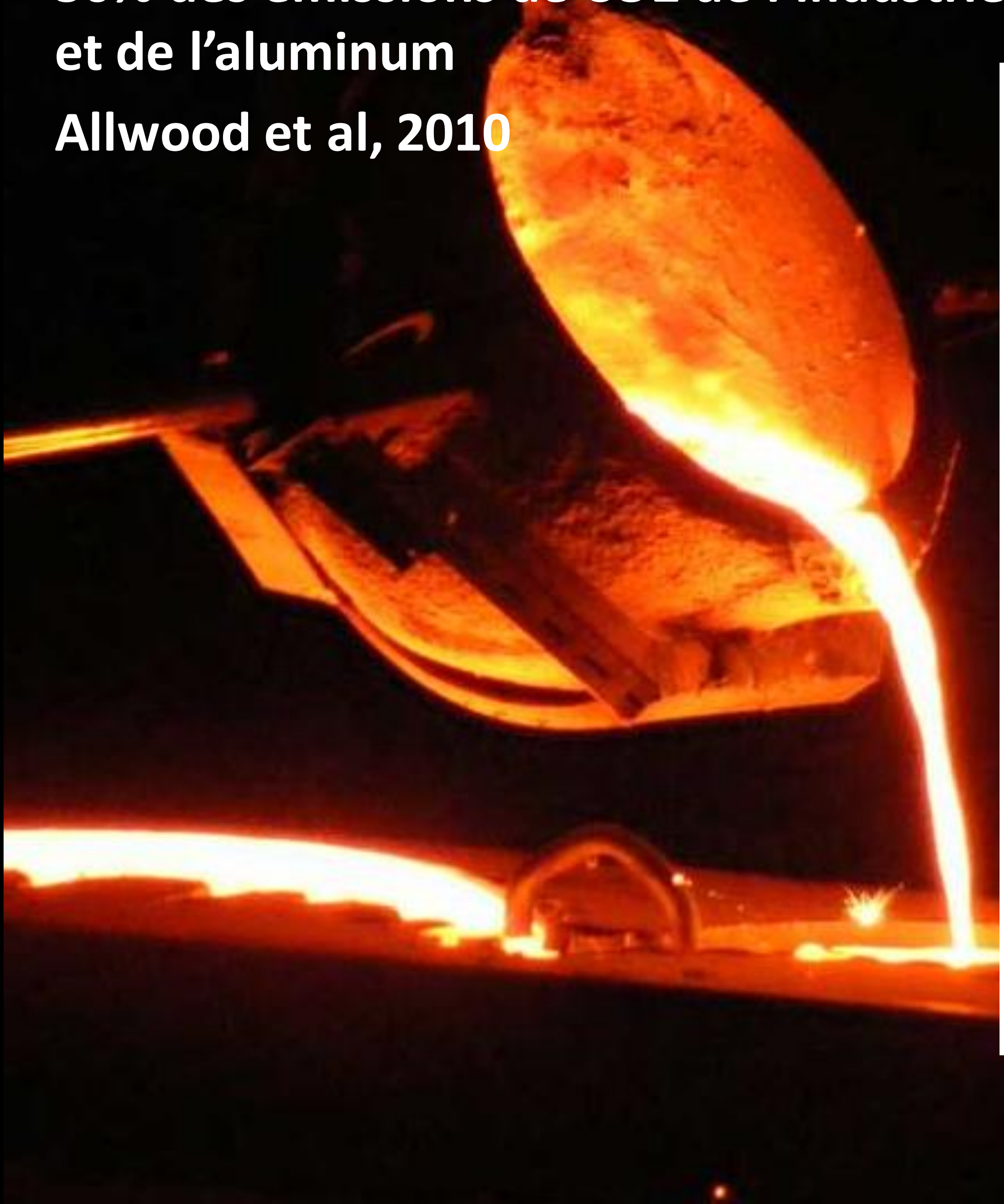
passagers-kilometres

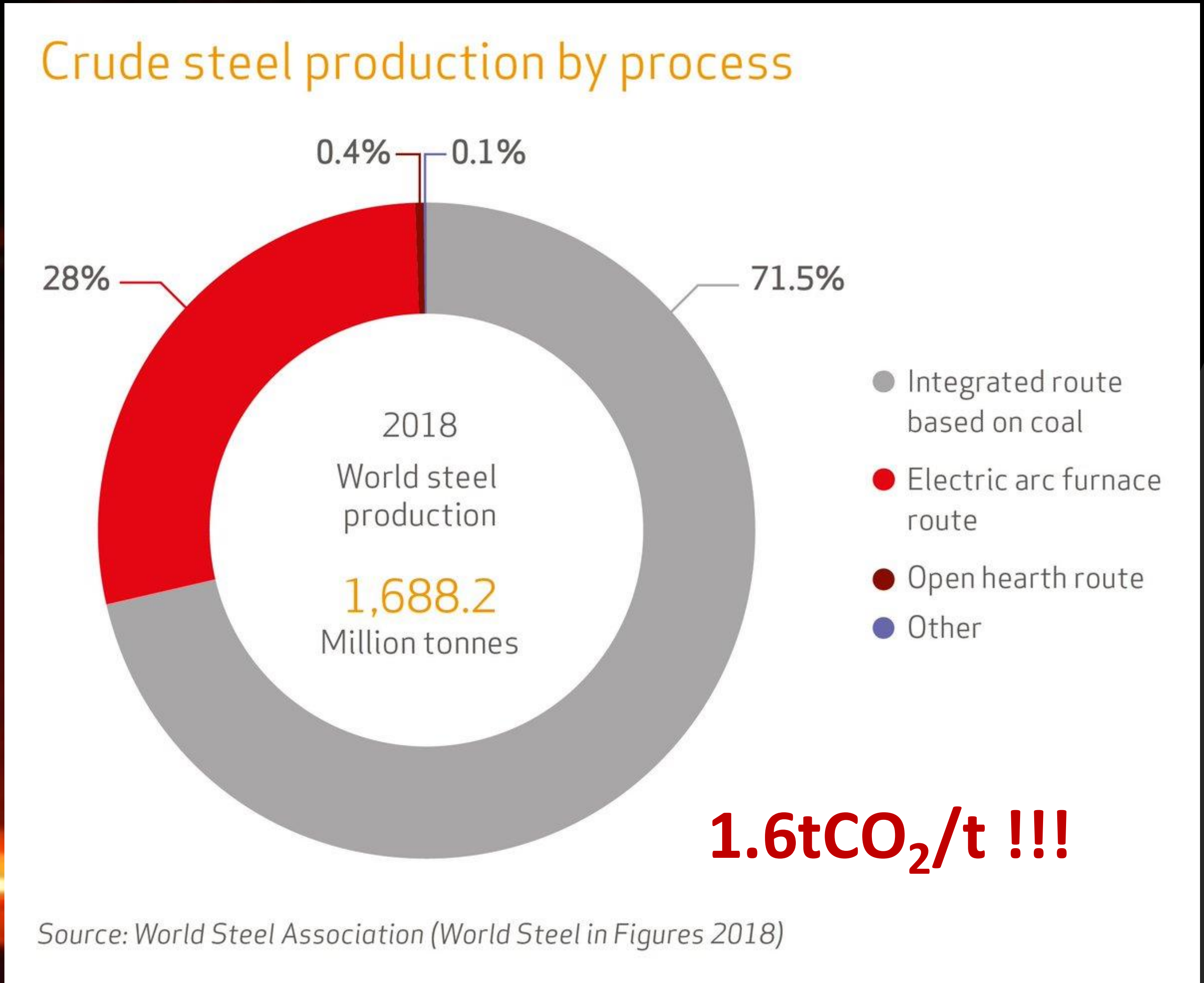
75x ↑



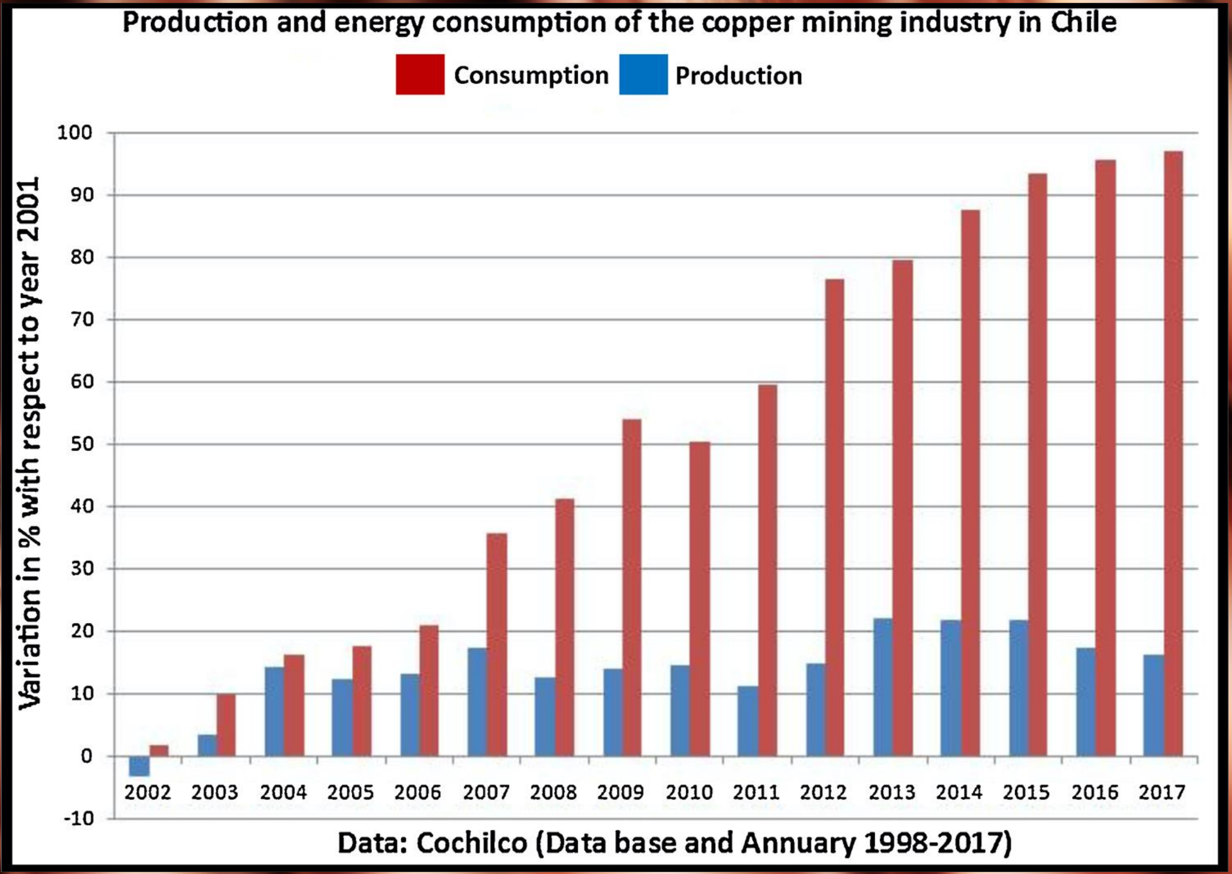
50% des émissions de CO_2 de l’industrie sont émise pour la production de l’acier, du ciment et de l’aluminum

Allwood et al, 2010



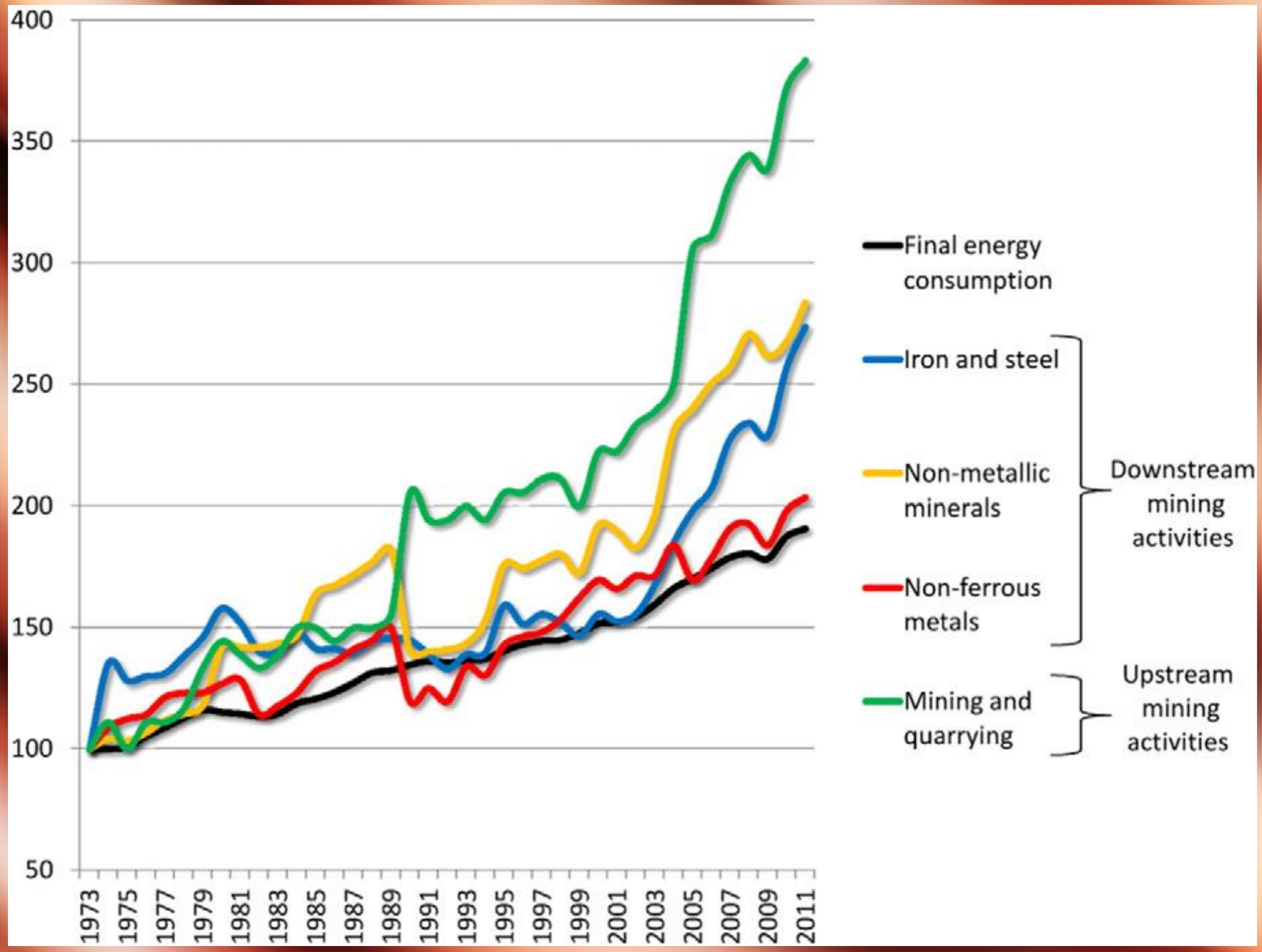


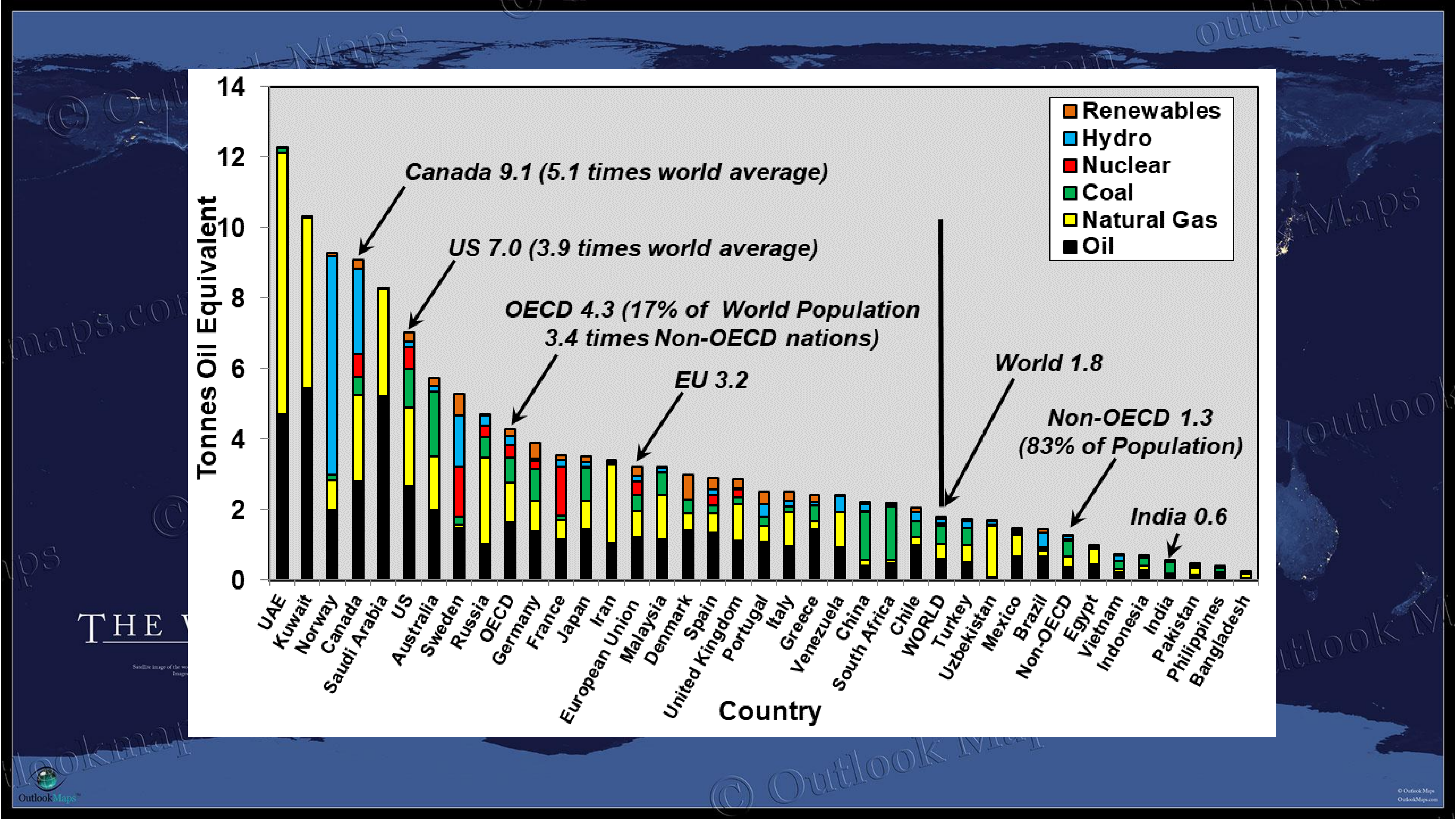
$1.6 tCO_2/t$!!!



N. Hagens, Ecological Economics, 2020

F. Fizaine, V. Court, Ecological Economics, 110 (2015)

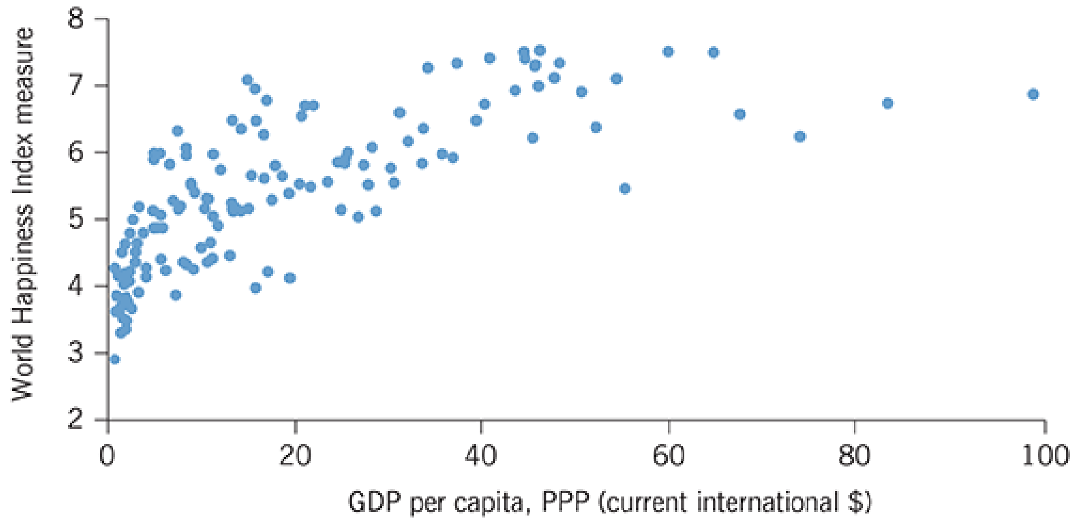




Renewables
Hydro
Nuclear
Coal
Natural Gas
Oil
Canada 9.1 (5.1 times world average)
US 7.0 (3.9 times world average)
OECD 4.3 (17% of World Population
3.4 times Non-OECD nations)
EU 3.2
World 1.8
Non-OECD 1.3
(83% of Population)
India 0.6
Tonnes Oil Equivalent
0
2
4
6
8
10
12
14
UAE
Kuwait
Norway
Canada
Saudi Arabia
US
Australia
Sweden
Russia
OECD
Germany
France
Japan
Iran
European Union
Malaysia
Denmark
Spain
United Kingdom
Portugal
Italy
Greece
Venezuela
China
South Africa
Chile
WORLD
Turkey
Uzbekistan
Mexico
Brazil
Non-OECD
Egypt
Vietnam
Indonesia
India
Pakistan
Philippines
Bangladesh
Country

L’énergie fait le bonheur?

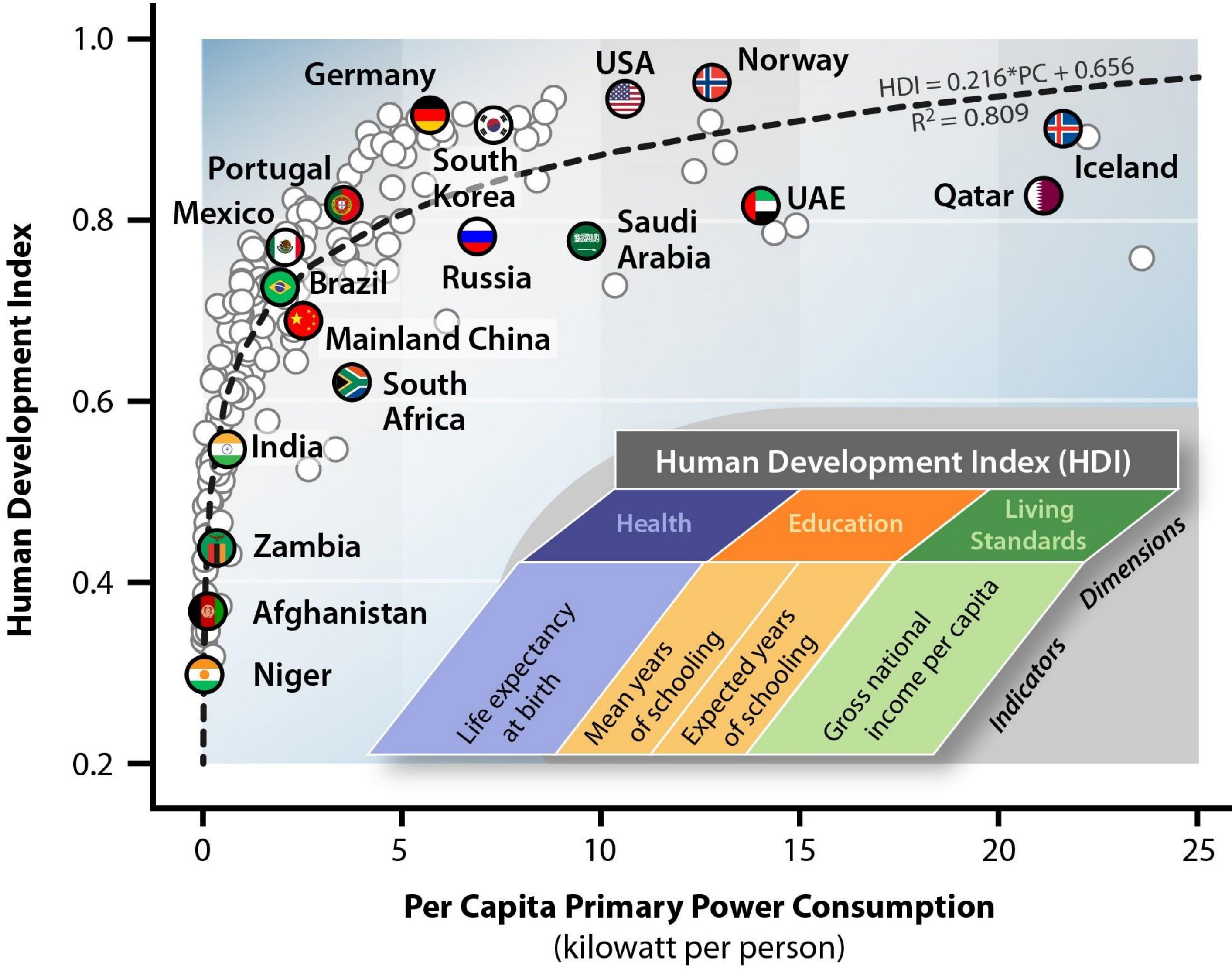
Figure 1. Happiness and GDP per capita average (2013–2015)



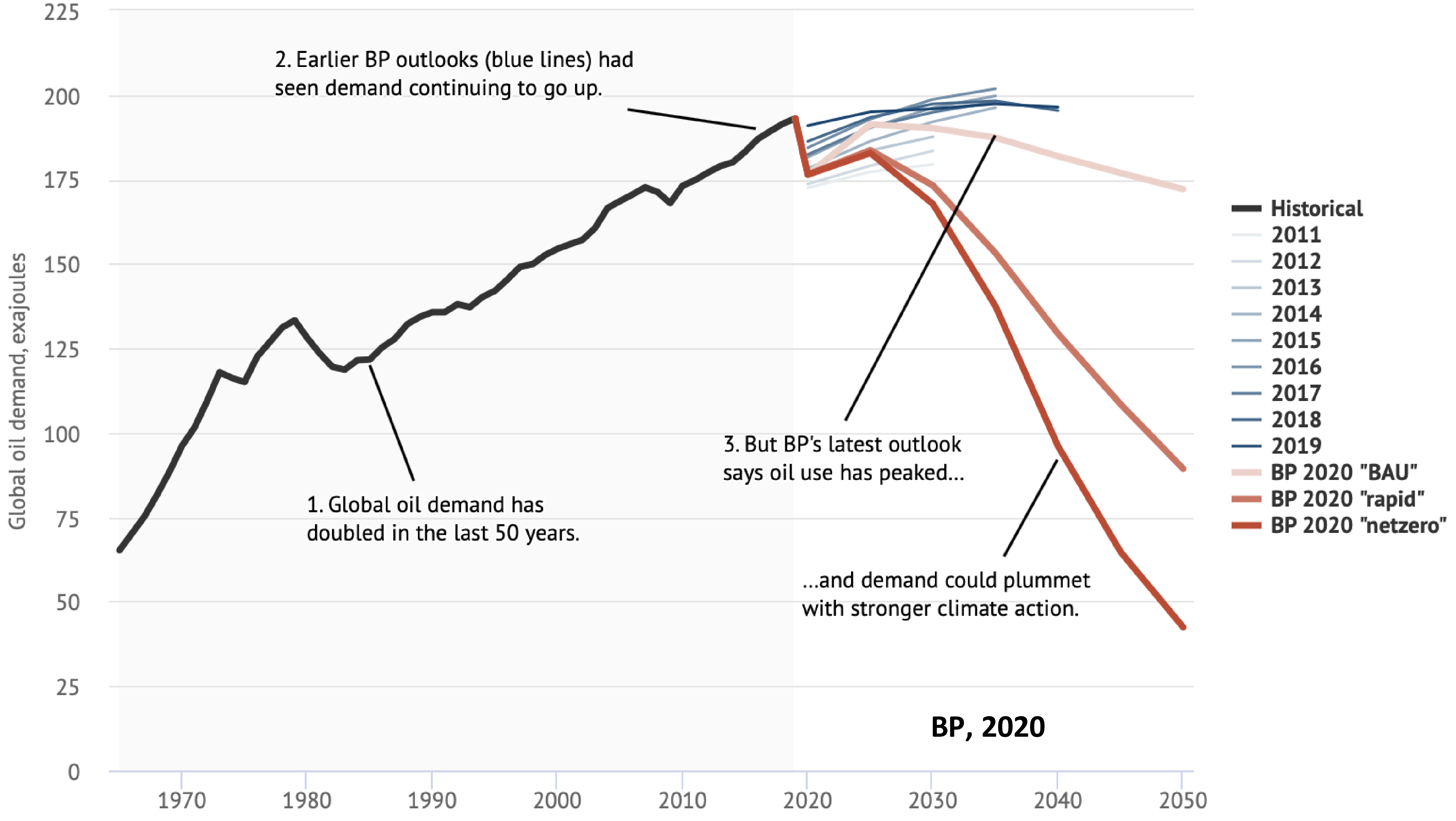
Note: The World Happiness Index is a subjective measure with values ranging from 0 (“completely dissatisfied”) to 10 (“completely satisfied”).

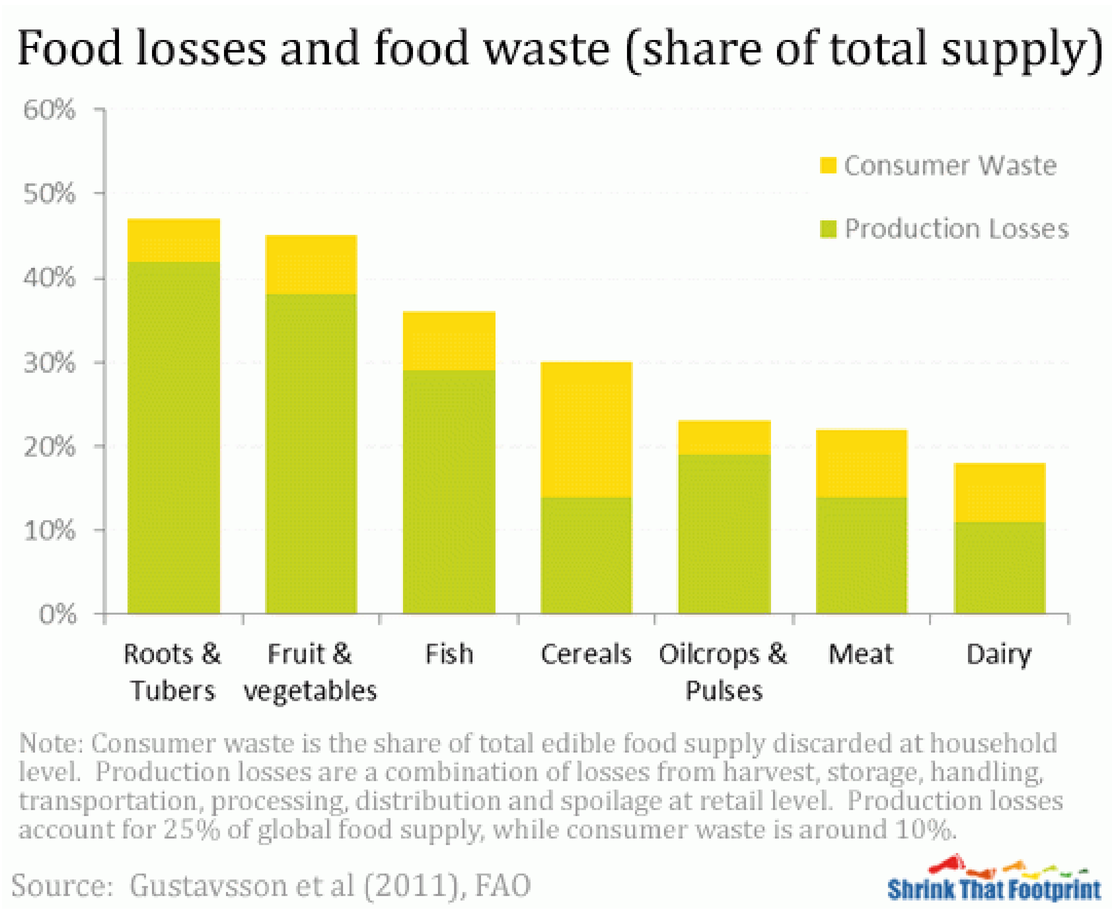
Source: Author’s own compilation based on data from the World Happiness Report 2016. Online at: http://worldhappiness.report/ed/2016/; World Bank, World Development Indicators. Online at: http://data.worldbank.org/products/wdi.

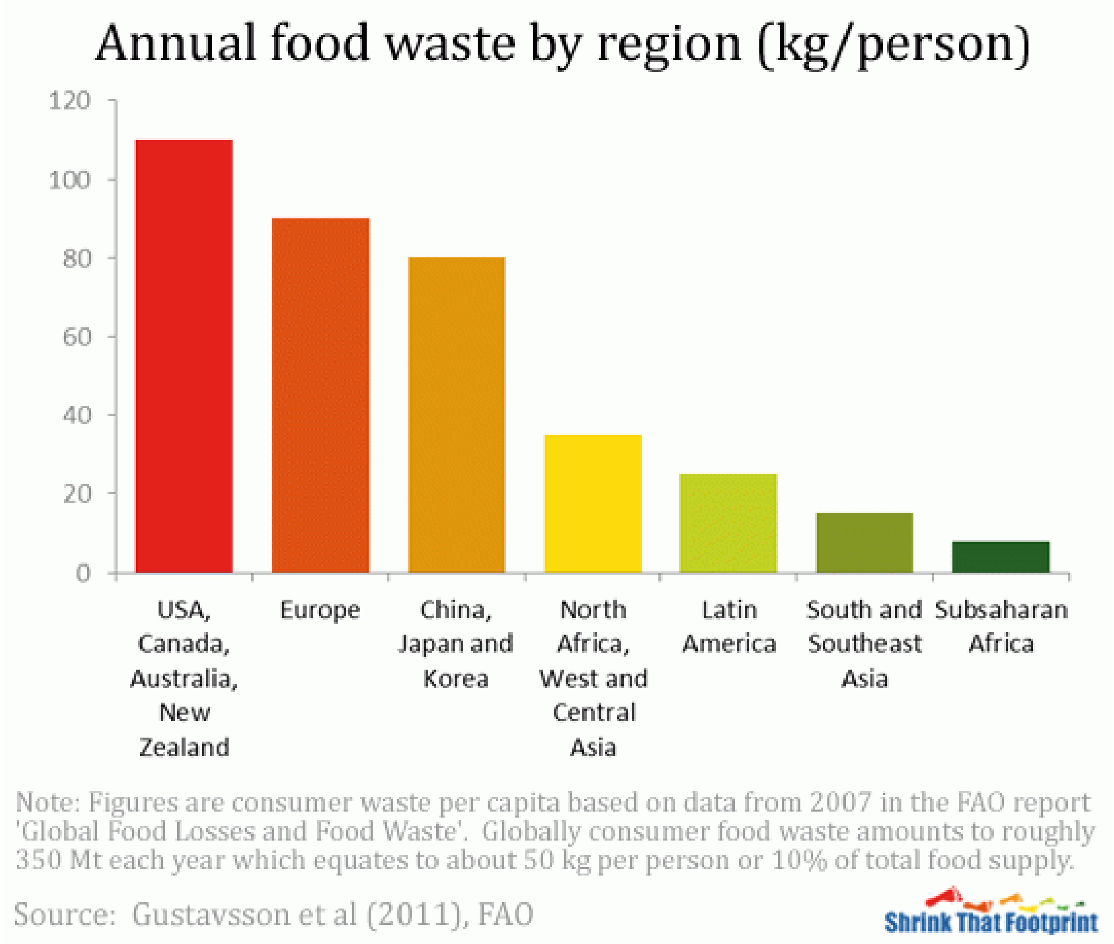
I Z A
World of Labor



Pic pétrolier?

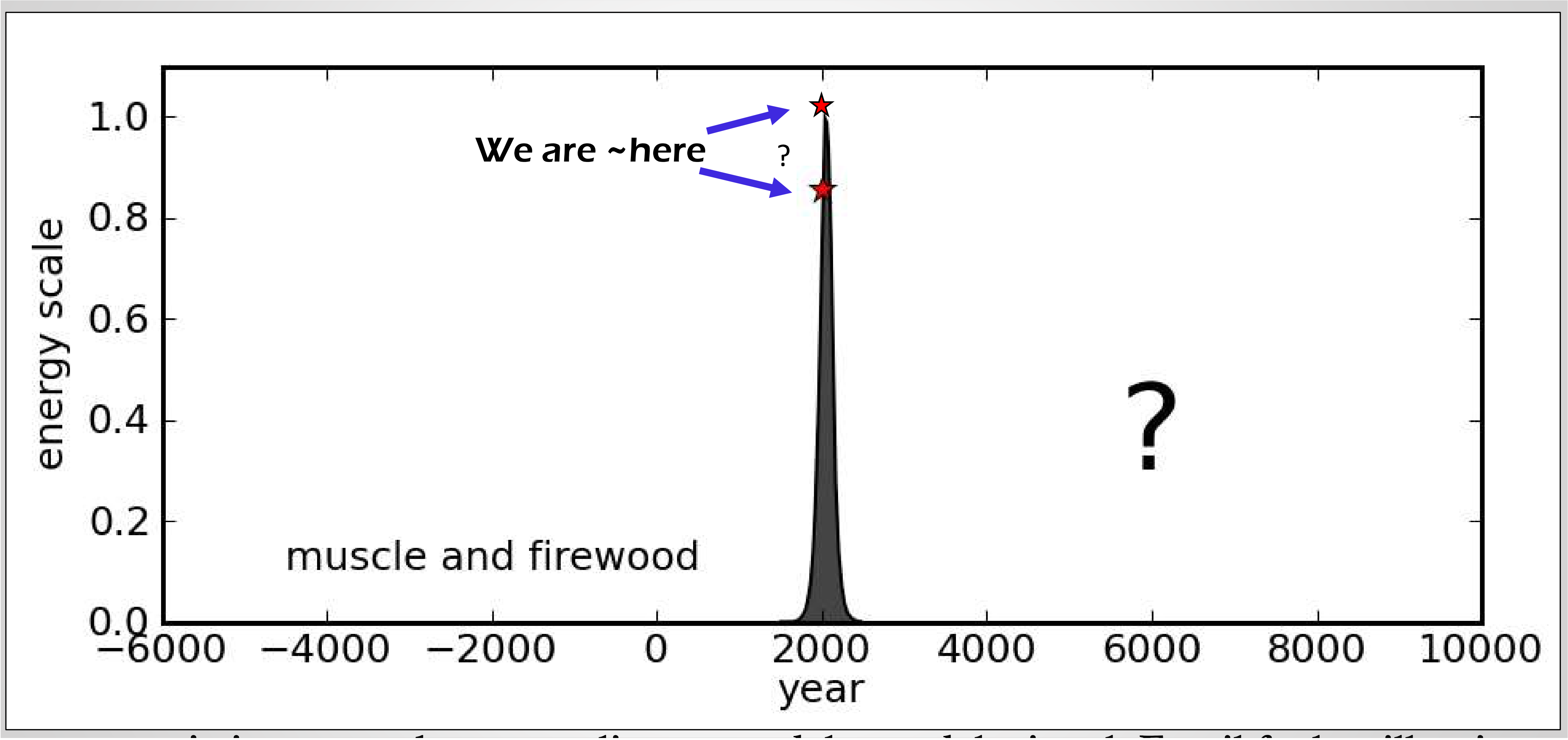




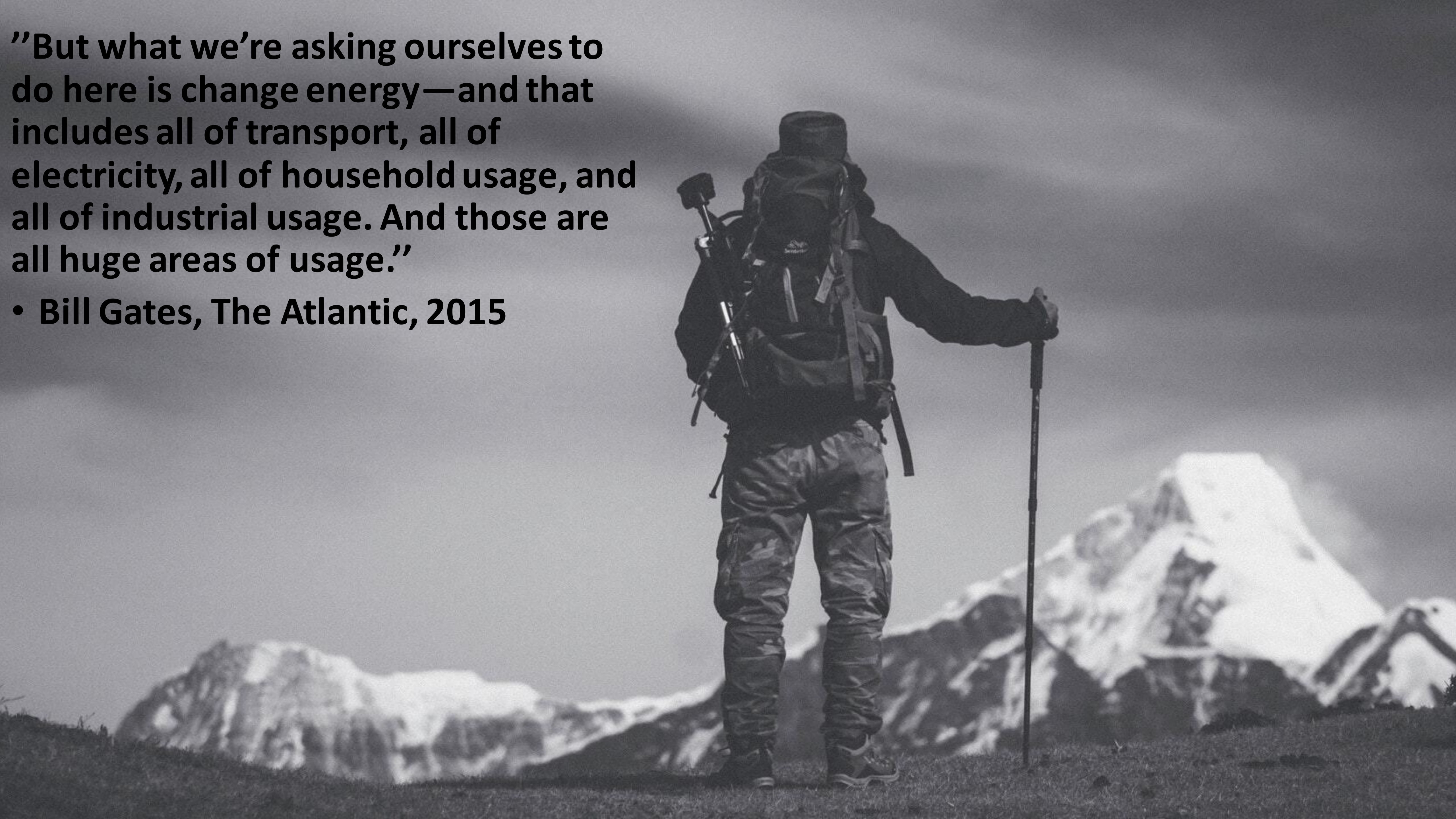


http://shrinkthatfootprint.com/the-big-footprint-of-food-waste

Le “carbon pulse”



N. Hagens, « The human predicament»



''But what we're asking ourselves to do here is change energy—and that includes all of transport, all of electricity, all of household usage, and all of industrial usage. And those are all huge areas of usage.''

- **Bill Gates, The Atlantic, 2015**