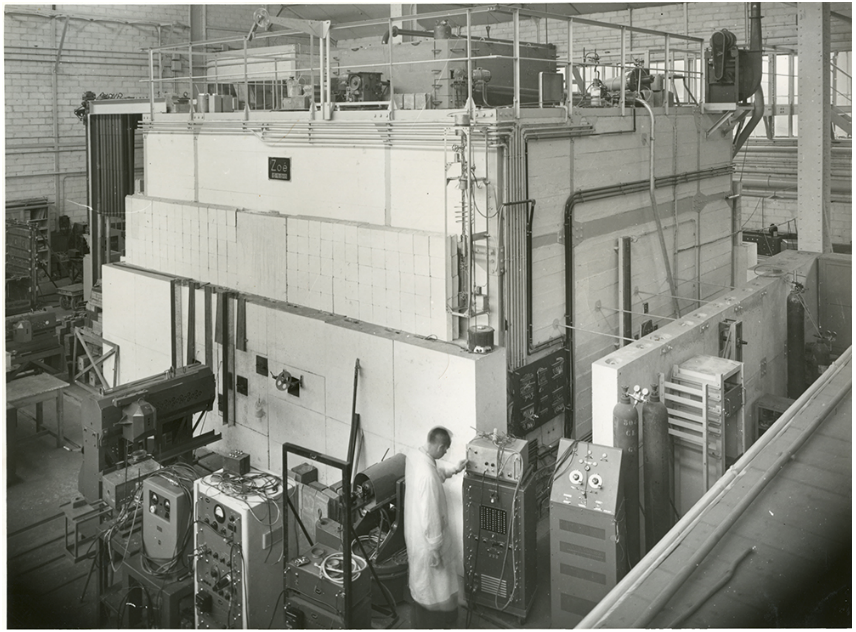
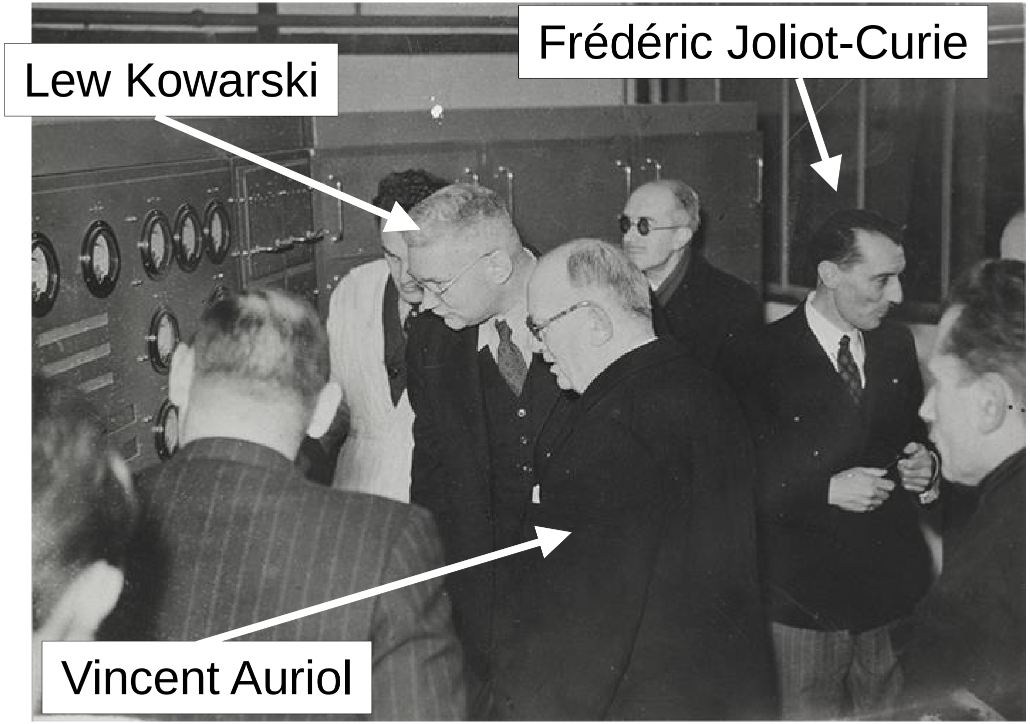
Nuclear energy in France

- October 1945: the Atomic Energy Commision (CEA: Commisariat à l'Énergie Atomique) is created. Its goal is to "pursue fundamental and applied research on atomic energy, to be used for science, industry and defense". Frédéric Joliot-Curie is its first high-commissioner, Raoul Dautry its first general administrator.
- April 1946: after nationalizing ~1700 private electricity companies, the public company EDF (Électricité de France) is created.

Nuclear energy in France

- December 1948: built by Joliot-Curie team at CEA, the first French atomic pile, Zoé (Zéro, Oxyde d’uranium, Eau lourde) goes critical.





Nuclear energy in France

- 1952: Félix Gaillard, member of the governement, presents the first plan for nuclear energy in France. It leads to the development and construction of **9 UNGG reactors (Natural Uranium, Graphite moderator, Gaz cooled)**. 3 of them are dedicated to plutonium production (Marcoule in the south of France) and operated by CEA, 6 are operated by EDF for electricity production (Chinon, St-Laurent, Bugey)

Nuclear energy in France

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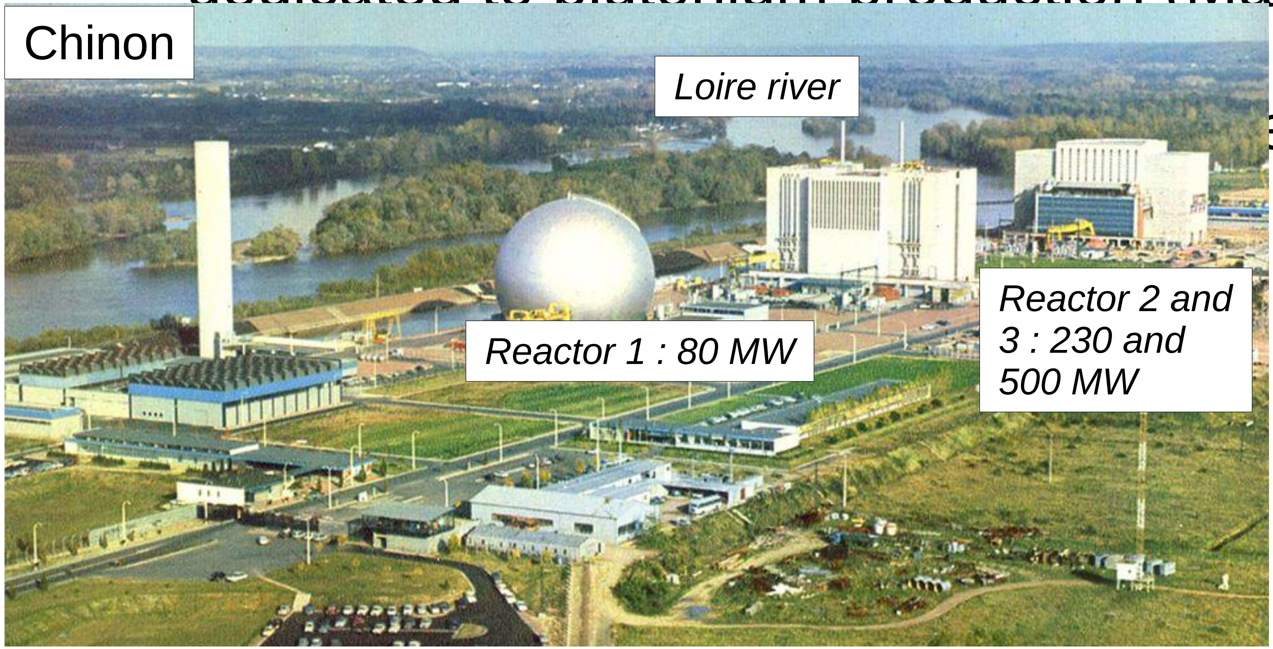

Nuclear energy in France

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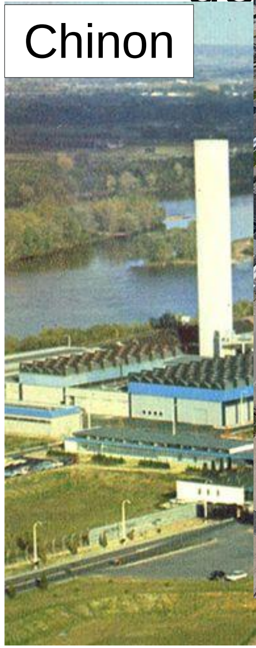

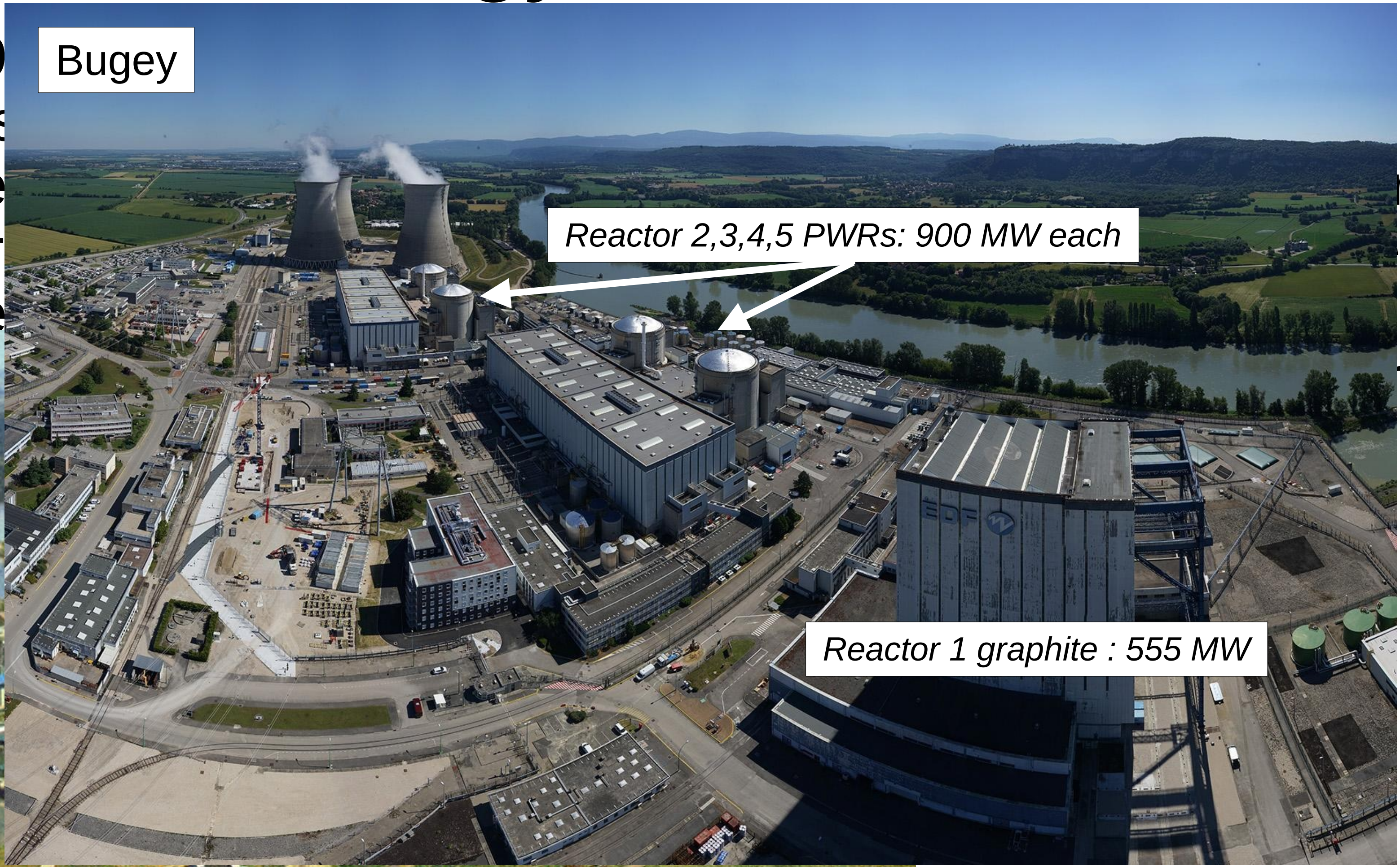

Nuclear energy in France

- In parallel to the Graphite-Gas reactor, CEA starts to investigate other reactor technologies that would consume less uranium.
- In 1953, the first studies on fast reactor are started. Metallic uranium+plutonium is chosen for the fuel, liquid sodium for the cooling. They lead to the construction of small scale prototypes (Harmonie, Masurca, Rapsodie)
- In 1968 starts the construction of the first large scale prototype fast reactor in France, with a net power of 250 MW. It is called **Phénix.**

Nuclear energy in Franc

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Phénix

Nuclear energy in France

- In the **US, the light-water moderated and cooled reactors are actively developed**
  - In August 1957 the Vallecitos (CA) power plant became the electricity generating nuclear power plant. It used a BWR (boiling water reactor) built by **General Electric**
  - In December 1957, the Shippingport (PA) reactor becomes the first electricity generating PWR in the world. It was built by **Westinghouse**, and the PWR design is derived from naval reactor

Nuclear energy in France

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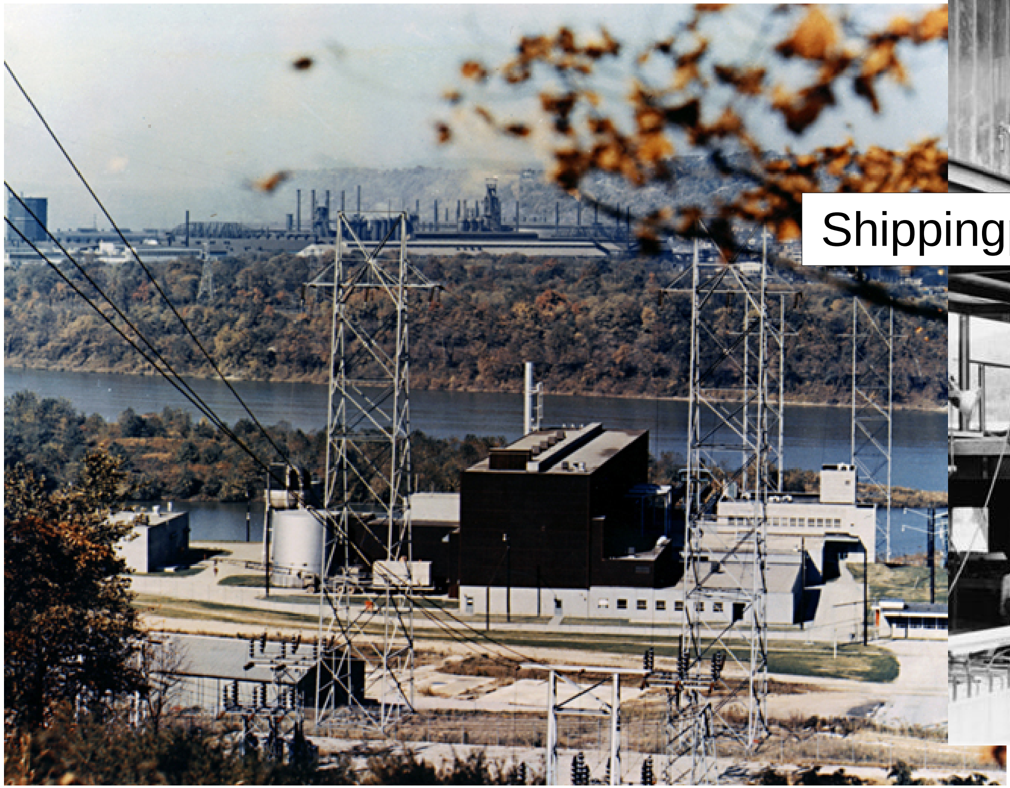
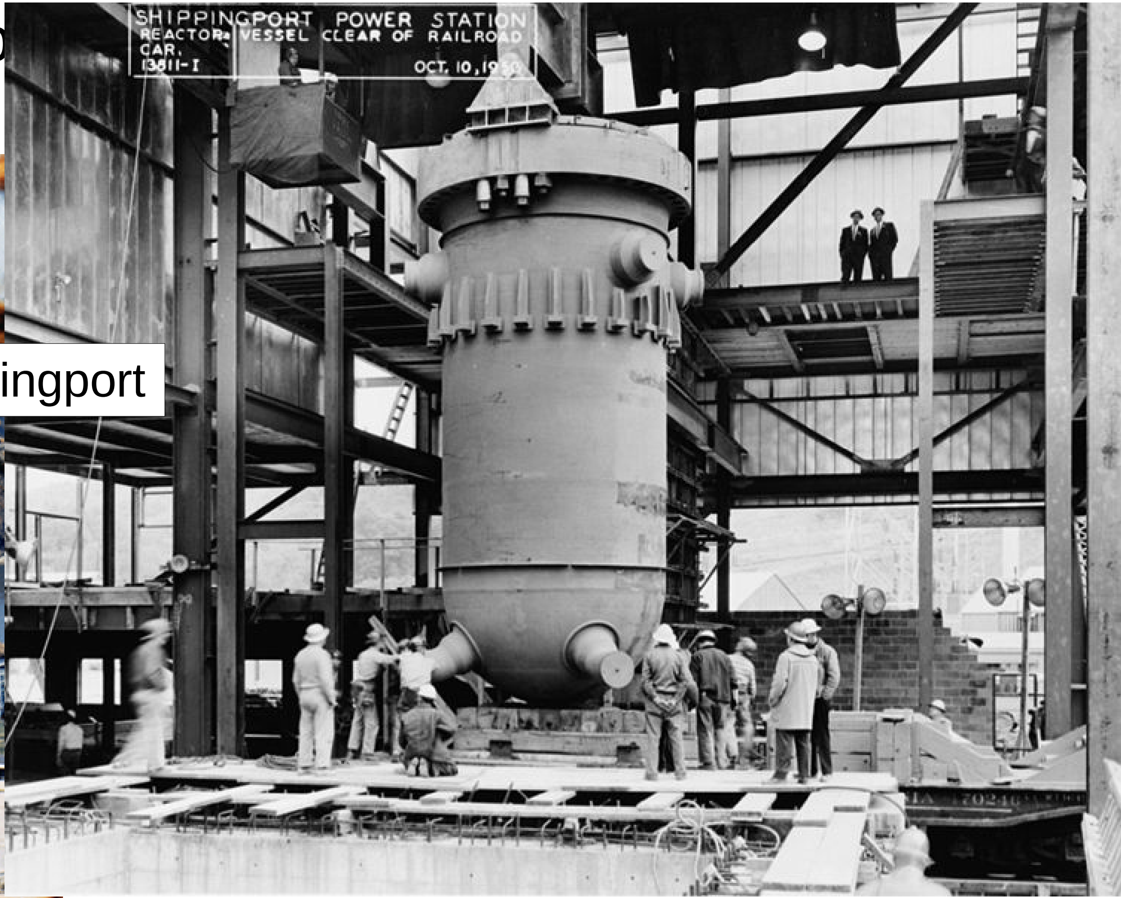




Shippingport

Nuclear energy in France

- In the second half of the 1960s, a “design war” will start in France
- On one side, the supporters of the national UNGG design, CEA mainly
  - It was seen as a tool for national independence, and was also a way to produce easily plutonium for military purposes
- On the other side, the supporters light-water (PWR and BWR) design, EDF
  - EDF built and operated several UNGG reactors and experienced difficulties with them (cooling pipes breakages, partial core meltdown in St Laurent in 1969…)
  - Reactor physics would not allow to go beyond 500 MW with UNGG (the reactor became unstable)

Nuclear energy in France

- In the 1960s, the PWR and BWR technologies started to become commercial products
  - Their power capacity was increasing: Shippingport (PWR) 60 MW, Yankee Rowe (PWR) 167 MW, Indian Point (PWR) 257 MW, Dresden (BWR) 900 MW
  - Their cost was decreasing, and there was enough fuel enrichment capacity to provide slightly enriched uranium
  - They were independent from military considerations (military grade plutonium cannot be produced in light water reactors)

Nuclear energy in France

- Two private companies in France bought design licenses for light-water reactors
  - Schneider and Westinghouse created Framatome (Franco-américaine de constructions atomiques) in 1958 to build PWR
  - CGE (Compagnie Générale d’Électricité) partners with General Electric to build BWR
- The **first 200 MW PWR built in France is located in Chooz**, close to the Belgian border and started in 1967. It was built in partnership by EDF and several Belgian electricity companies.

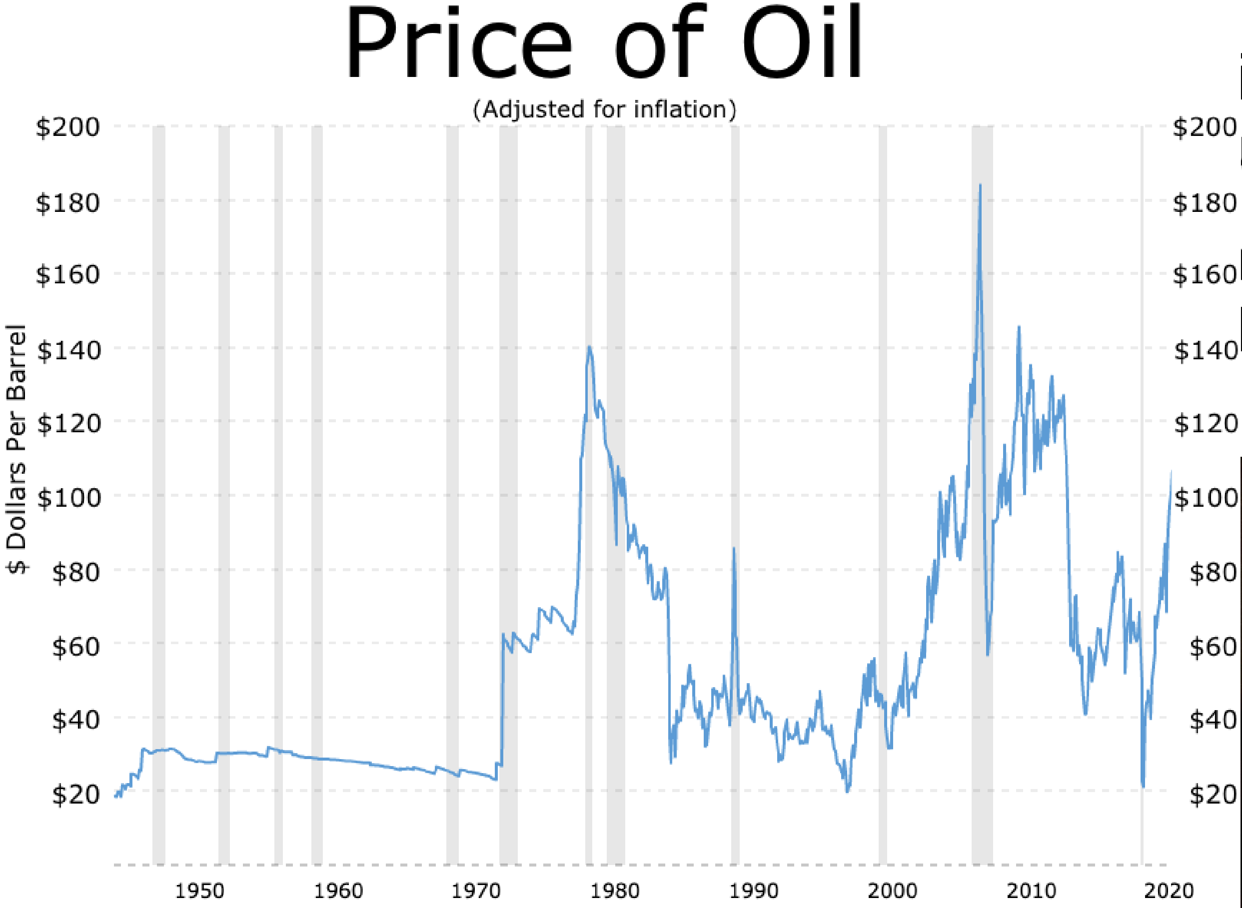
Nuclear energy in France

- In Belgium, a large scale 900 MW PWR is built in Tihange in 1969, in association with EDF
  - The nuclear island of the plant is designed by Framatome, on the model of the US Beaver Valley plant
- The know-how starts to build in Framatome and EDF
- A plan is made by EDF to build several 900 MW PWR and BWR in France
  - EDF would like to diversify its power plants suppliers
  - But the PWR remains cheaper: in 1970, EDF orders 2 reactors for Fessenheim (Alsace) and 4 for Bugey (Ain)

Nuclear energy in France

- Before 1973, the plan was to build a limited number of nuclear power plants, since the oil price were quite low
- An event will change radically the destiny of the French nuclear program: the Yom Kippur War in October 1973 between Israel and the Syria-Egypt coalition.
- Led by King Faisal of Saudi Arabia, the OAPEC (Organization of Arab Petroleum Exporting Countries) decreased production and proclaimed an oil embargo. Oil price increased by 300 %, and remained high even after the embargo was lifted in 1974

Nuclear energy in France



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Nuclear energy in France

- In 1973, ¾ of the French energy supplies relies on importations. An increase in the share of nuclear power is already planned.
- After the Kippur War, a government council led by president Georges Pompidou and prime minister Pierre Messmer validates the construction of **16, 900 MW reactors in the 1973-1978 period.**
  - These are the CP1 reactors (Tricastin, Gravelines. Dampierre, Blayais)
  - They are followed by 10 more CP2 reactors (St-Laurent, Chinon, Cruas)

Nuclear energy in France

- The second oil crisis in 1979 (caused by the Iranian revolution) strengthen the choice of nuclear electricity in France
- But the construction program slows down, as the electricity consumption doesn´t increase as much as predicted.
- Still the following governments (Giscard presidency 1974-1981, Miterrand presidencies 1981-1995) support the continuation of the nuclear program
- Larger reactors are constructed: the P4 design reaches 1300 MW, and the N4 design 1500 MW
  - The N4 design from Framatome is fully independent from the Westinghouse license

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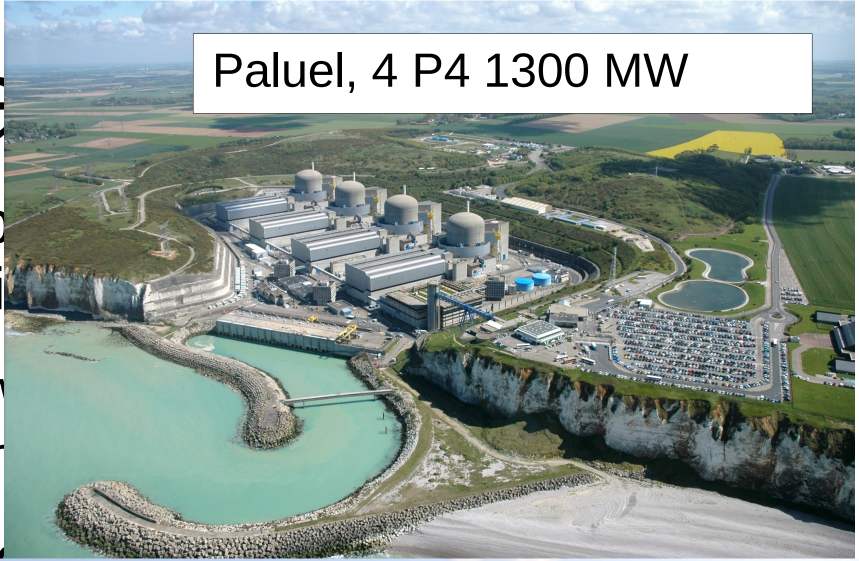
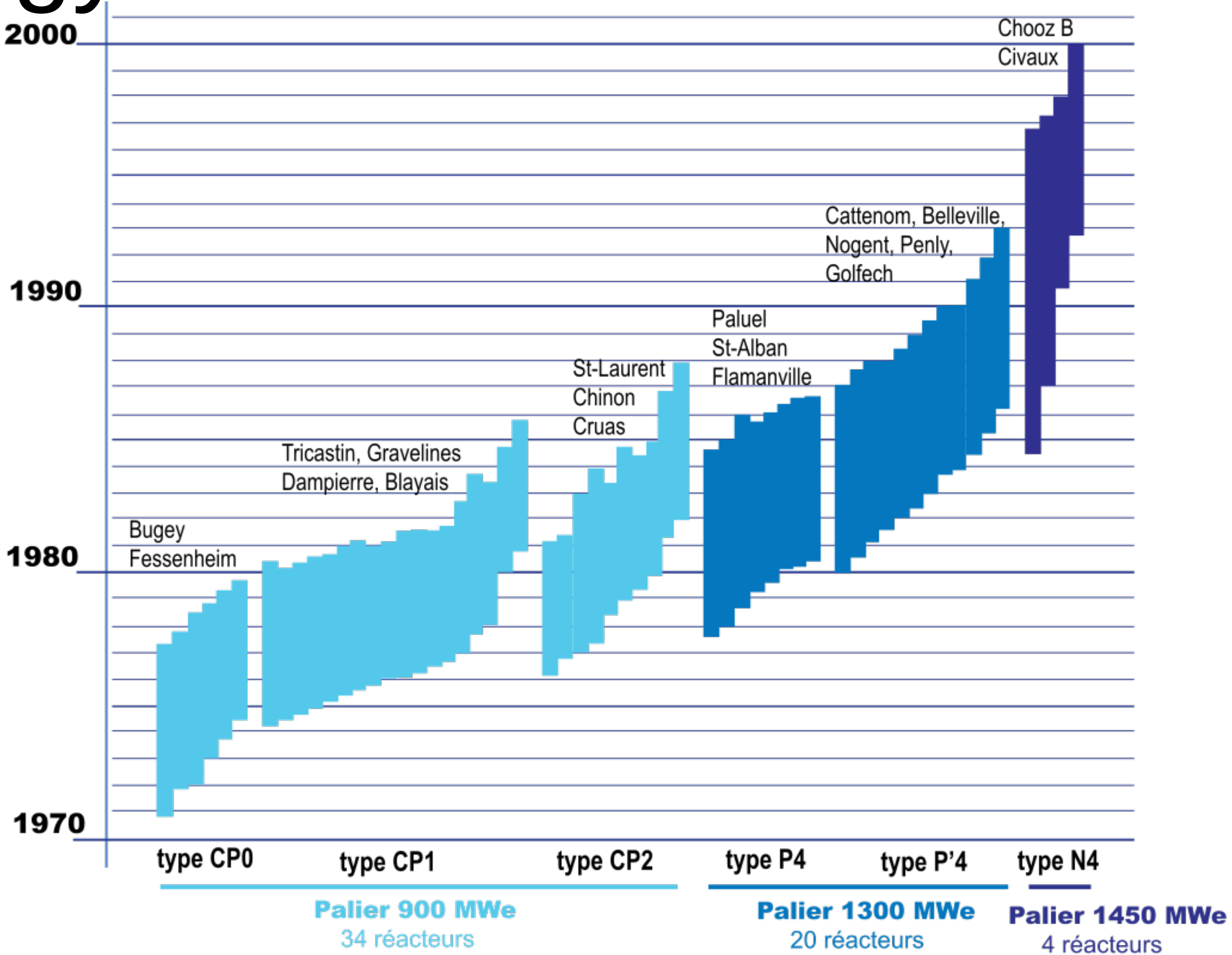


Nuclear energy in France

- In total **58 PWR are constructed in France over 20 years**
- In **2019, 70% of the french electricity came from nuclea**r, 10% from hyrdoelectric power, 8% from solar+wind
- In 2019, with 400 TWh of nuclear electricity, France was the second largest nuclear producer in the world behind the US (800 TWh)



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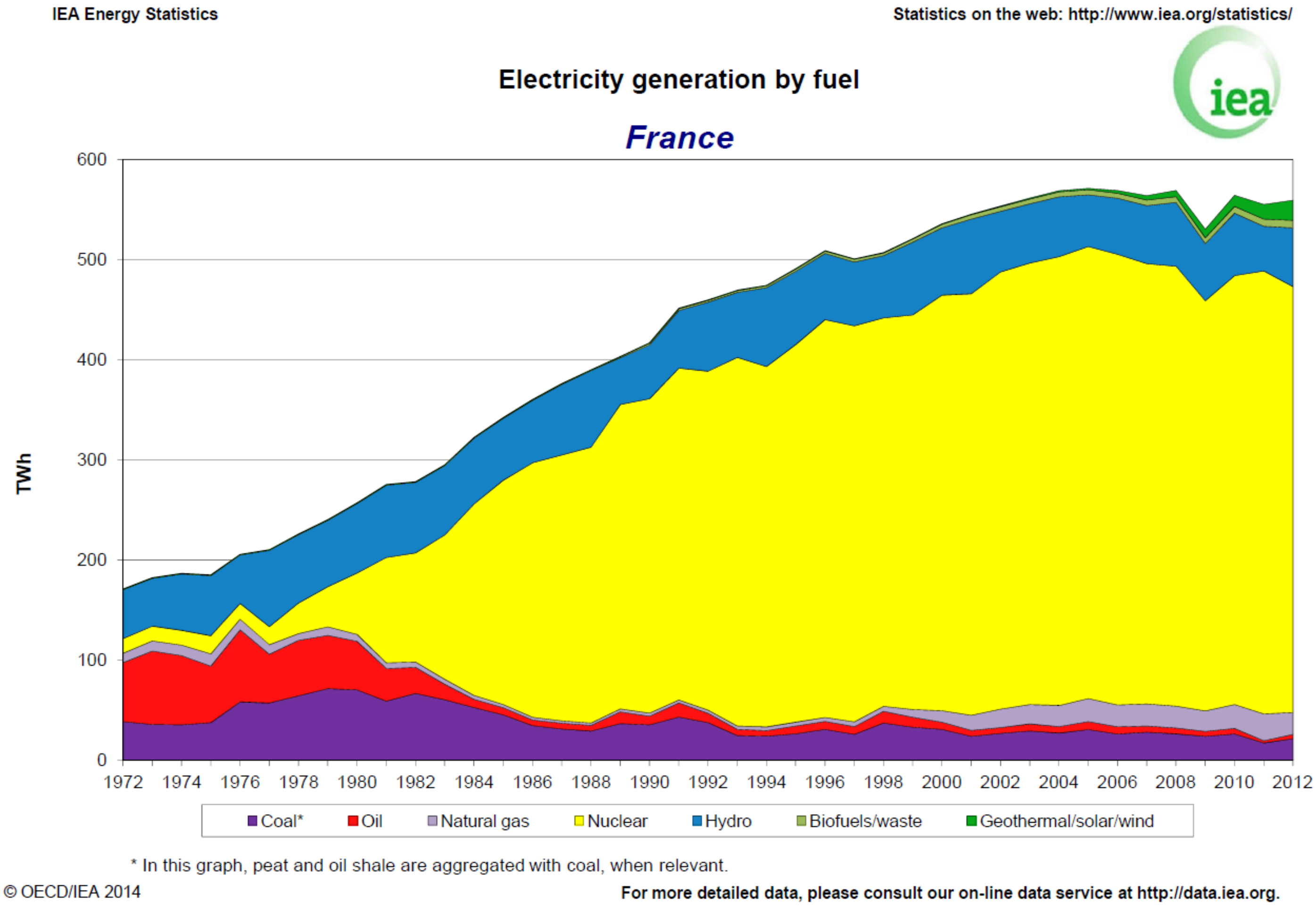
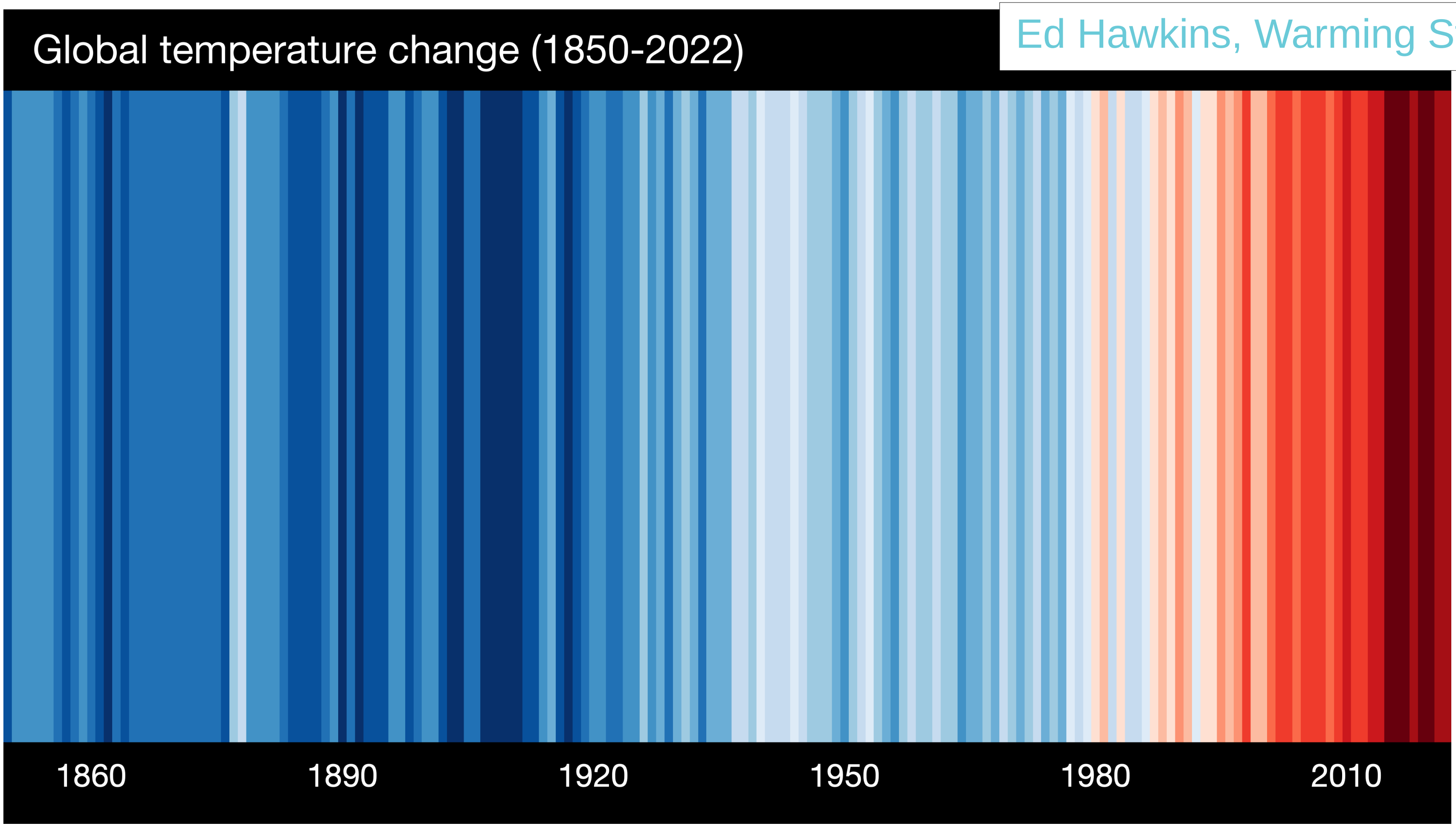


Nuclear energy in France

- The idea with sodium fast reactors was to have them take the relay of PWR reactors
  - Would allow to use all the Uranium content (instead of just U 235)
  - Reduce the minor actinides activity in spent
  - Reduce the dependency on uranium imports: with current amount of natural uranium stored in France, electricity could be supplied for ~1000 years with fast reactors

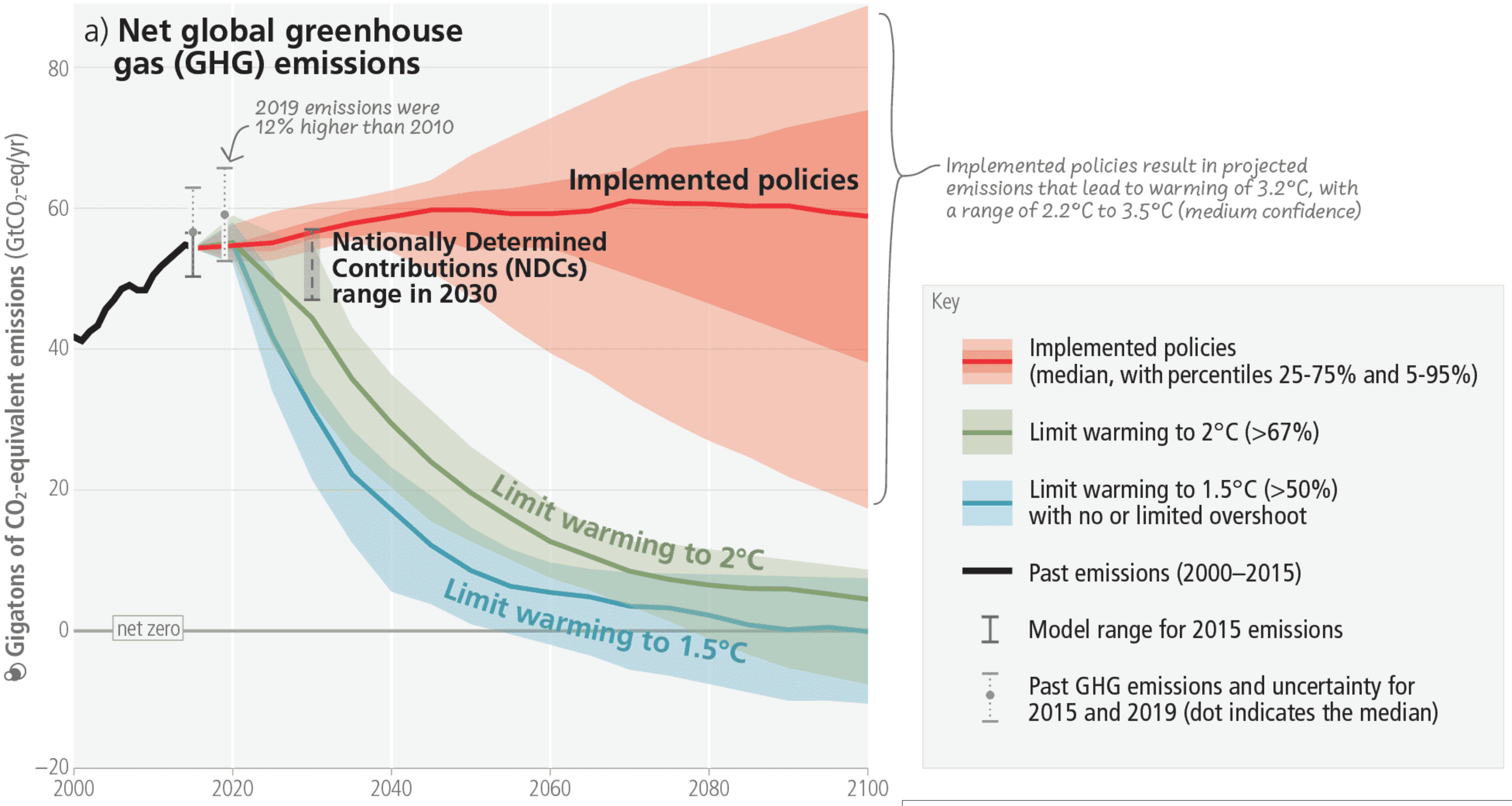
The global context



Ed Hawkins, Warming Stripes

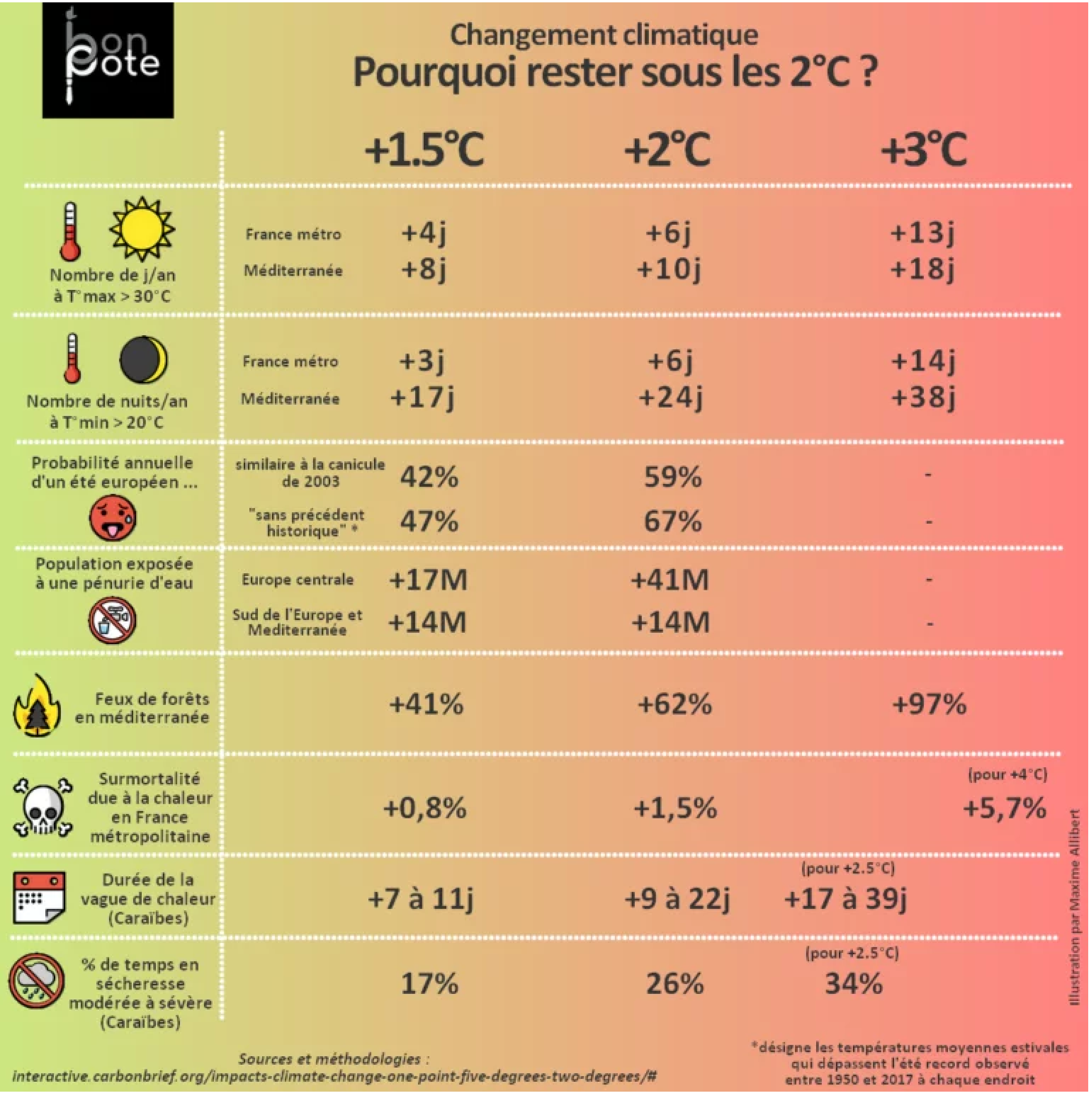
Limiting warming to 1.5°C and 2°C involves rapid, deep and in most cases immediate greenhouse gas emission reductions

Net zero CO_2 and net zero GHG emissions can be achieved through strong reductions across all sectors



IPCC AR6 Summary for Policy Makers

- For continental Europe: more frequent, longer heatwaves (think 2022), coastal flooding, extreme events (remember 2021 floodings)
- This in turn affects agricultural exploitation, city and rural areas livability


bon Pote

Changement climatique

Pourquoi rester sous les 2°C ?

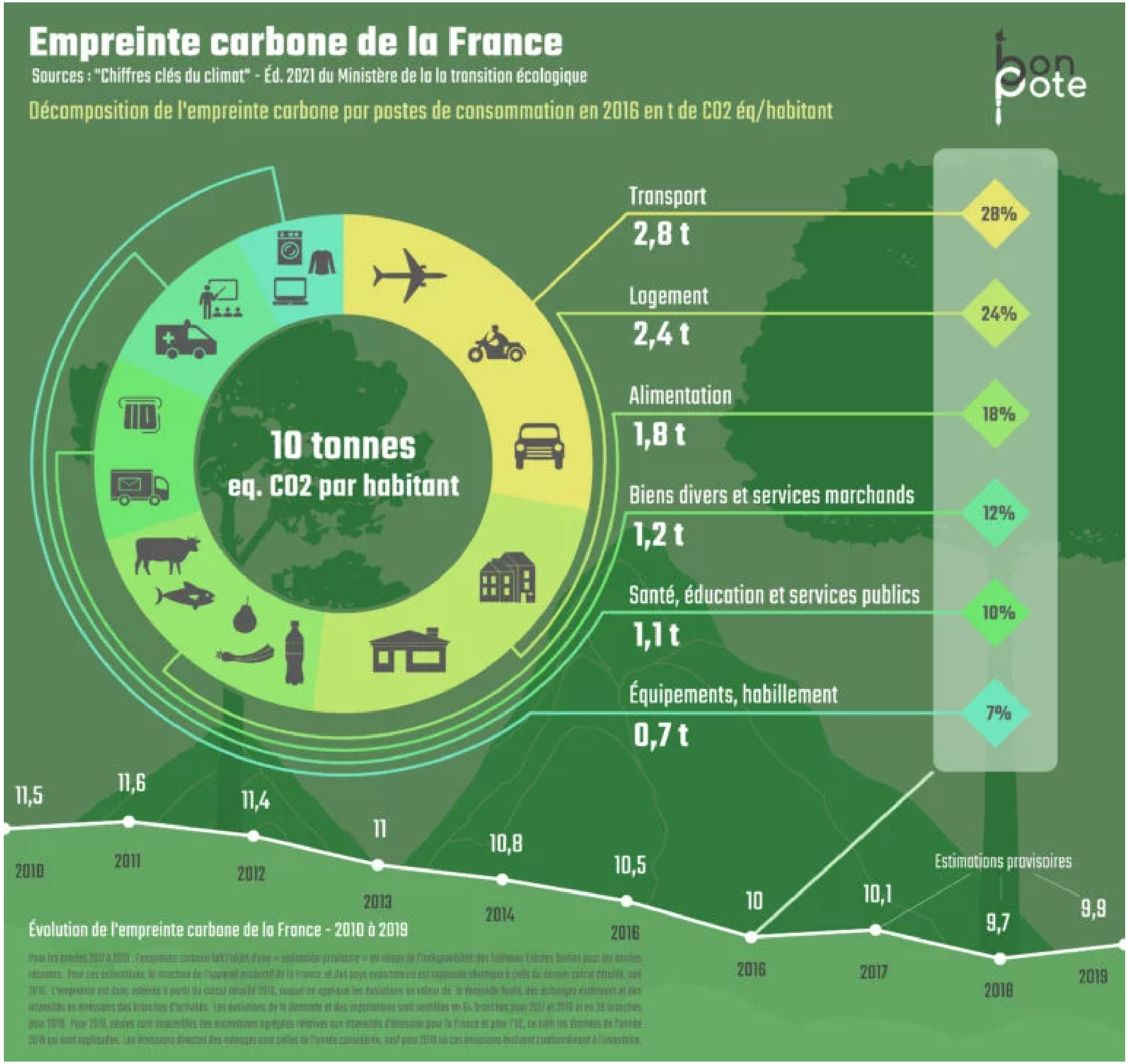
		+1.5°C	+2°C	+3°C
Nombre de j/an à T°max > 30°C	France métro	+4j	+6j	+13j
	Méditerranée	+8j	+10j	+18j
Nombre de nuits/an à T°min > 20°C	France métro	+3j	+6j	+14j
	Méditerranée	+17j	+24j	+38j
Probabilité annuelle d'un été européen ...	similaire à la canicule de 2003	42%	59%	-
	"sans précédent historique" *	47%	67%	-
Population exposée à une pénurie d'eau	Europe centrale	+17M	+41M	-
	Sud de l'Europe et Mediterranée	+14M	+14M	-
Feux de forêts en méditerranée		+41%	+62%	+97%
Surmortalité due à la chaleur en France métropolitaine		+0,8%	+1,5%	(pour +4°C) +5,7%
Durée de la vague de chaleur (Caraïbes)		+7 à 11j	+9 à 22j	(pour +2.5°C) +17 à 39j
% de temps en sécheresse modérée à sévère (Caraïbes)		17%	26%	(pour +2.5°C) 34%

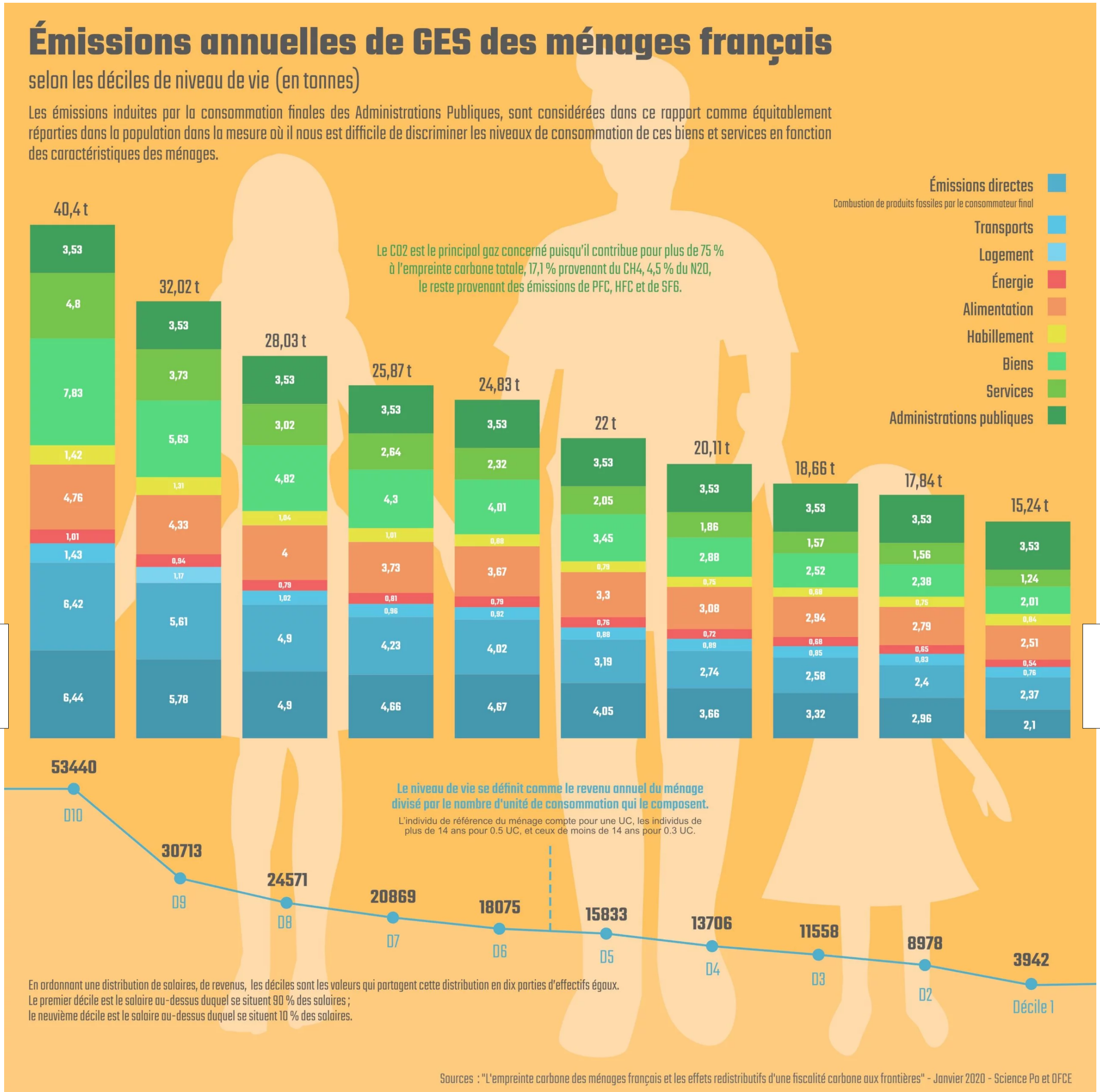
Sources et méthodologies : interactive.carbonbrief.org/impacts-climate-change-one-point-five-degrees-two-degrees/#

*désigne les températures moyennes estivales qui dépassent l'été record observé entre 1950 et 2017 à chaque endroit

Illustration par Maxime Allibert

- Electricity represents ¼ of the final energy consumption in France
- 65 % of the final energy consumption are fossil fuels
- This directly translates in terms of CO2 emissions
- To limit the global temperature rise to 2 Celsius by the end of the century, the carbon footprint must reduce to **2t CO2 / person**

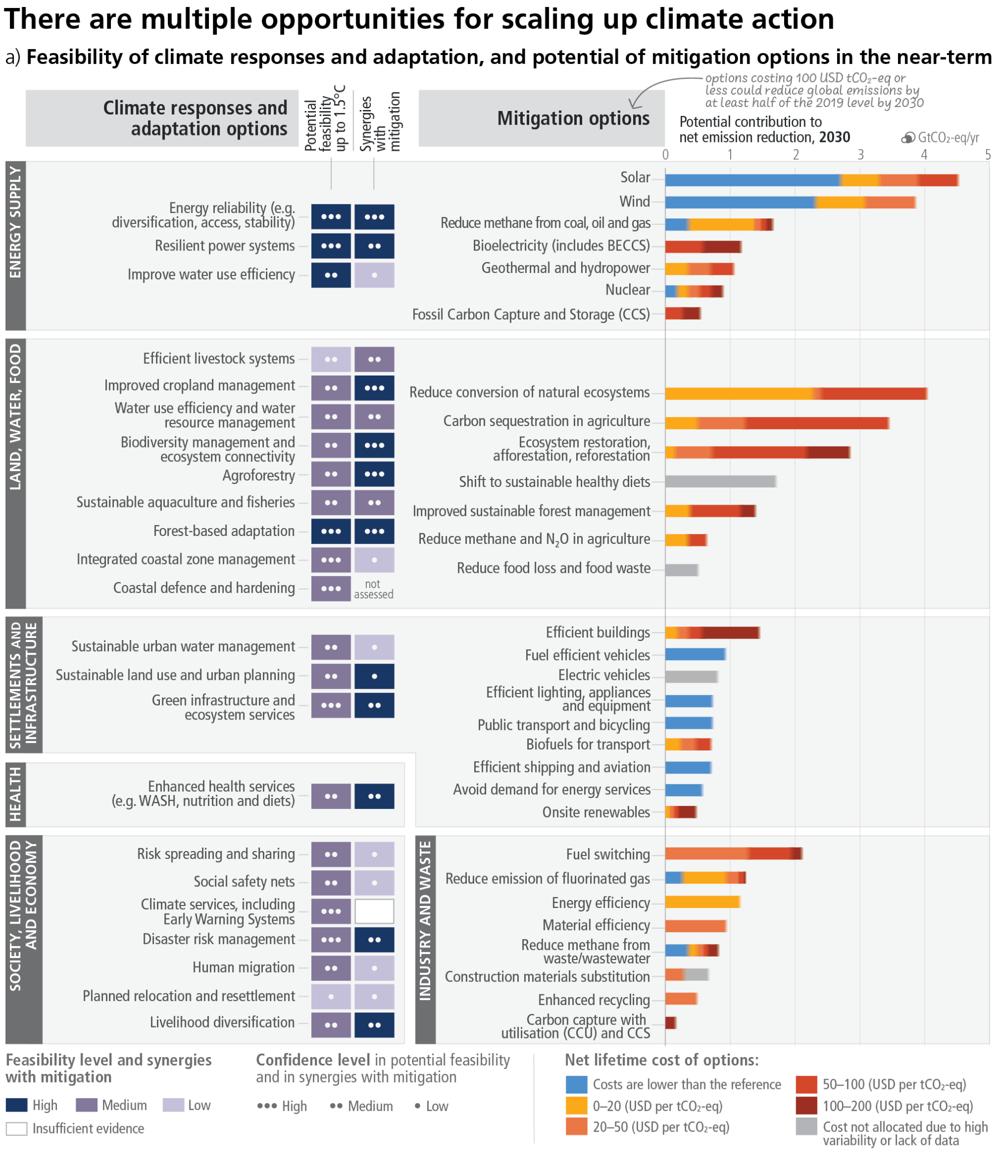




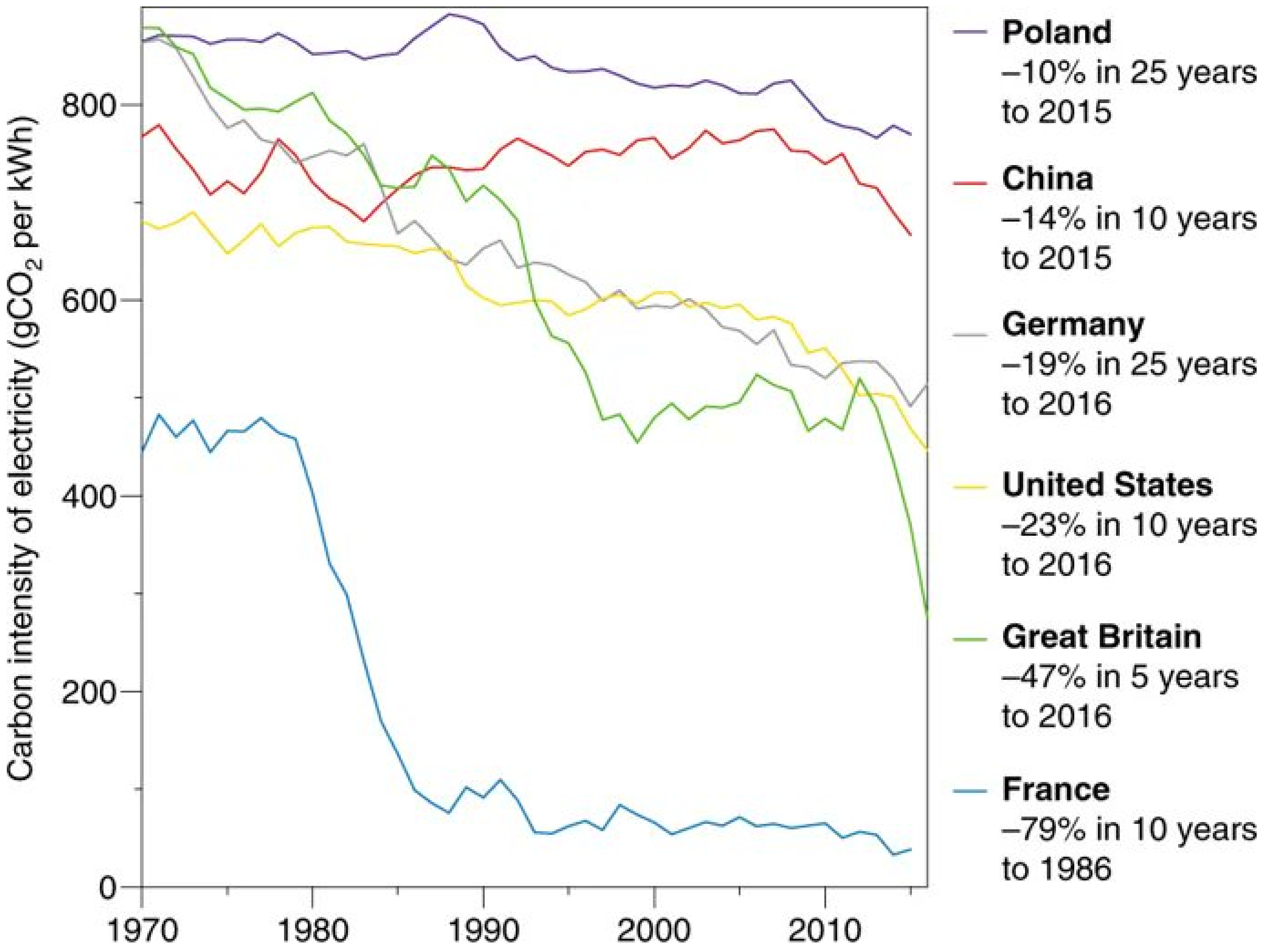
9th decile
(richest 10 %)

1st decile
(poorest 10 %)

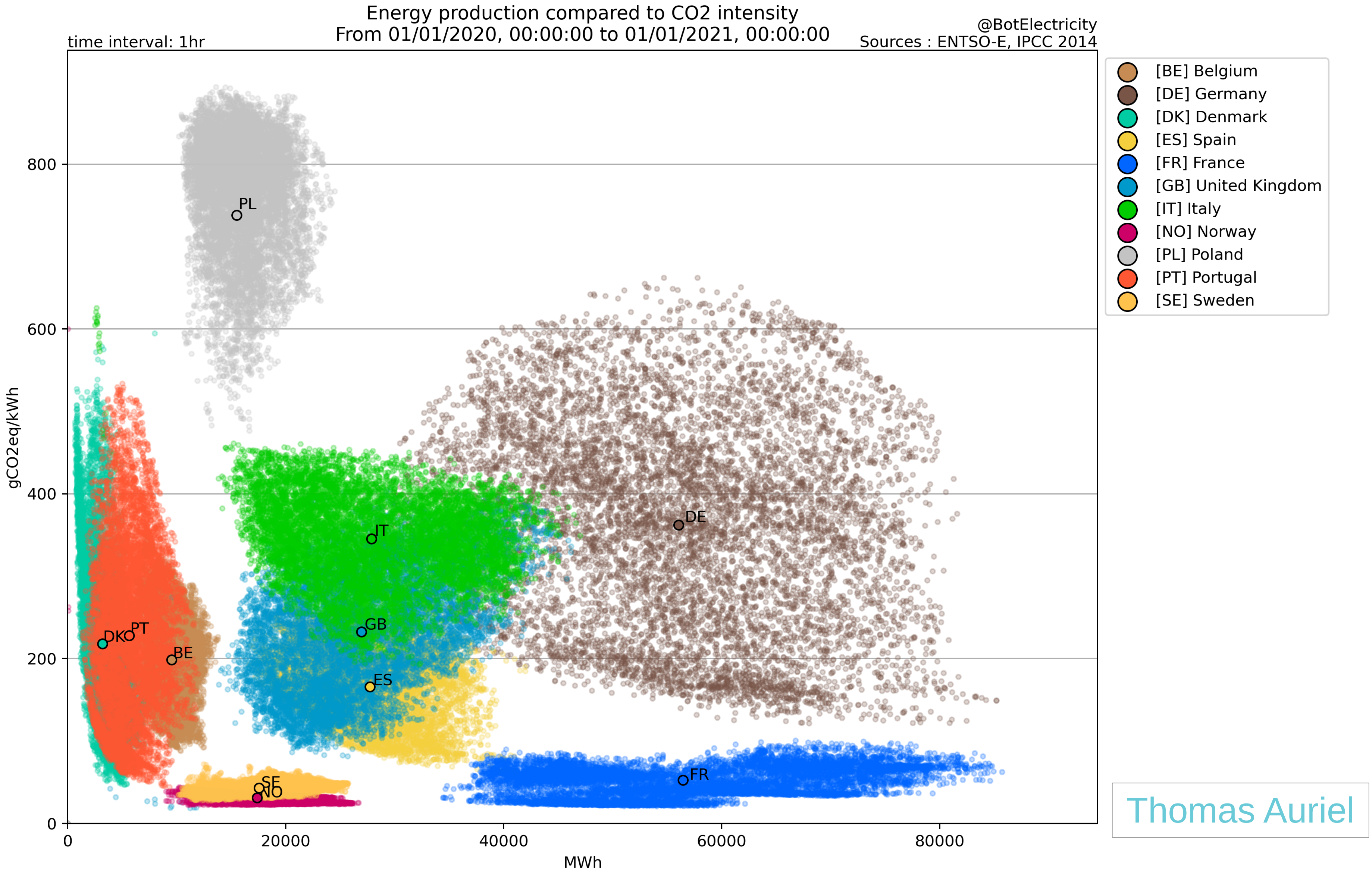
- Increase electrification (electric vehicles, heat pumps...)
- Develop public transportation
- Change diets (plant based)



IPCC AR6 Summary for Policy Makers



Carbon intensity of electricity (gCO2 per kWh)
800
600
400
200
0
1970
1980
1990
2000
2010
Poland
–10% in 25 years to 2015
China
–14% in 10 years to 2015
Germany
–19% in 25 years to 2016
United States
–23% in 10 years to 2016
Great Britain
–47% in 5 years to 2016
France
–79% in 10 years to 1986


Energy production compared to CO2 intensity
From 01/01/2020, 00:00:00 to 01/01/2021, 00:00:00
time interval: 1hr
@BotElectricity
Sources : ENTSO-E, IPCC 2014
gCO2eq/kWh
MWh
0
200
400
600
800
0
20000
40000
60000
80000
PL
IT
DE
GB
ES
DK
PT
BE
SE
NO
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Thomas Auriel