Graphs SATOR - Making the energy transition a success - English version

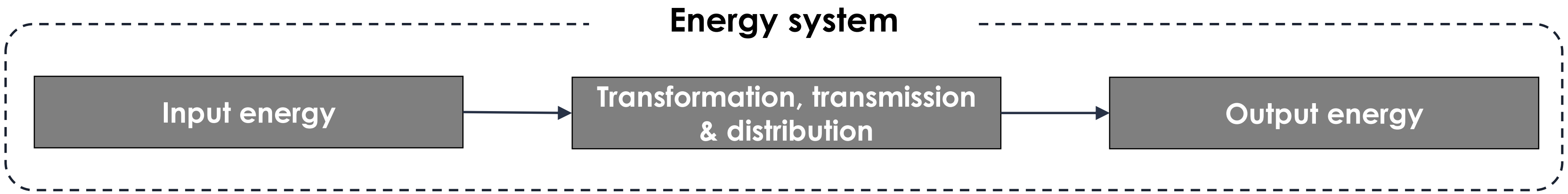
The challenges of a future energy revolution

Energy, how to measure it?

Power X Time = Energy

	Watt (W)	Heures (h)	Watt.hour (Wh)
Light bulb	10 W	100 hours	1 000 Wh = 1 kWh
Washing machine	1000 W	1 hour	1 000 Wh = 1 kWh
A wind turbine	2 000 000 W = 2 MW	Éq. ~2 500 hours / an	~5 000 MWh
A nuclear reactor	1 000 000 000 W = 1 000 MW	Éq. 7 000 hours / an	7 000 000 MWh = 7 TWh
	X 500	X 3	X 1500

What is an energy system?

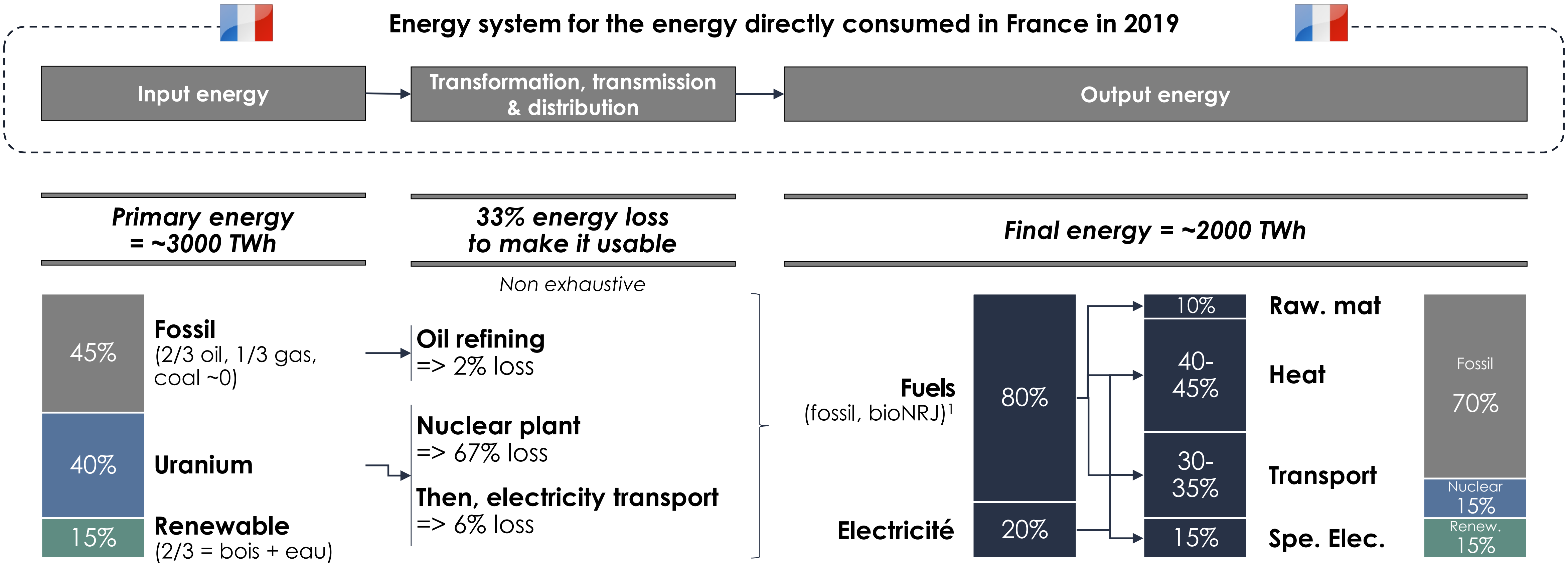


Energy system

Input energy → Transformation, transmission & distribution → Output energy

Human body	- Food	- Digestion - Blood	- Breathing - Running - Thinking
Human society	***Primary energy*** - Sun ▪ Plants ▪ Animals ▪ *Fossil energies* ▪ Water ▪ Wind - Underground, nuclear	- Transformation : refining, gas treatment, etc. - Conversion into another energy vector (e.g. electricity) - Grid: transmission, distribution, storage	***Final energy*** - All the energy bills - Several uses: heating, cooling, lighting, moving, communicating, etc.

The French energy system



Energy system for the energy directly consumed in France in 2019

Input energy → Transformation, transmission & distribution → Output energy

Primary energy = ~3000 TWh	*33% energy loss to make it usable*	*Final energy = ~2000 TWh*

Non exhaustive

- 45% **Fossil** (2/3 oil, 1/3 gas, coal ~0) → **Oil refining** => 2% loss
- 40% **Uranium** → **Nuclear plant** => 67% loss
  Then, electricity transport => 6% loss
- 15% **Renewable** (2/3 = bois + eau)

Fuels (fossil, bioNRJ)[1]: 80%

Electricité: 20%

10%	**Raw. mat**	Fossil 70%
40-45%	**Heat**	Nuclear 15%
30-35%	**Transport**	Renew. 15%
15%	**Spe. Elec.**	

Sources : https://negawatt.org/scenario-2022/sankeys/2019-simplifie ; Note : (1) réseau de chaleur inclus par simplicité

1 liter of oil is a super power!

1 person biking
for 1 day

1 kWh → × 10 → 10 kWh

1 litre of oil

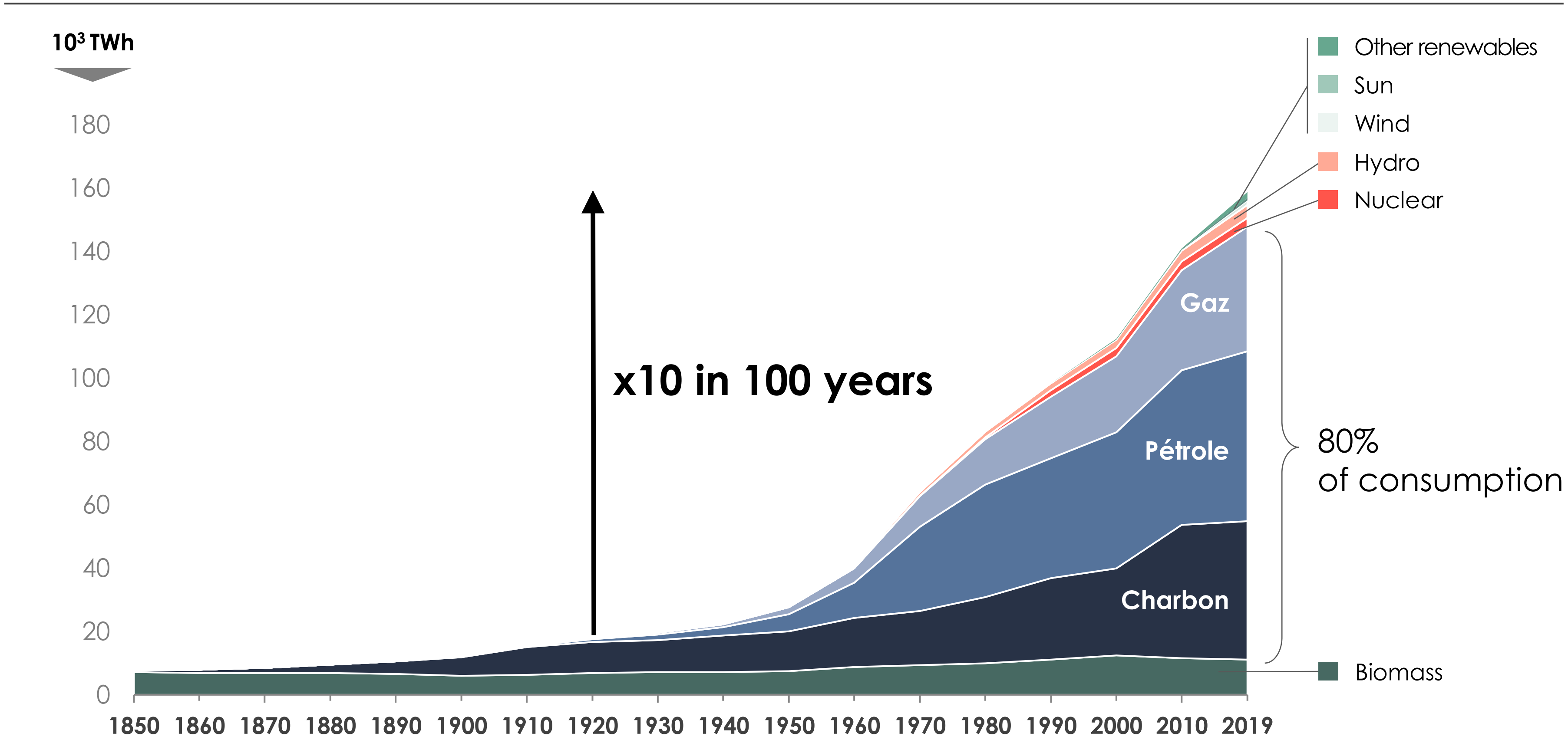
10 people for 1 day:
10 x 10 €/h x 8h

800 € ← × 400 ← 2 €

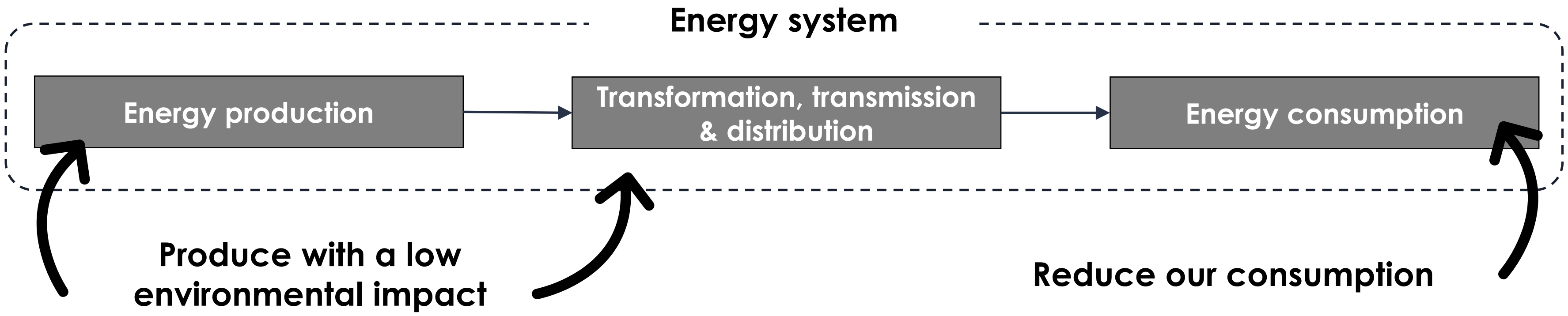
1 litre of oil

World: primary energy consumption has been multiplied by 10 in 100 years ; 80% comes from fossil fuels

Global energy consumption by type | 1850 – 2019, primary energy



Sources: BP Statistical Review of World Energy, Vaclav Smil: Energy Transitions: Global and National Perspectives, Our World in Data, CDIAC, analyses Carbone 4



Energy system

Energy production

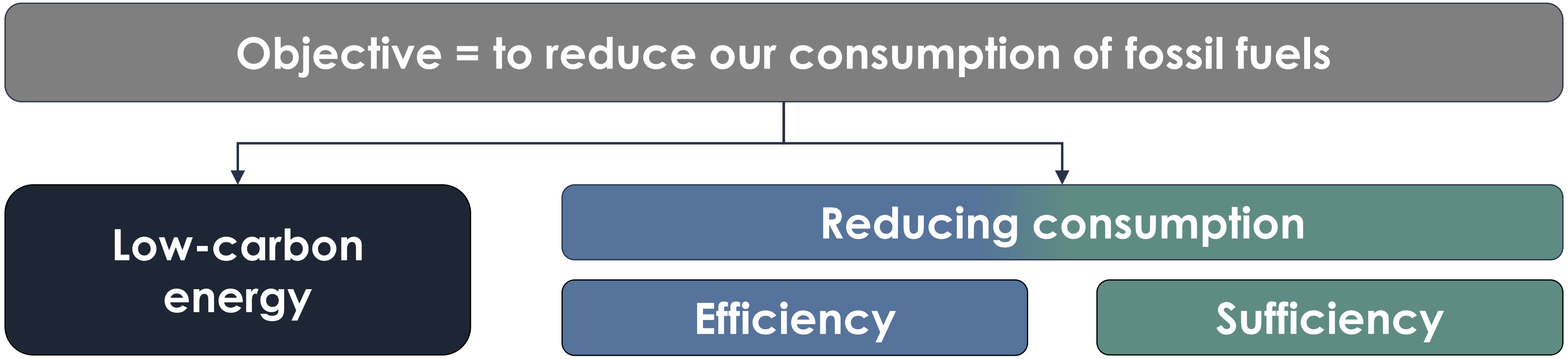
Transformation, transmission & distribution

Energy consumption

Produce with a low environmental impact

Reduce our consumption

Climate: 3 big levers to meet these challenges



Objective = to reduce our consumption of fossil fuels

Low-carbon energy

Reducing consumption

Efficiency

Sufficiency

	Low-carbon energy	Efficiency	Sufficiency
Objective	***« I substitute »***	***« I improve » (Given the same need)***	***« I question the need »***
Illustration with transport	➤ **Electric cars** ➤ **Biofuels** (not all!)	➤ Improve the **engine performance**	**Less fast**: reduce speed limits, bike > car **Less far** : train > plane **Less**: telecommuting
	50%	**50%**	
	« easiest »		**« top priority »**

Note: (1) 1/3 of greenhouse gas emissions come from other sources than fossil fuels, but the logic of the 3 levers remains applicable; (2) the x% are calculated from the average of Ademe's S2 and S3 scenarios (Transition(s)).

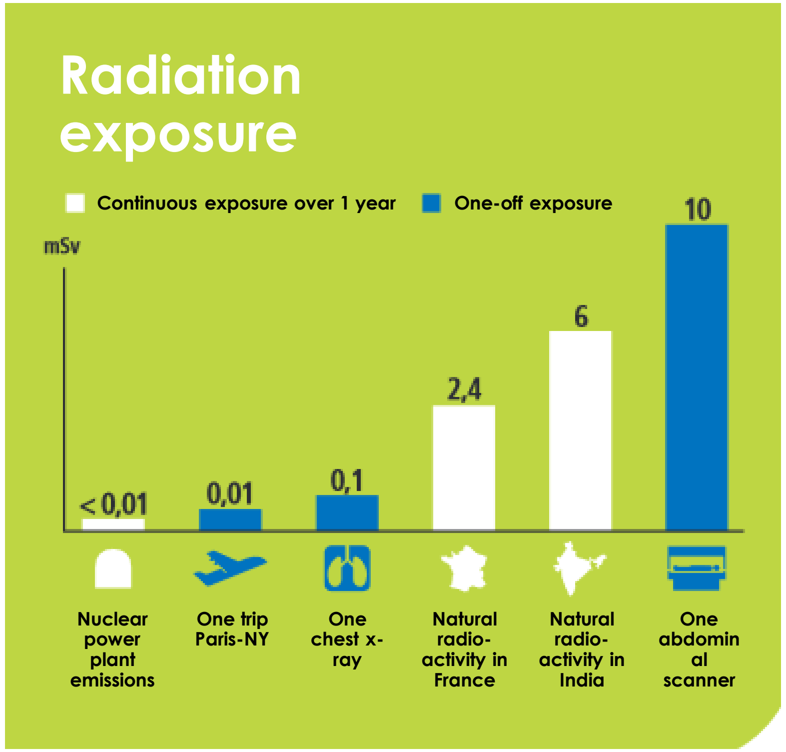
How to assess and compare the energies?

	Indicators *In life cycle*	**Raw materials Extraction & transformation**	**Transport & distribution**	**Usage**	**End of life**	**Example : 1 MWh of natural gas**
Planet boundaries	**Greenhouse gases** (energy)	**Quantity of energy X carbon intensity of energy => $kgCO_2e$**				**200**
	Critical materials	**Kg**				**Not significative**
	Land occupation (biodiversity, acceptability)	**m^2**				**0,1**
Economy	**Total costs**	**€**				**20 à 100€**
	% « local » added value (local jobs, NRJ dependance)	**%**				**< 50%**
Other specific dimensions						**Local pollution** **Social**

Sources : ADEME, ONU, IRENA, RTE

Nuclear power, between passion and reason

What is radioactivity?



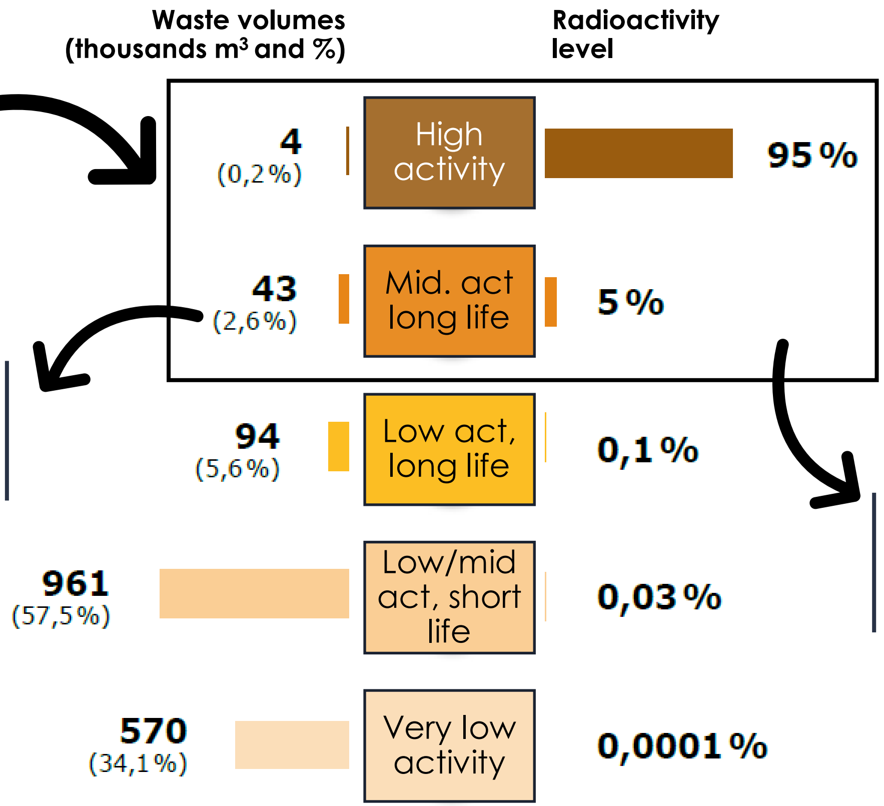
Source: IRSN

And what about radioactive waste?

Stock of nuclear waste in France, by category (2019)

Most hazardous waste: a lot of ionizing radiation for a long time

~15 Olympic-sized pools



Waste volumes (thousands m³ and %)		Radioactivity level
4 (0,2 %)	High activity	95 %
43 (2,6 %)	Mid. act long life	5 %
94 (5,6 %)	Low act, long life	0,1 %
961 (57,5 %)	Low/mid act, short life	0,03 %
570 (34,1 %)	Very low activity	0,0001 %

Deep geological disposal (Cigéo project)
To bury them underground, 500m deep, without the need for human intervention. The site would operate for 100 years before being closed.

Radioactive between 31 and 100,000 years

Sources : RTE, Futurs Energétiques 2050, Andra

Nuclear conclusion: 5-indicator dashboard - focus on environmental indicators

Use → **1 MWh of electricity**

Indicators *In life cycle*	**Units**	**Natural gas**	**Existing nuclear**	**New nuclear**
Greenhouse gases (energy)	$kgCO_2e$	**~450**	**~10**	**~10**
Critical materials	**Kg**	**Not significative**	**Not significative**	**Not significative**
Land occupation (biodiversity, acceptability)	**m^2**	**0,2**	**0,1**	**0,1**
Total costs	**€**	**40 à 200€**	*The economic components will be covered in the course on the electricity mix.*	
% « local » added value (local jobs, NRJ dependance)	**%**	**< 50%**		
Other specific dimensions	**-**	**Local pollution** **Social**	**Accident risk** **Waste** **Climate: cooling water**	

Sources: ADEME, ONU, IRENA, RTE

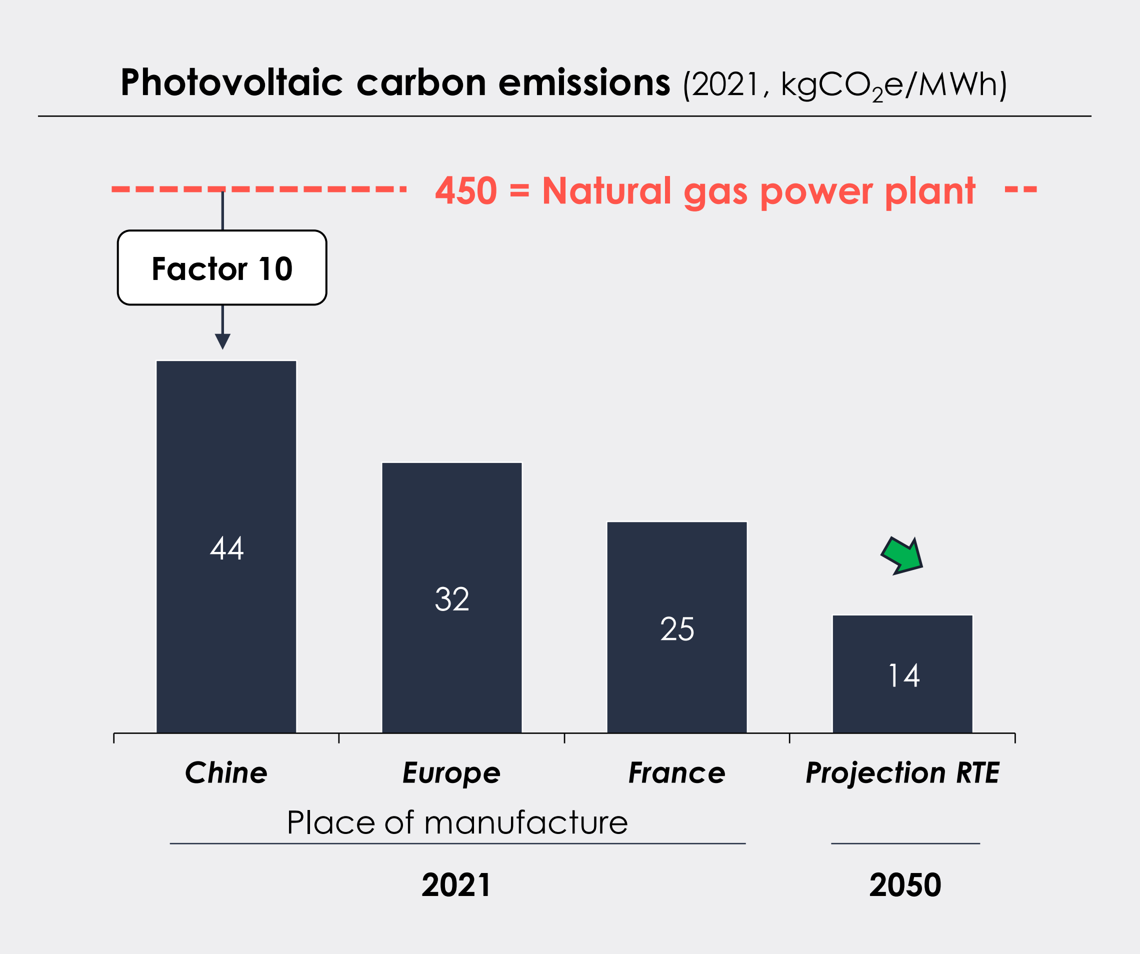
Electric renewables, zero defects?

Hydroelectricity: what are the environmental impacts?

Use →		1 MWh of electricity	
Indicators *In life cycle*	**Units**	**Natural gas**	**Hydraulics**
Greenhouse gases (energy)	$kgCO_2e$	~450	~10
Critical materials	Kg	Not significative	Not significative
Land occupation (biodiversity, acceptability)	m^2	0,2	10
Total costs	€	60 à 220€	*The economic components will be covered in the course on the electricity mix*
% « local » added value (local jobs, NRJ dependance)	%	< 50%	
Other specific dimensions	-	Local pollution Social	Climate: river flow decreases by -10/-40%

Sources: ADEME, ONU, IRENA, RTE

Myth #1: The carbon footprint of PV panels is not good enough to decarbonize our already low-carbon electricity mix



Sources: ADEME, AIE, RTE

Wind turbines: some key figures

Characteristics	Unit	Onshore wind	Offshore wind
Power	MW	**3**	**10**
Height	meters	150	250
Operating time	Nb hours/year	**2500**	**3500**
Energy production	MWh	**7500**	**35000**
Consumption equivalent	Nb citizens	200	1000

Enjoy stronger, steadier and higher winds than on land

A380 wingspan = 80m
Tour Eiffel = 330 m

Sources: CDE, WindEurope, MTE

Conclusion electric renewables: 5-indicator dashboard - focus on environmental indicators

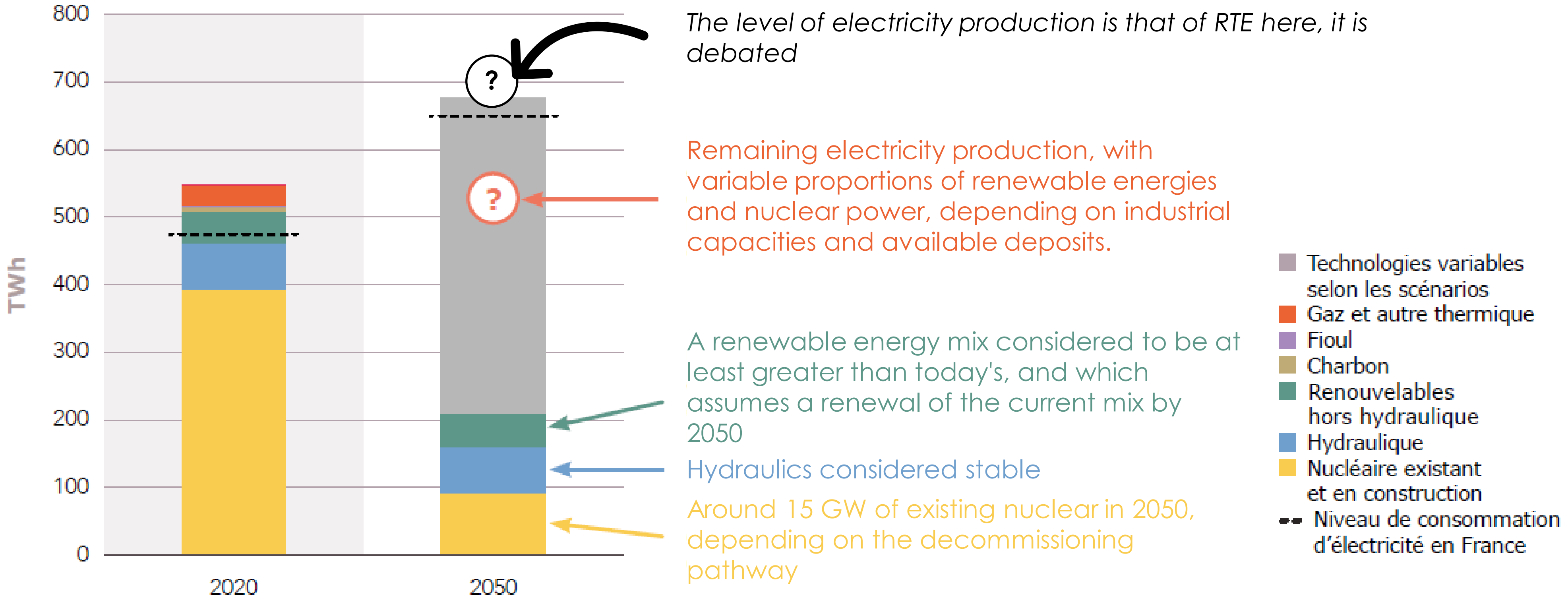
	Use →	1 MWh of electricity						
Indicators *In life cycle*	**Units**	**Natural gas**	**Existing nuclear**	**New nuclear**	**Hydraulics**	**Photovoltaics** (ground, roof)	**Onshore wind**	**Offshore wind**
Greenhouse gases (energy)	kgCO$_2$e	~450	~10	~10	~10	~40 *Further decline*	~10	~10
Critical materials	Kg	Not significative	Not significative	Not significative	Not significative	Next-generation rare earths?	Not significative	A little rare earth
Land occupation (biodiversity, acceptability)	m^2	0,2	0,1	0,1	10	10	2	2
Total costs	€	60 à 220€	*The economic components will be covered in the course on the electricity mix*					
% « local » added value (local jobs, NRJ dependance)	%	< 50%						
Other specific dimensions	-	Local pollution Social	Accident risk Waste Climate: cooling water		Climate: river flow decreases by -10/-40%	Variable	Variable	Variable

Sources: ADEME, ONU, IRENA, RTE

Electricity mix: nuclear VS renewables

The terms of the debate: 2/3 of electricity generation in 2050 will be decided today

Outlook for electricity generation (2020-2050, TWh)



The level of electricity production is that of RTE here, it is debated

Remaining electricity production, with variable proportions of renewable energies and nuclear power, depending on industrial capacities and available deposits.

A renewable energy mix considered to be at least greater than today's, and which assumes a renewal of the current mix by 2050

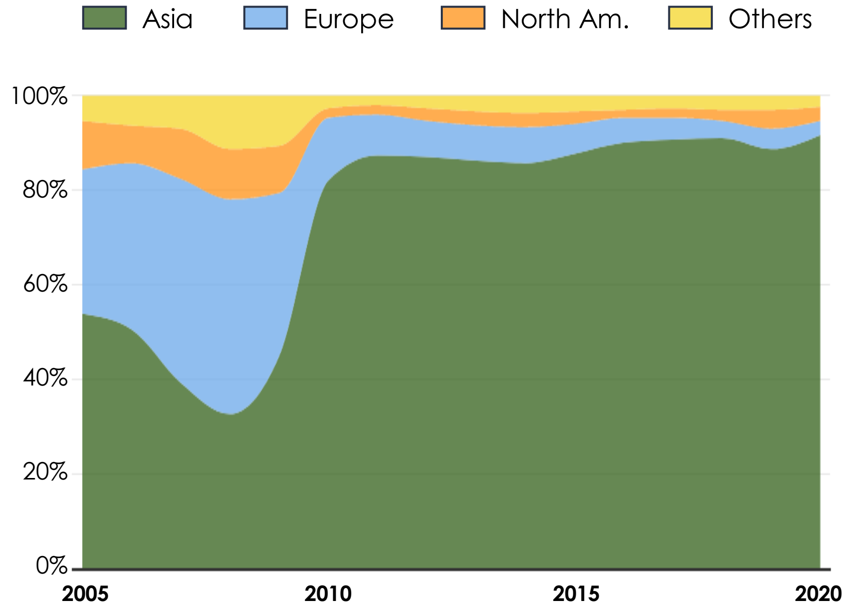
Hydraulics considered stable

Around 15 GW of existing nuclear in 2050, depending on the decommissioning pathway

Source: RTE, Futurs énergétiques 2050

Energy independence: the case of solar PV

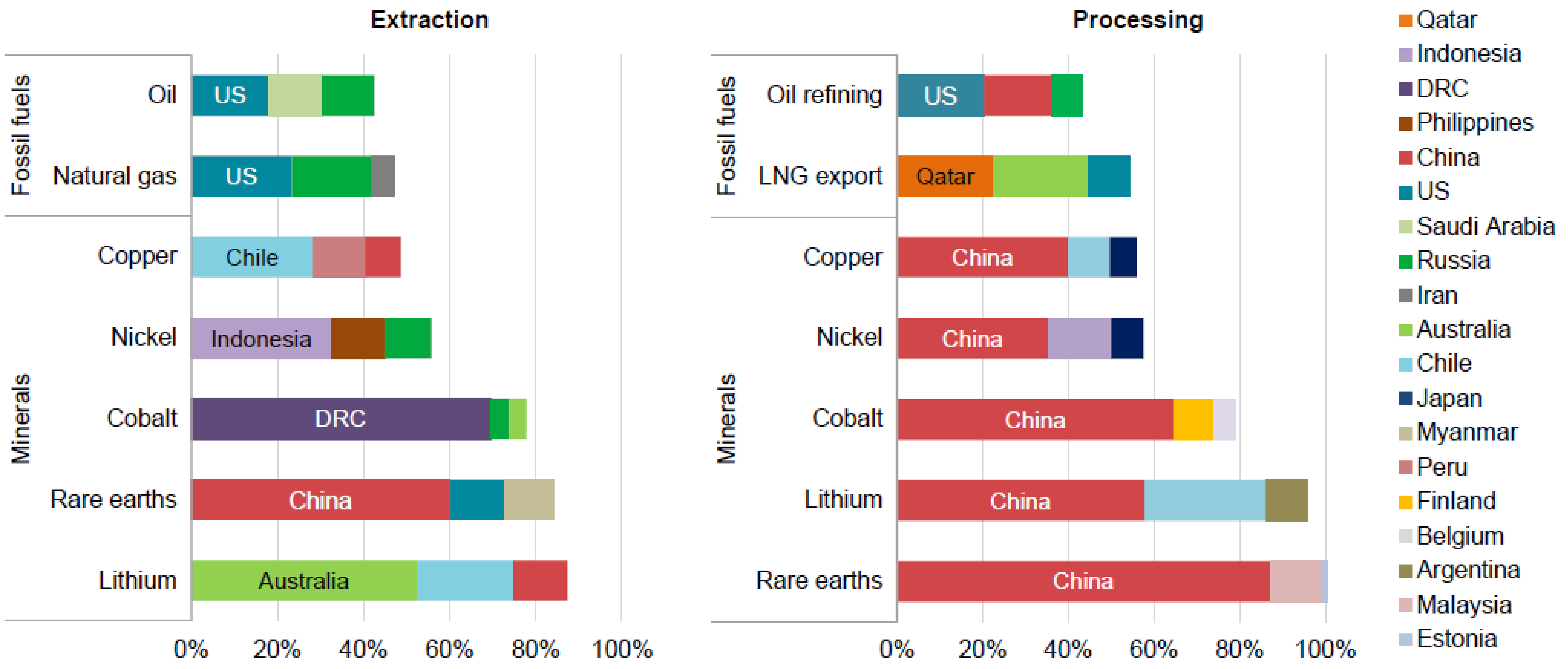
PV panel manufacturing market share
(2005-20, % MW)



Sources : https://www.energymonitor.ai/tech/renewables/what-the-closure-of-germanys-only-wind-blade-factory-says-about-its-energy-transition/ ; https://iea.blob.core.windows.net/assets/d2ee601d-6b1a-4cd2-a0e8-db02dc64332c/SpecialReportonSolarPVGlobalSupplyChains.pdf ; https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2022/Jul/IRENA_Power_Generation_Costs_2021.pdf?rev=34c22a4b244d434da0accde7de7c73d8

China has already positioned itself in the transformation of metals for the energy transition: > 40% market share

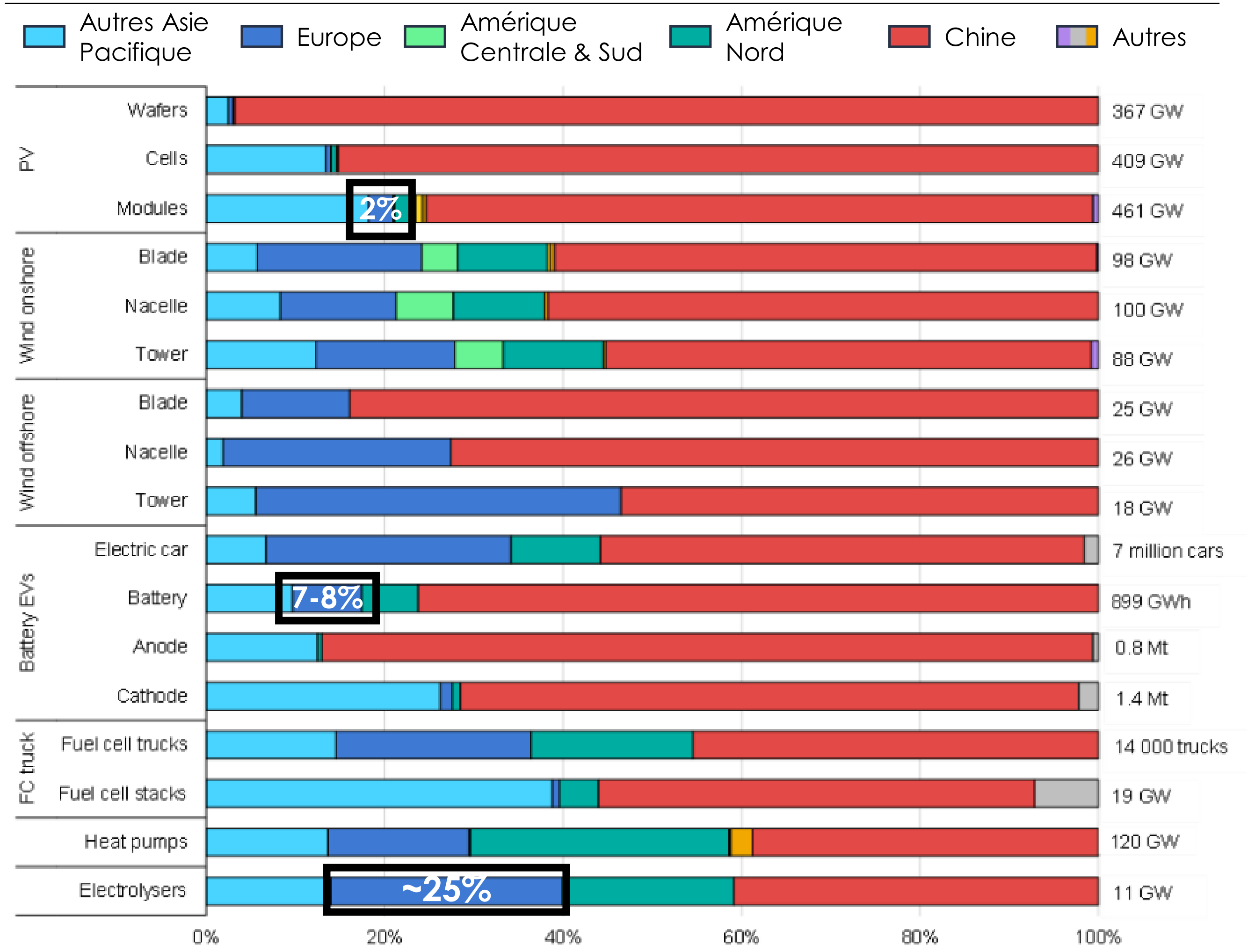
Share of the 3 main producing countries for the extraction and processing of certain materials (2019)



Note : LNG = Liquified Natural Gas
Source: AIE

Europe has lost its PV industry, is defending its interests better in batteries and is well positioned in electrolysers

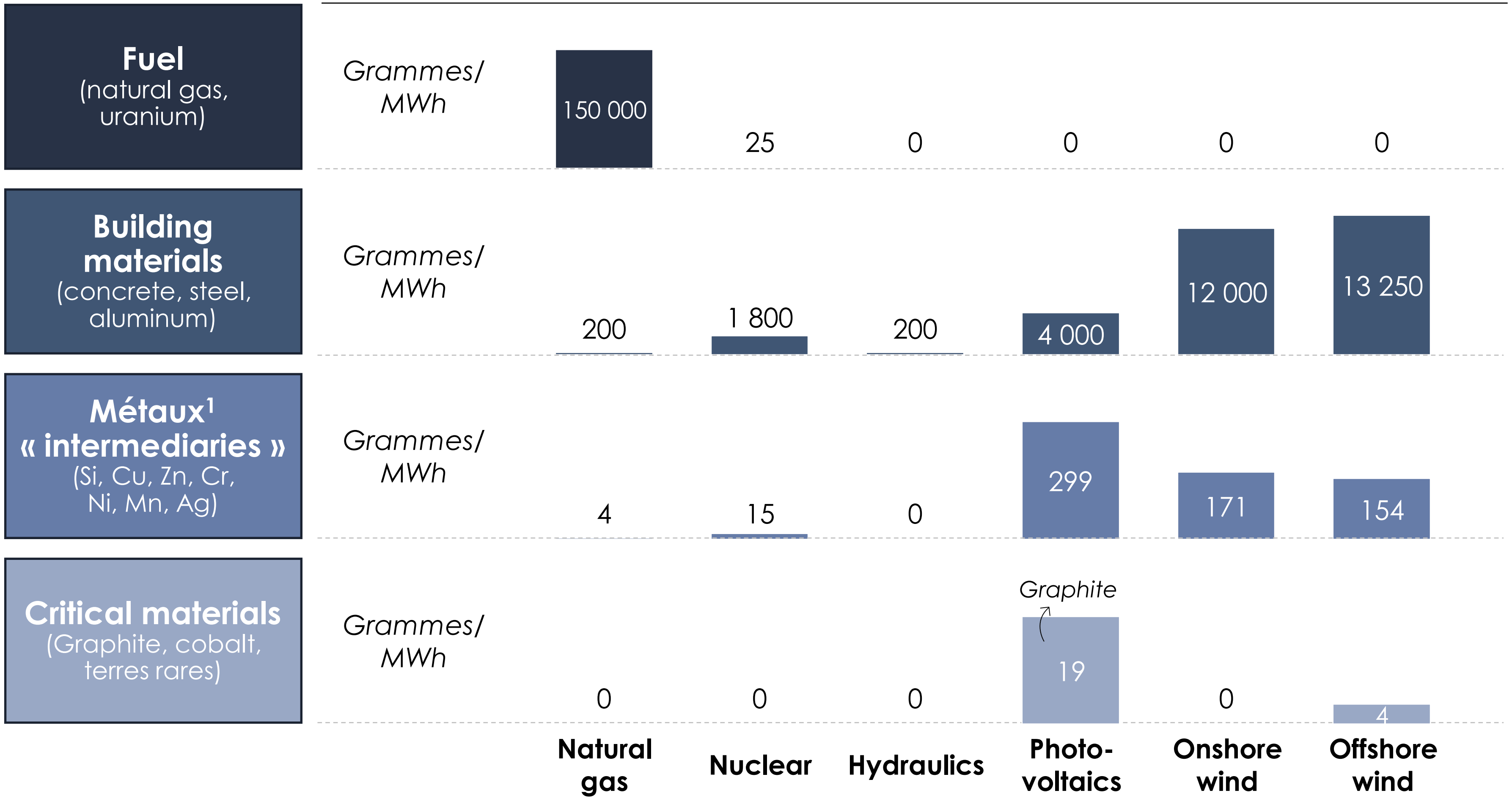
Share of regions producing certain low-carbon technologies (2021)



Note : FC = fuel cell = pile à combustible ; Sources : AIE, Energy Technology Perspectives 2023

Consumption of materials: not all energies are equal

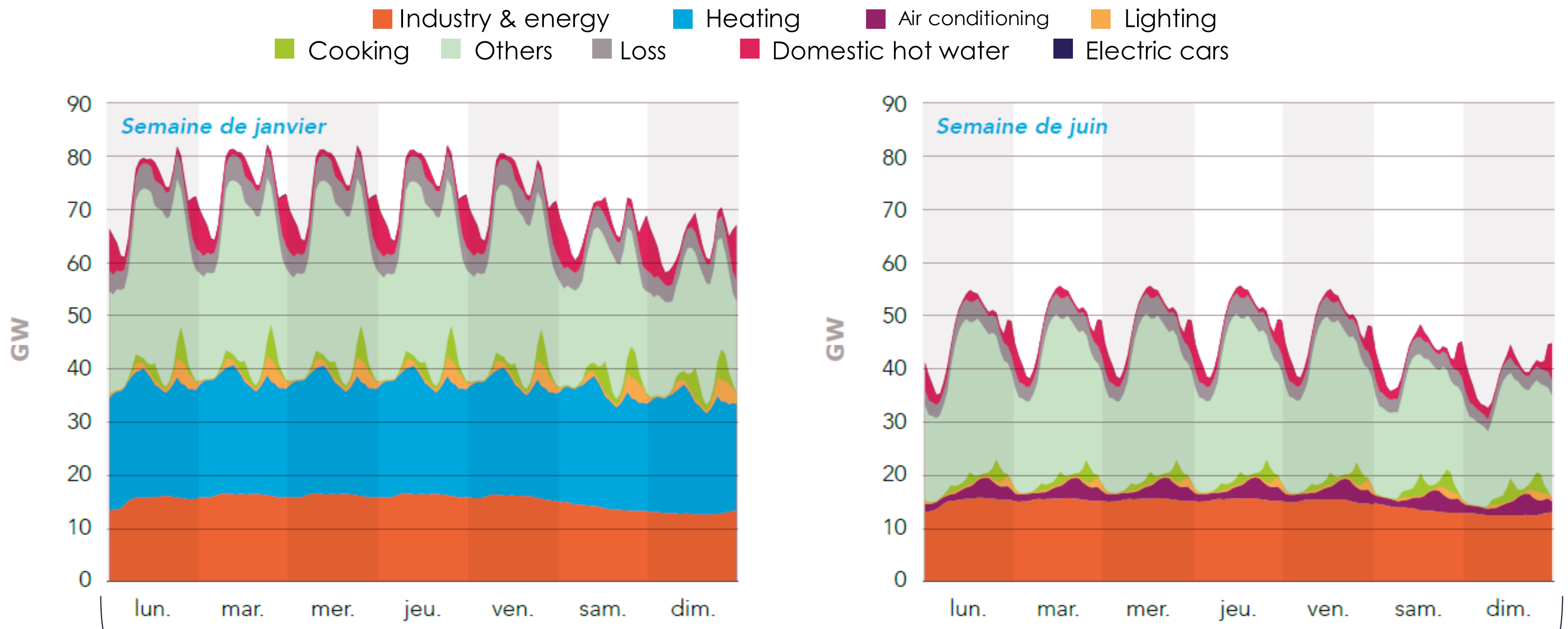
Material intensity by power generation mode (g matériau / MWh)



Note : Silicon metal is placed in the "intermediate" category because 1) it is at the critical limit of supply disruption according to the European Commission; 2) it is a relatively abundant material.
Sources: RTE, Futurs Energétiques 2050 ; AIE ; https://www.brgm.fr/fr/actualite/infographie/metaux-critiques-chiffres-cles-2022

Consumption and production must be balanced at all times

Weekly consumption profile by use (2020)



Equilibrium at all times: production = consumption

Production modes +/- controllable

Storage (STEP, batteries)

Consumption fluctuates widely ...

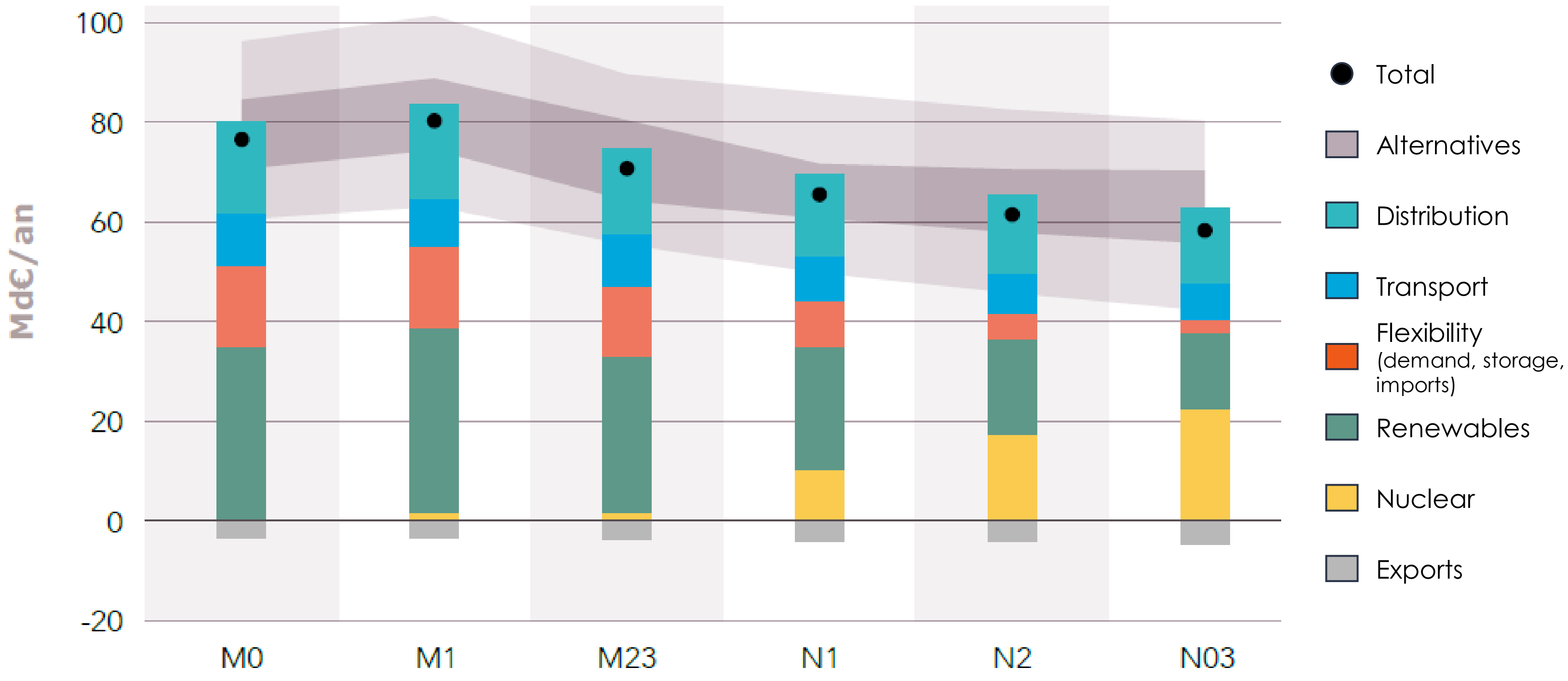
- **Daytime:** consumption peaks in the morning when everyone gets up, and around 6-7pm when everyone goes home (cooking, lighting)
- **Summer** : no heating, little air conditioning
- **Domestic hot water** is programmed to consume at night

- **Electricity is very difficult to store**
- **Fossil, hydraulic and nuclear power are controllable VS variable solar and wind power**

Sources: RTE, Futurs Energétiques 2050

The complete costs of the electrical system are not very differentiating whether it is a lot of nuclear or renewables

Full annualized costs of scenarios to 2060 (Mds € / an)

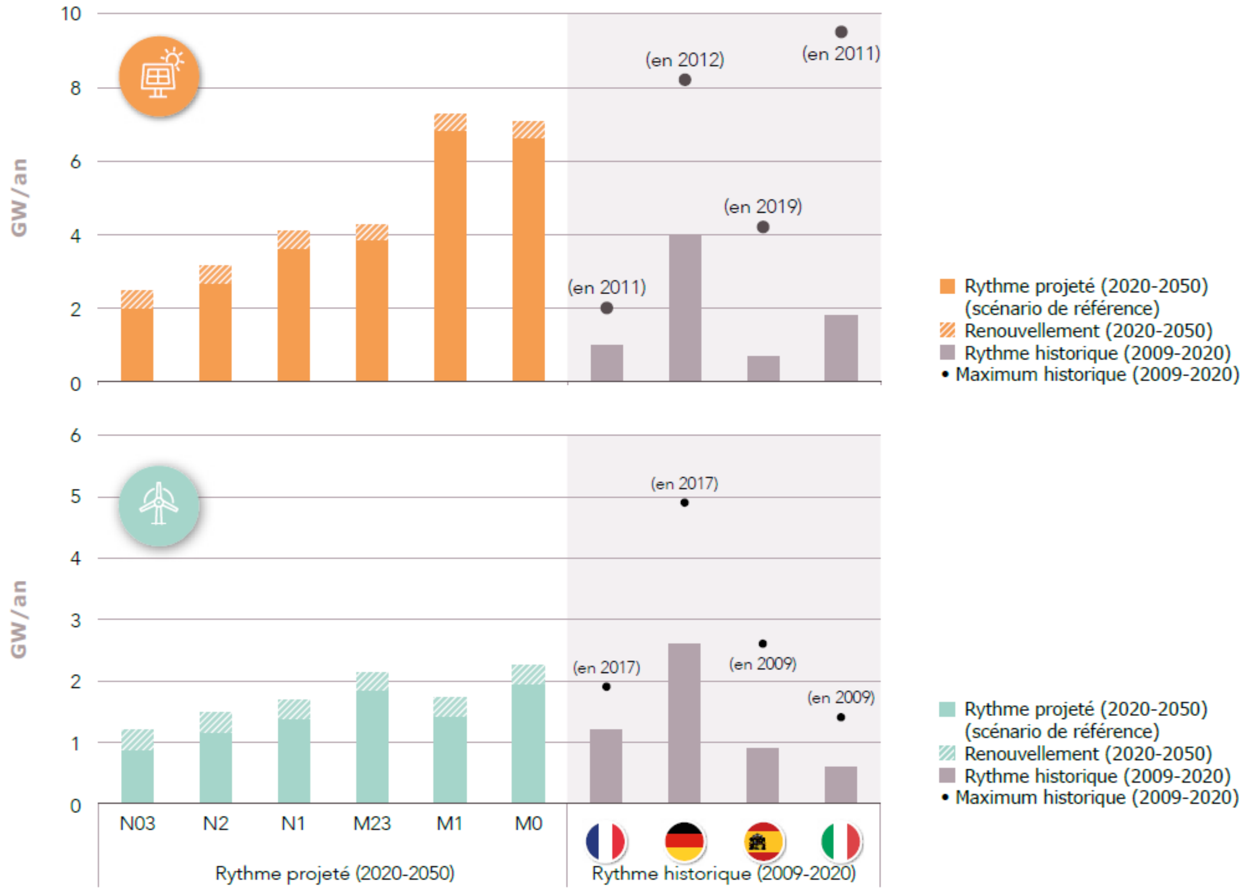


% nuclear	**0%**	**13%**	**13%**	**26%**	**36%**	**50%**
% new nuclear	**-**	-	-	12%	22%	27%
% PV + wind	88%	75%	75%	63%	53%	38%

Sources: RTE, Futurs Energétiques 2050 ; CNRS ; ADEME ; Cours des comptes

Achieving these deployment rates is an industrial challenge

Historical and projected average deployment rates: PV and onshore wind power



Sources: RTE, Futurs Energétiques 2050

5-indicator dashboard: electricity

	Use →	1 MWh of electricity						
Indicators *In life cycle*	**Units**	**Natural gas**	**Existing nuclear**	**New nuclear**	**Hydraulics**	**Photovoltaics** (ground, roof)	**Onshore wind**	**Offshore wind**
Greenhouse gases (energy)	$kgCO_2e$	~450	~10	~10	~10	~40 *Further decline*	~10	~10
Critical materials	Kg	Not significative	Not significative	Not significative	Not significative	Next-generation rare earths?	Not significative	A little rare earth
Land occupation (biodiversity, acceptability)	m^2	0,2	0,1	0,1	10	10	2	2
Total costs	€	60 à 220€	40 à 70€	70 à 120€	30 à 60€	40 à 180€	60 à 90€	70 à 110€
% « local » added value (local jobs, NRJ dependance)	%	< 50%	> 90%	> 90%	> 90%	**70%** *Relocate, recycle?*	> 90%	> 90%
Other specific dimensions	-	Local pollution Social	Accident risk Waste Climate: cooling water		Climate: river flow decreases by -10/-40%	Variable	Variable	Variable

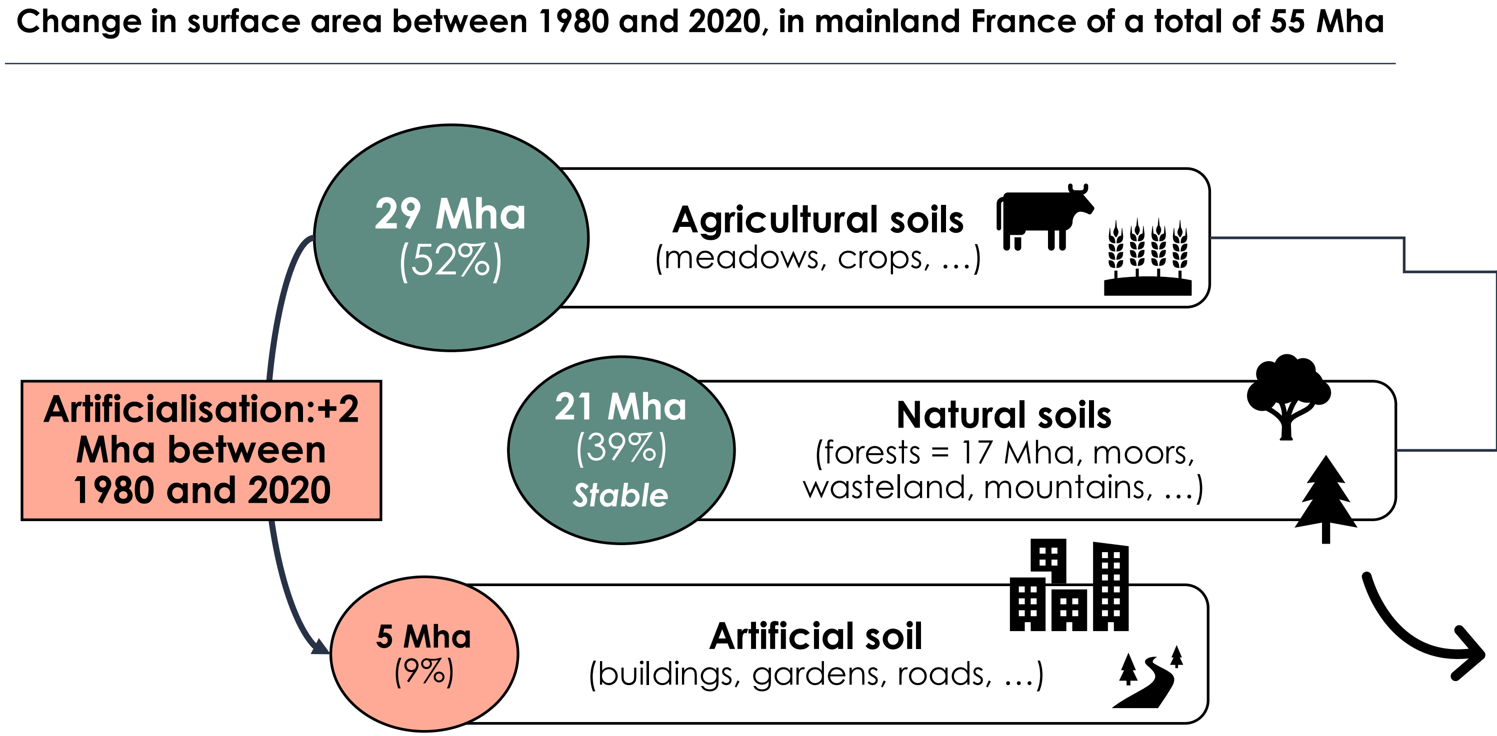
Sources: ADEME, ONU, IRENA, RTE

Plant energy (biomass/bioenergy)

Definitions: what is biomass? Bioenergy?

	Fossil energies	Energies from biomass
Solid	Coal	Wood, plant fibers
Liquid	Oil	Liquid biofuels
Gas	Natural gas	Biogas, biomethane

Biomass comes from agricultural and forest land: strong artificialization to the detriment of agricultural land over the past 40 years



Change in surface area between 1980 and 2020, in mainland France of a total of 55 Mha

Artificialisation:+2 Mha between 1980 and 2020

29 Mha
(52%)

Agricultural soils
(meadows, crops, …)

21 Mha
(39%)
Stable

Natural soils
(forests = 17 Mha, moors, wasteland, mountains, …)

5 Mha
(9%)

Artificial soil
(buildings, gardens, roads, …)

Many services rendered

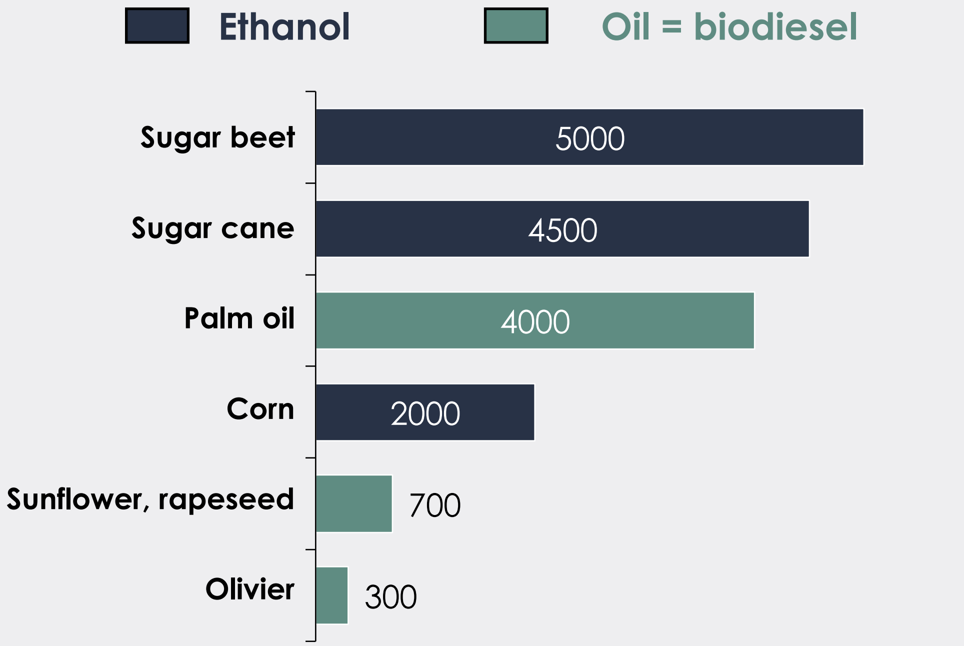
- **Food**
- **Materials** (construction, textiles, furniture, paper, cardboard, etc.)
- **Energy**
- **Carbon storage**
- **Biodiversity**
- **Inspiration, well-being**

Between 1900 and 1980, forest cover rose from 19% of mainland France to 31%

Sources: *La ville stationnaire*, Philippe Bihouix, Sophie Jeantet, Clémence de Selva

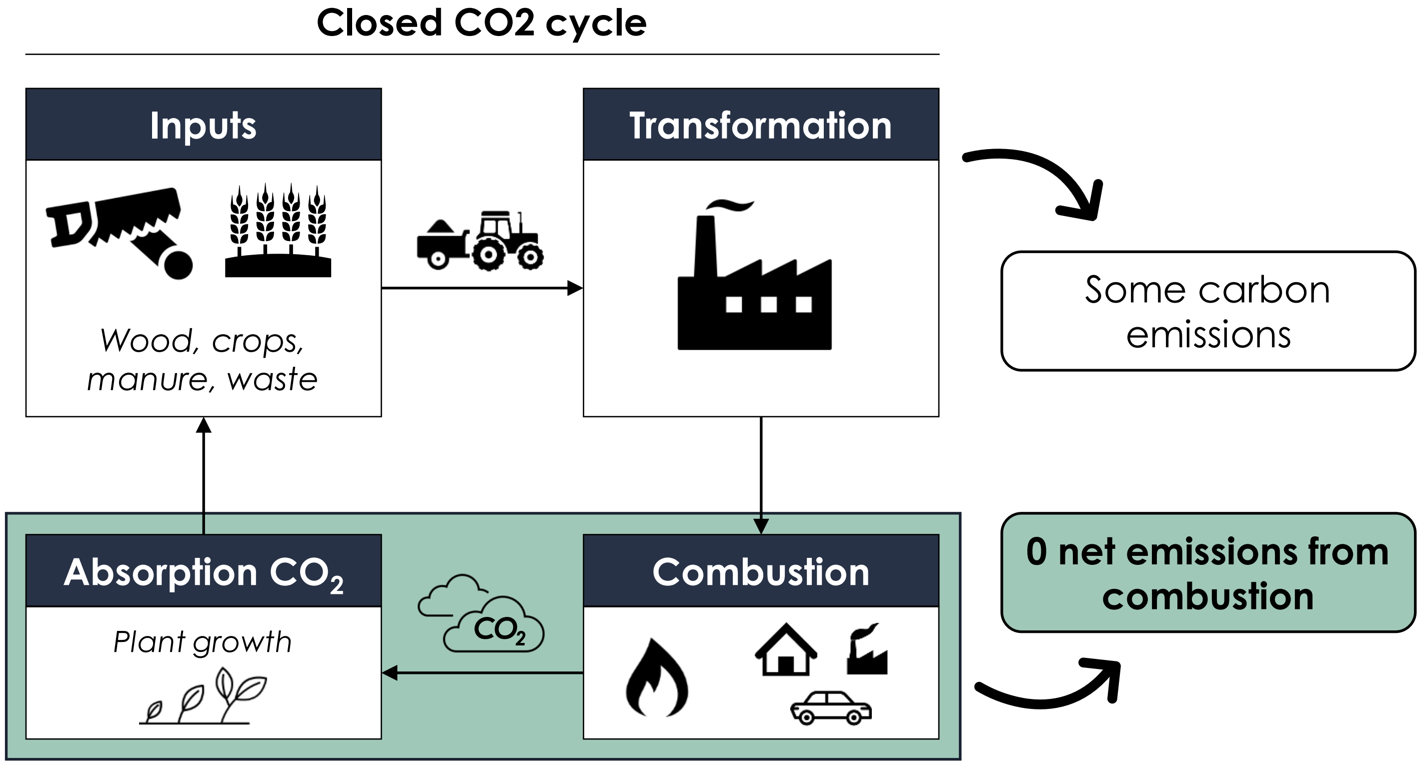
Energy efficiency: biomass generates little energy at the surface

Energy yield per unit area - Illustration of biofuels from selected crops (Litres/ha)



Note: the Litre is an approximation of the energy content; (1) this yield includes the energy consumed to transform the beet into ethanol
Sources : FAO

Carbon emissions linked to the combustion of biomass are considered zero if the biomass is replanted



Closed CO2 cycle

Inputs

Wood, crops, manure, waste

Transformation

Absorption CO_2

Plant growth

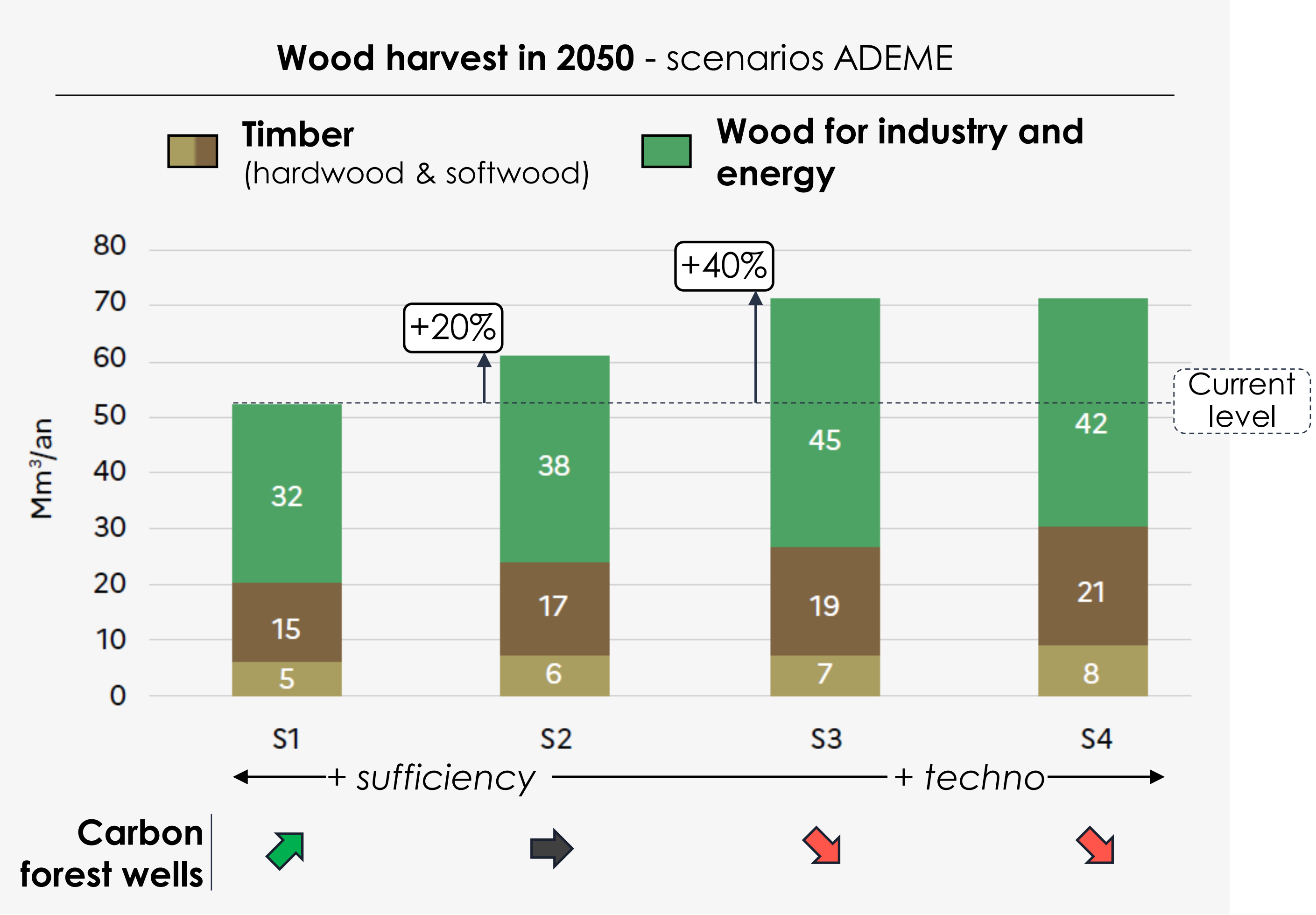
Combustion

Some carbon emissions

0 net emissions from combustion

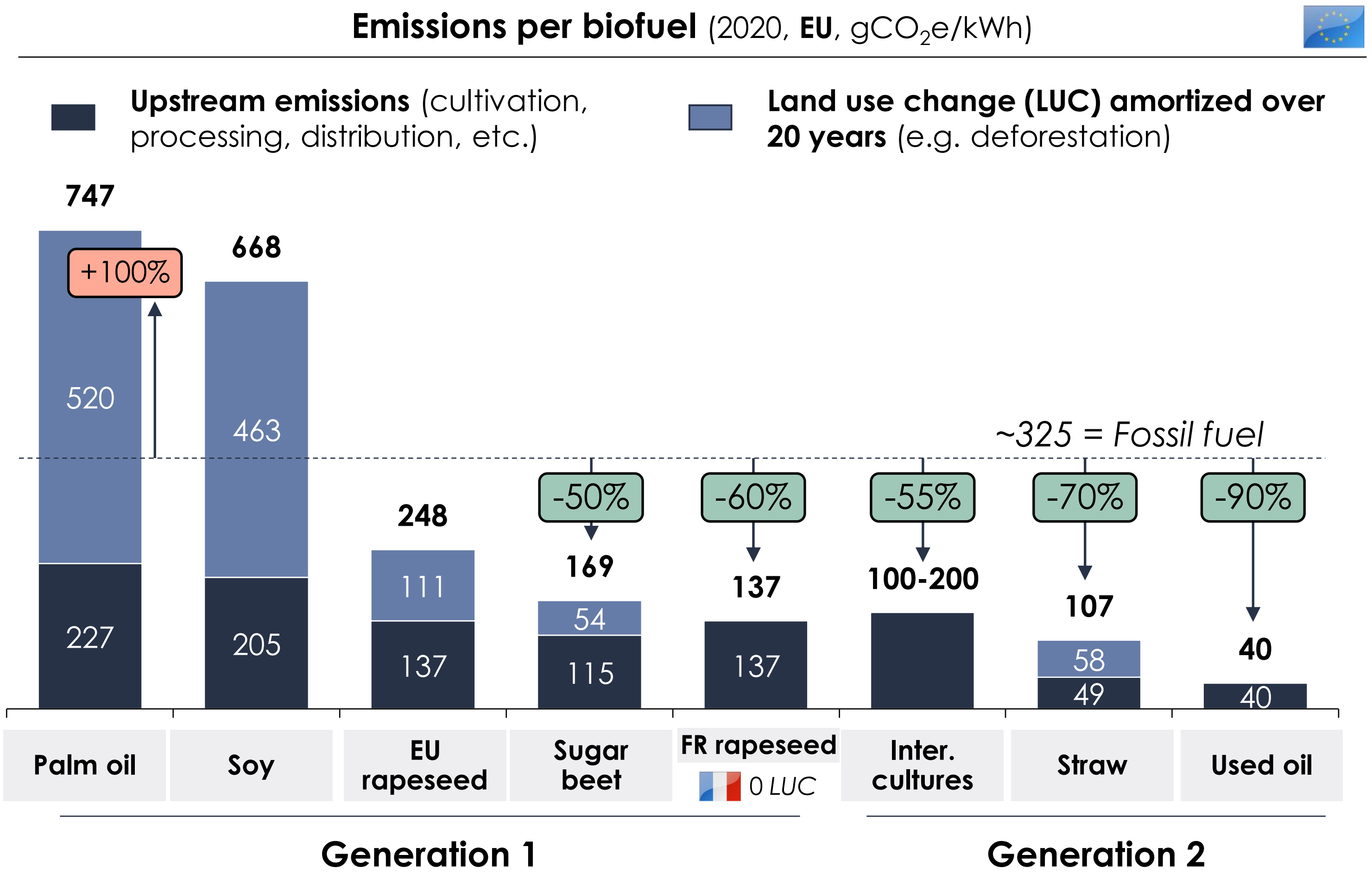
Source: ADEME

Forests & wood: contrasting strategies between increasing harvesting and preserving wells



Sources : Transition(s) 2050, ADEME ; INRAE

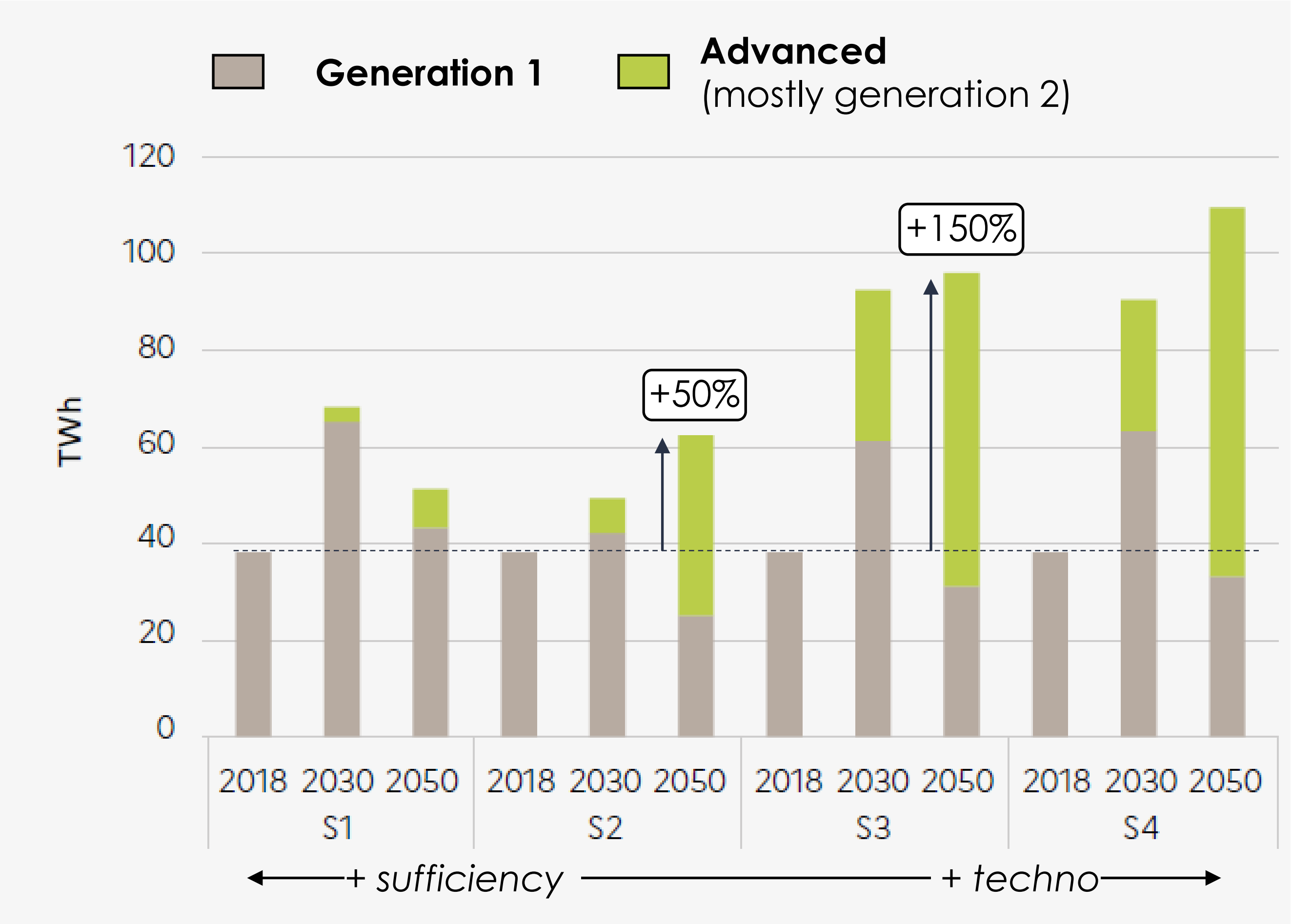
Depending on its origin and raw material, a biofuel is +/- a good idea for the climate.



Sources : ICCT, European Commission, Globiom

Liquid biofuels: an increase in production of between +50% and +150% for the central scenarios, to supply the aviation industry.

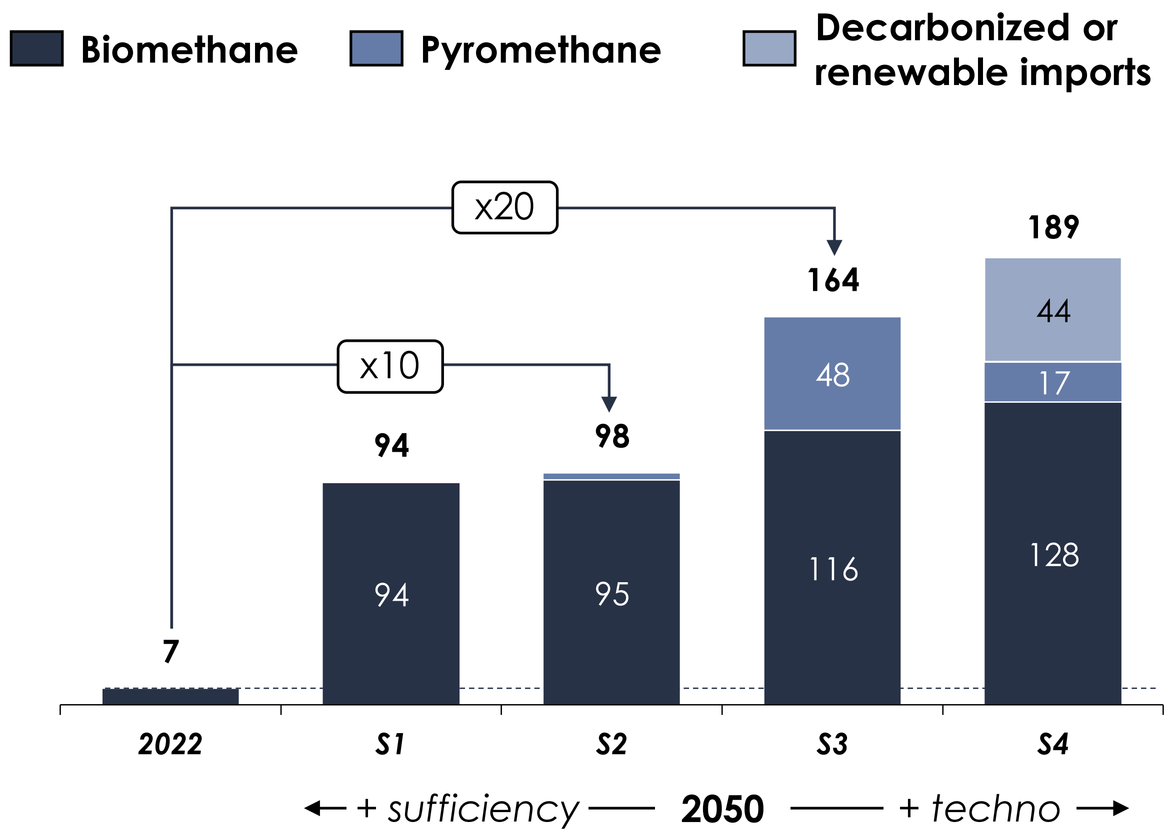
Share of biofuels in 2018, 2030 and 2050 - scenarios ADEME



Source : Transition(s) 2050, ADEME

Renewable gases: a 10-20-fold increase by 2050

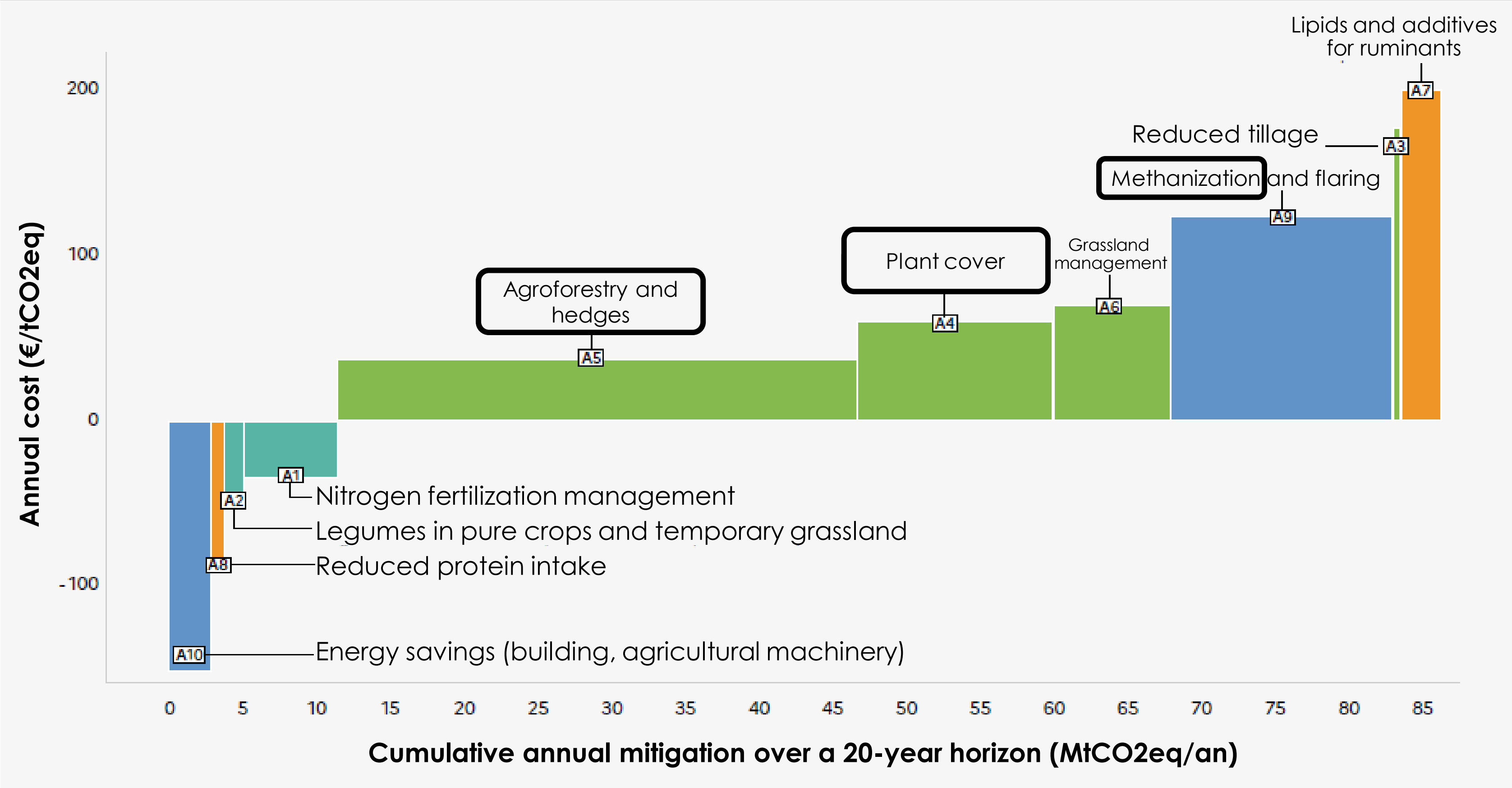
Renewable gas production (TWh, 2022-50 - scénarios ADEME)



Source : Transition(s) 2050, ADEME

3 major agricultural practices to store carbon, enrich biodiversity and produce renewable energy

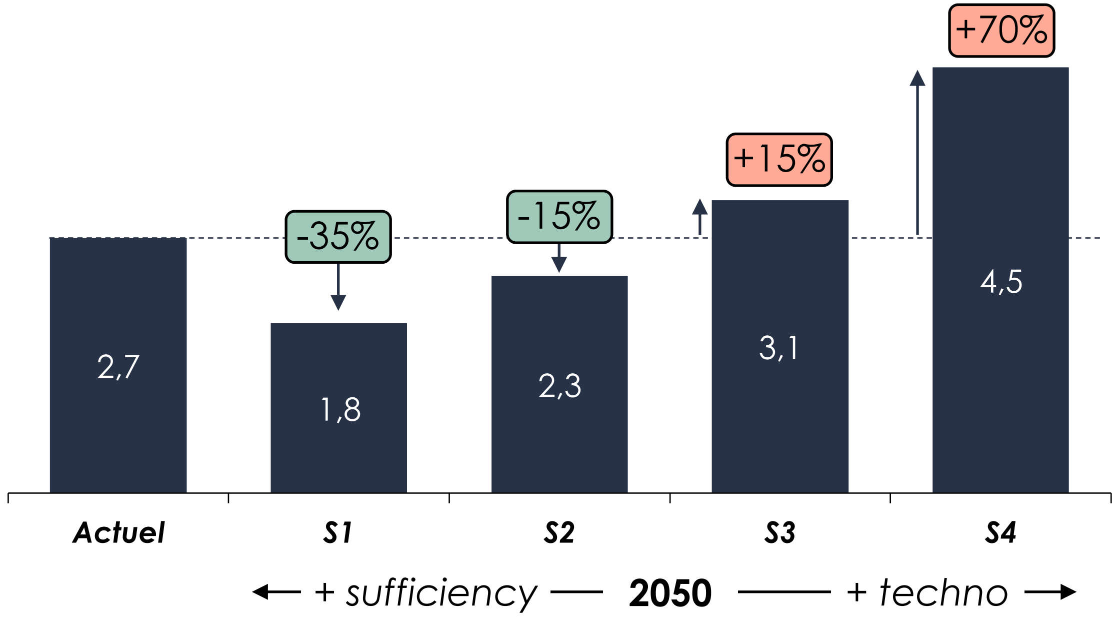
Annual GHG emissions mitigation costs and potential over 20 years for the main action levers in mainland France



Source : Transition(s) 2050, ADEME

Producing more biomass in scenarios S3 and S4 has a heavy counterpart in terms of water consumption, VS S1 and S2

Water consumption for irrigation
(Mds m³ / year, 2018-50 - scenarios ADEME)



Source: Transition(s) 2050, ADEME

5-indicator dashboard: bioenergy

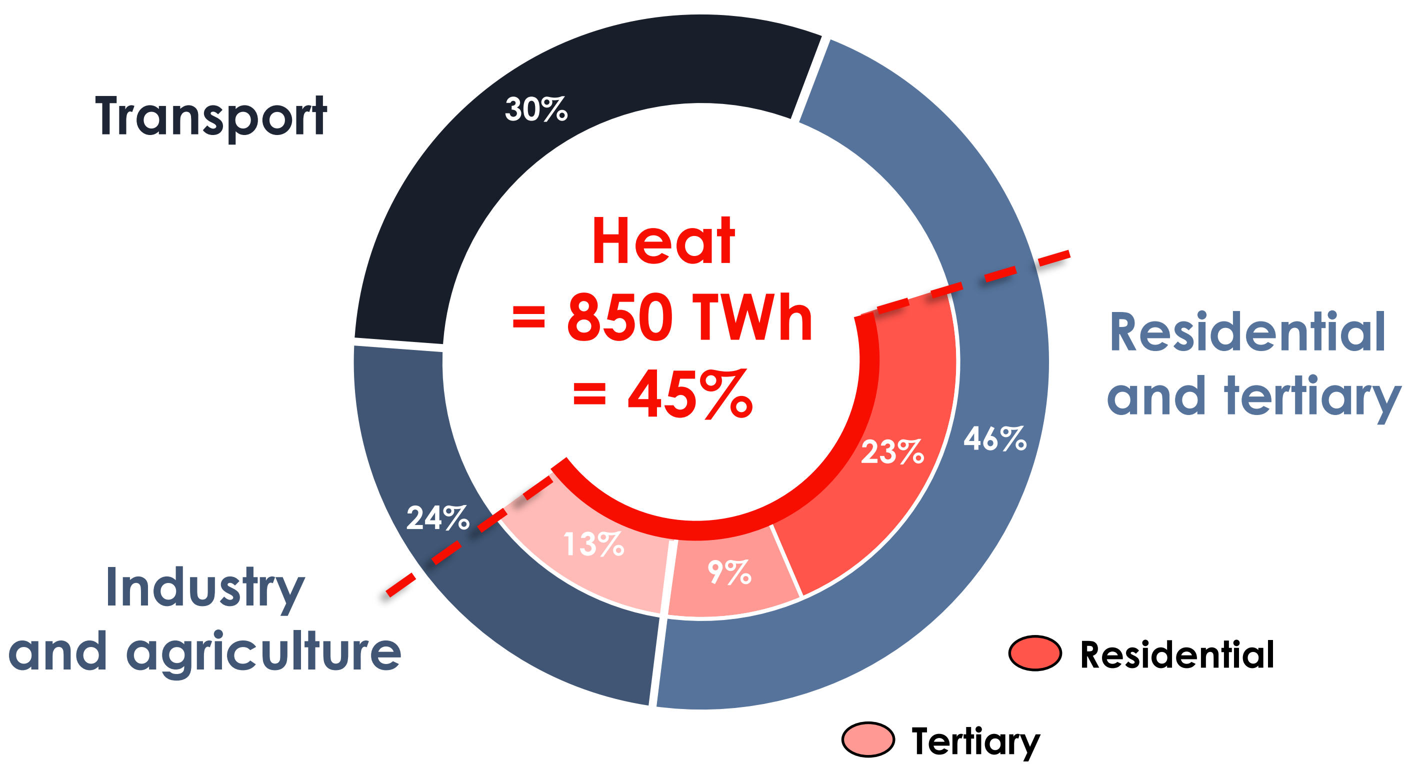
Use →		1 MWh gas	1 MWh wood	1 MWh liquid biofuel		1 MWh gas	1 MWh of electricity	
Indicators *In life cycle*	**Units**	**Natural gas**	**Wood**	**Biofuel 1^e Gén.**	**Biofuel 2^e Gén.**	**Biomethane**	**Existing nuclear**	**Photovoltaics** (ground, roof)
Greenhouse gases (energy)	kgCO_2e	~200	~20	100 à 800	40 à 150	~40	~10	~40 *Further decline*
Critical materials	Kg	Not significative	Not significative	Not significative	Not significative	Not significative	Not significative	Next-generation rare earths?
Land occupation (biodiversity, acceptability)	m^2	0,1	500	250	250	250	0,1	10
Total costs	€	40 à 100€	40 à 80€	50 à 90€	80 à 200€	80 à 100€	40 à 70€	40 à 180€
% « local » added value (local jobs, NRJ dependance)	%	< 50%	> 90% *70% for materials*	70% Relocate?	Not yet mature	> 90%	> 90%	70% *Relocate, recycle?*
Other specific dimensions	-	Local pollution Social	Climate : fire, droughts	Food Climate: yield	Climate: yield	Local pollution risk Climate: yield	Accident risk Waste Climate: water	Variable

Sources: ADEME, ONU, IRENA, RTE

Low-carbon heat, the great forgotten one

45% of energy is consumed in the form of heat

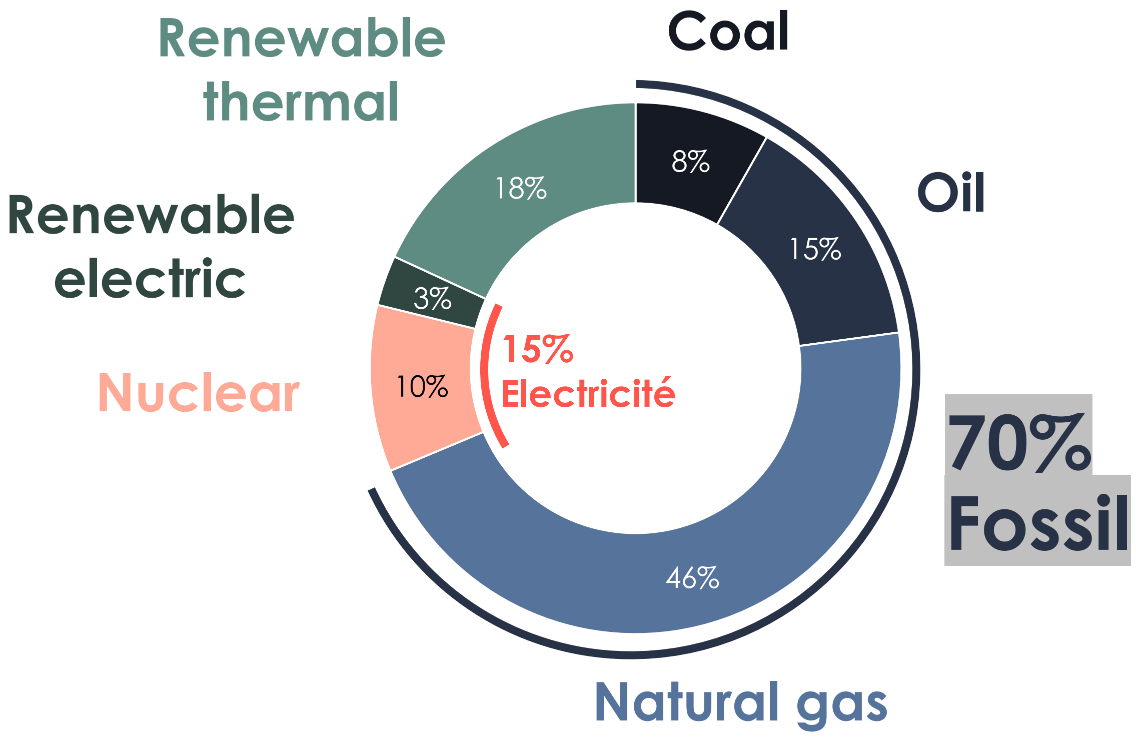
Heat use in final energy consumption in France
(%TWh, 2019, excluding non-energy uses)



Source: négaWatt, https://negawatt.org/scenario-2022/sankeys/2019-simplifie ; MTE

70% of heat is produced from fossil fuels

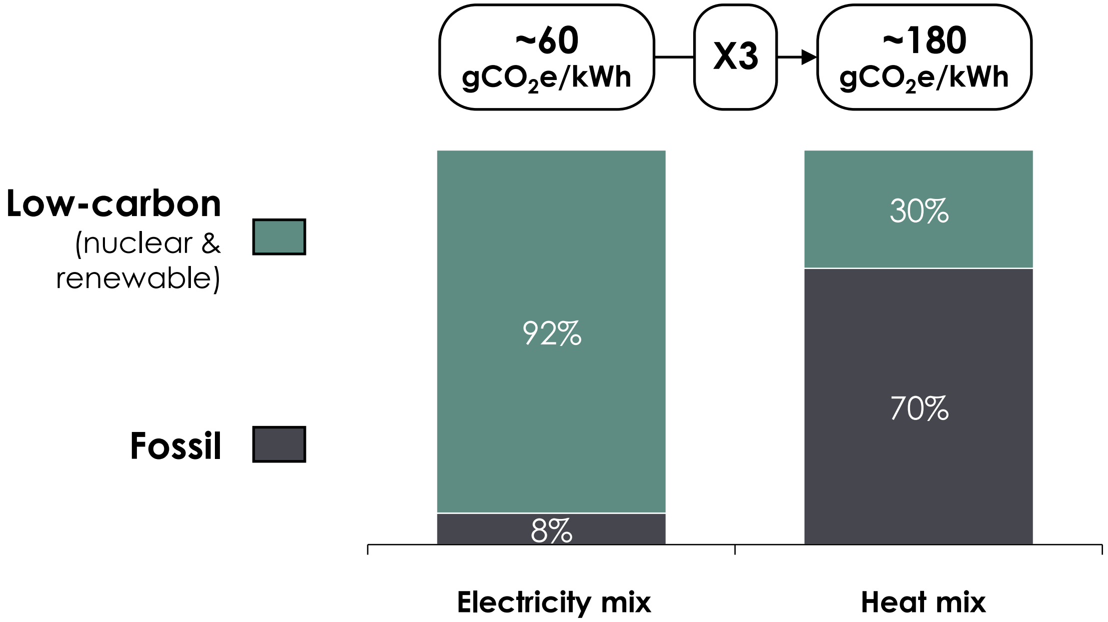
Energy consumed for heating purposes in France
(% TWh, 2019, excluding non-energy uses)



Source: négaWatt, https://negawatt.org/scenario-2022/sankeys/2019-simplifie

Carbon heat, forgotten by public authorities

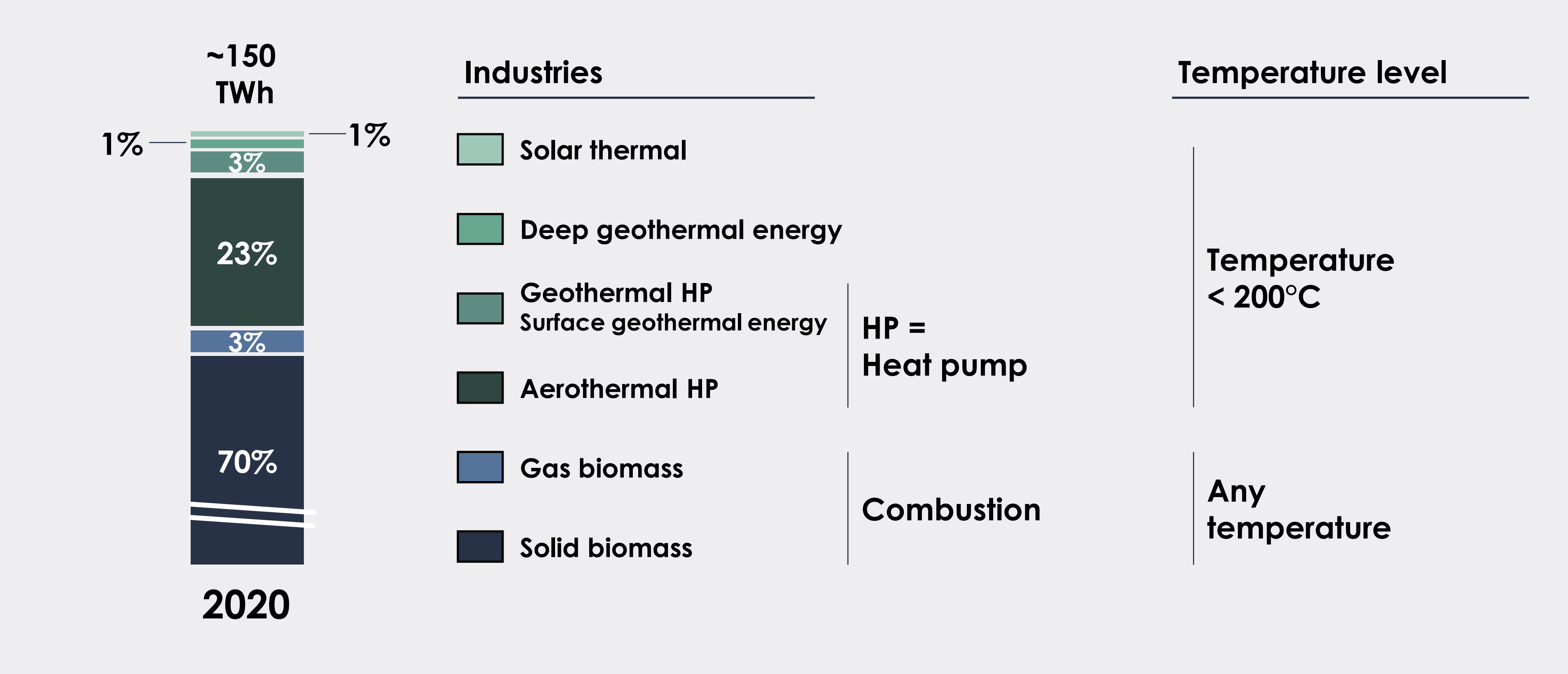
Fossil fuels VS low-carbon electricity and heat (% TWh, 2019)



Sources: RTE, négaWatt, ADEME

Renewable heat/thermal renewables: what production industries?

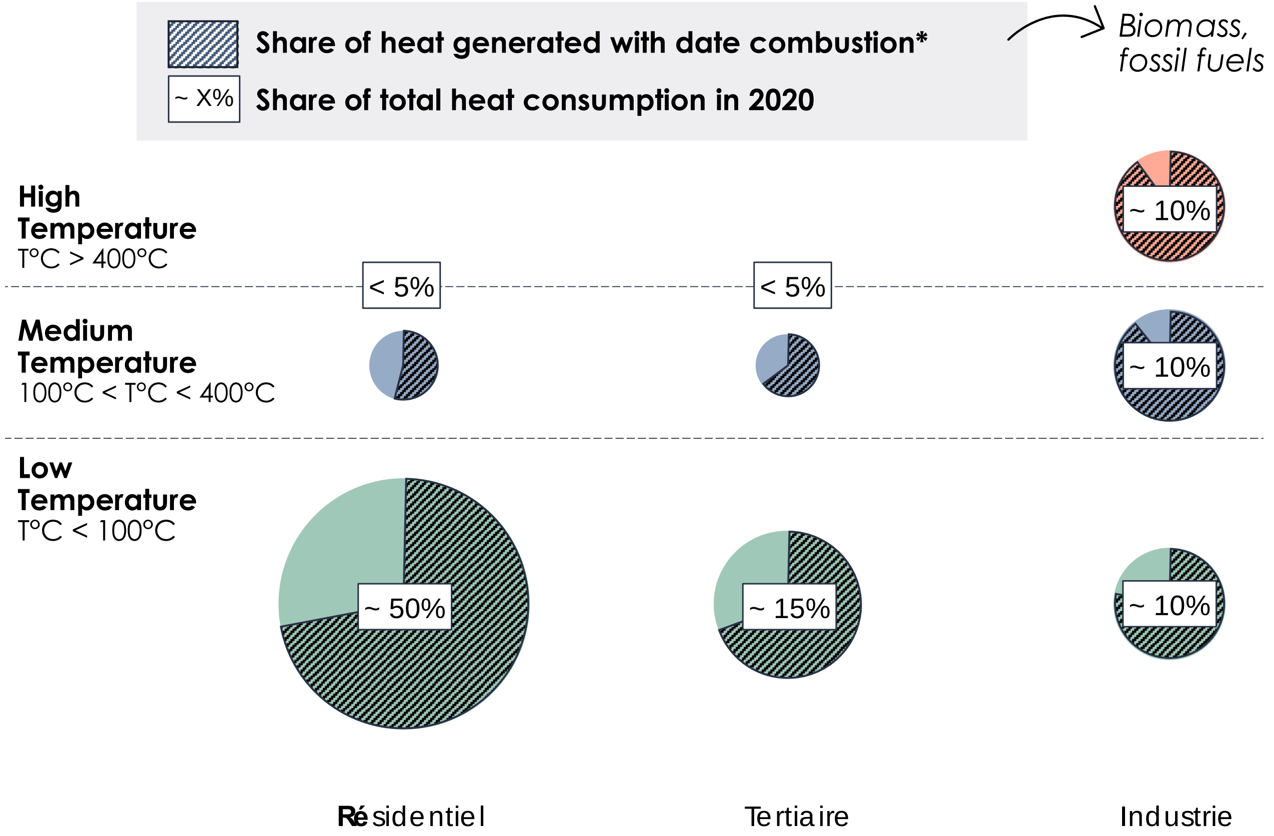
Renewable heat production systems (2020, % TWh)



For heat pumps, only calories drawn from the environment are counted.
Geographic scope: mainland France (as defined by the PPE)
Source: Panorama de la chaleur renouvelable, ADEME 2019, 2020, 2021, PPE, analyse Carbone 4

Low-temperature needs account for most of heating requirements, particularly in the residential and commercial sectors

Breakdown of heating requirements by temperature and sector in France (2020)

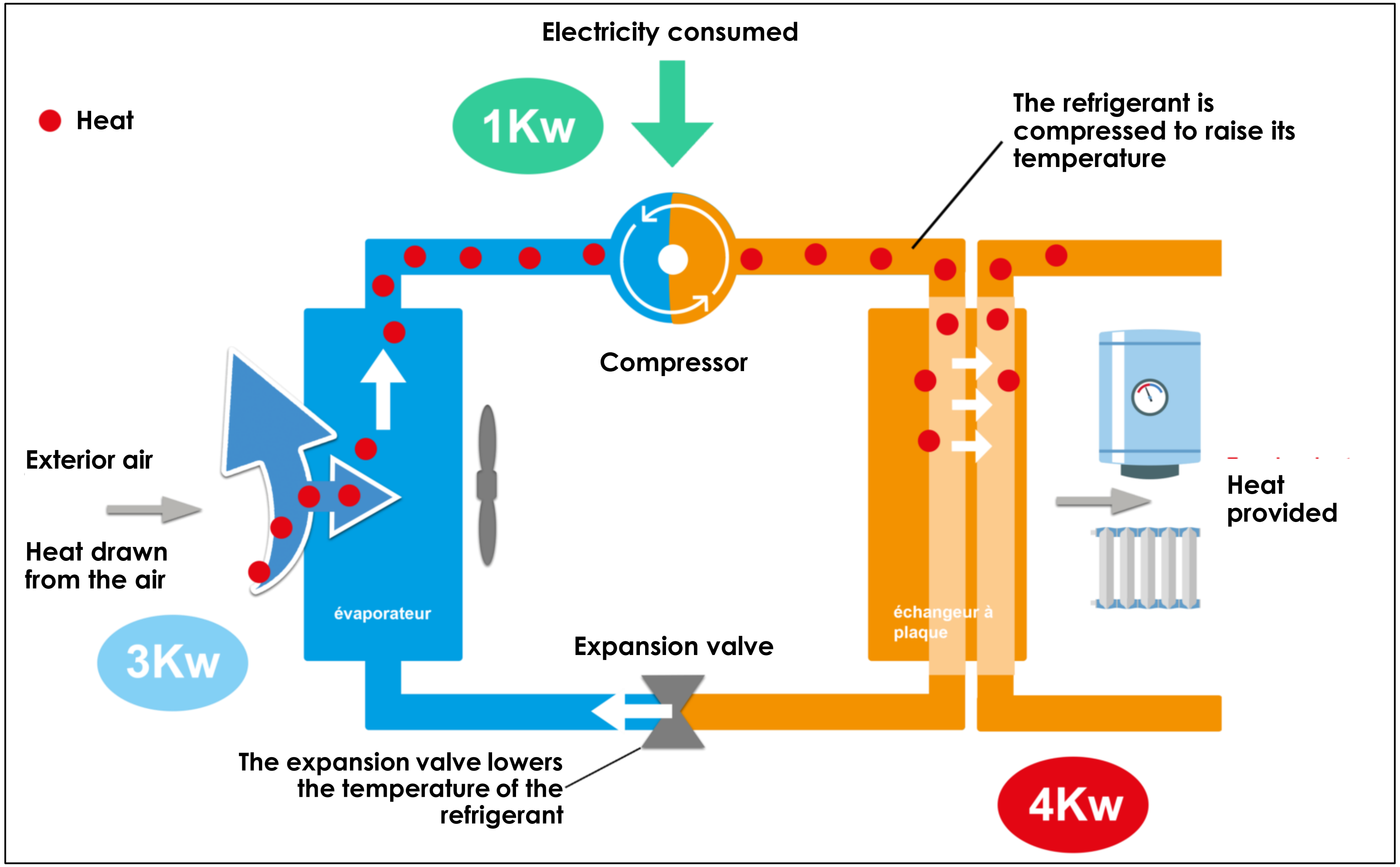


~75% heat needs are low-temperature

▨ **~75% low t°C heat covered by combustion**

* Renewable sources included. Sources: Consommations d'énergie par usage du résidentiel (2020, SDES), Consommation énergétique du secteur tertiaire (CEREN, 2020), Données sur l'énergie dans l'industrie (CEREN, 2016), Répartition par secteur de la consommation finale de l'industrie (SDES, 2019), Heating without global warming (IEA), analyse Carbone 4

The aerothermal heat pump: operating principle



● Heat

Electricity consumed

The refrigerant is compressed to raise its temperature

Compressor

Exterior air

Heat drawn from the air

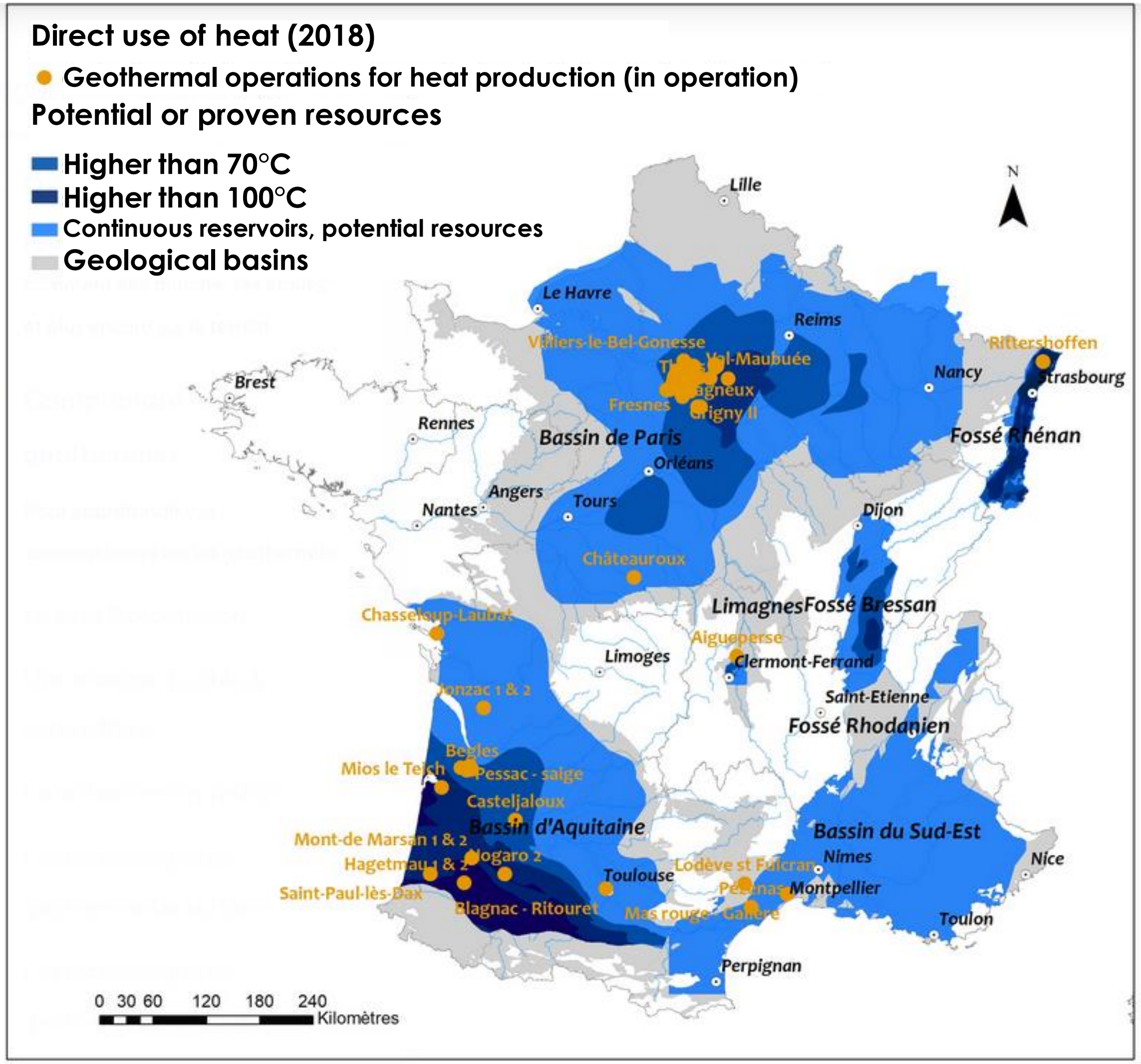
Heat provided

Expansion valve

The expansion valve lowers the temperature of the refrigerant

Source: CDE

Geothermal energy



Sources: https://www.geothermies.fr/les-technologies-de-geothermie-profonde ; https://www.carbone4.com/files/Publication_Carbone_4_Chaleur_renouvelable.pdf

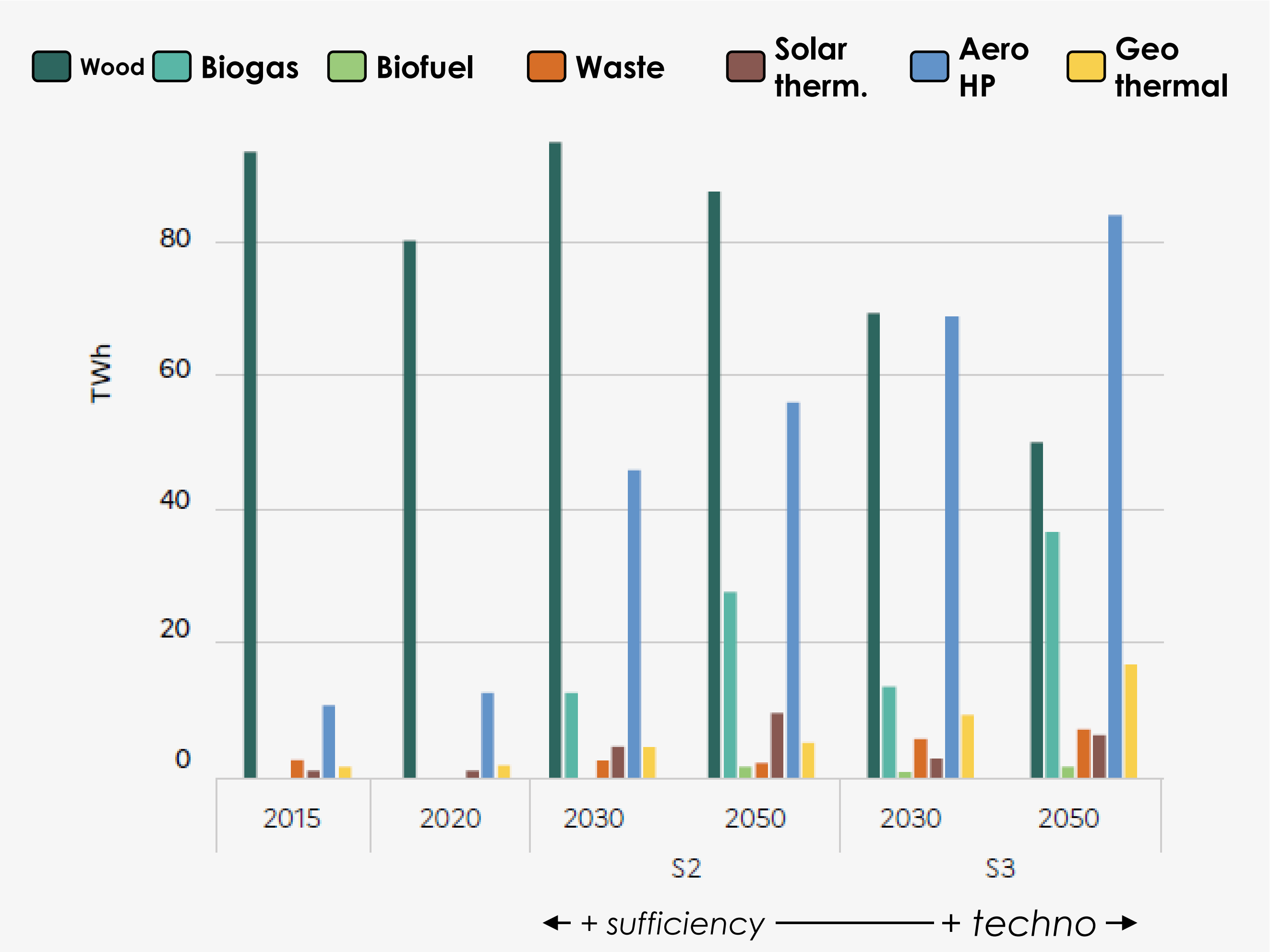
5-indicator dashboard: heat

Use →		1 MWh heat						1 MWh elec.
Indicators *In life cycle*	**Units**	**Natural gas**	**Wood**	**Biomethane**	**HP** (aero et geo)	**Deep geothermal**	**Solar therm.** (sol, toitures)	**Photovoltaics** (ground, roof)
Greenhouse gases (energy)	$kgCO_2e$	~200	~20	~40	~30	~10	~20	~40 *Further decline*
Critical materials	Kg	Not significative	Not significative	Non significatif	Non significatif	Non significatif	Non significatif	Next-generation rare earths?
Land occupation (biodiversity, acceptability)	m^2	0,1	500	250	0,1 *Elec mix*	<1	5	10
Total costs	€	40 à 100€	40 à 80€	80 à 100€	30 à 100€	20 à 80€	40 à 200€	40 à 180€
% « local » added value (local jobs, NRJ dependance)	%	< 50%	> 90% *70% for materials*	> 90%	80% Relocate?	> 90%	> 90%	70% *Relocate, recycle?*
Other specific dimensions	-	Local pollution Social	Climate : fire, droughts	Local pollution risk Climate: yield	Refrigerant	Local pollution risk	Variable	Variable

Sources: ADEME, ONU, IRENA, RTE

Renewable heat in ADEME scenarios: biomass stable overall, with a boom in aerothermal heat pumps

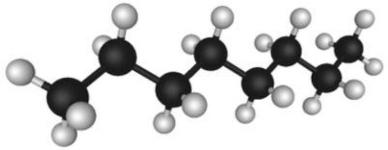
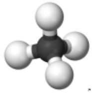
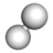
Renewable heat production outside networks - scenarios ADEME



Source: Transition(s) 2050, ADEME

Hydrogen, lost illusions?

Hydrogen contains 3 times more energy than gasoline for the same mass, but it has to be concentrated to be used

	Gasoline	**Methane**	**Hydrogen**
Molecule	 *C_8H_{18}*	 *CH_4 (Natural gas)*	 *H_2*
Mass density at room t°C[1] (kg/m^3)	**750 kg/m^3**	**0.7 kg/m^3**	**0.1 kg/m^3**
Energy density (kWh/kg)	**13 kWh/kg** *Liquid at 15°C* *1.3 litres = 1 kg*	**15 kWh/kg** *Liquid at -162°C* *2.4 litres = 1 kg*	**33 kWh/kg** *Liquid at -253°C* *14 litres = 1 kg*

Huge advantage: dense at room temperature

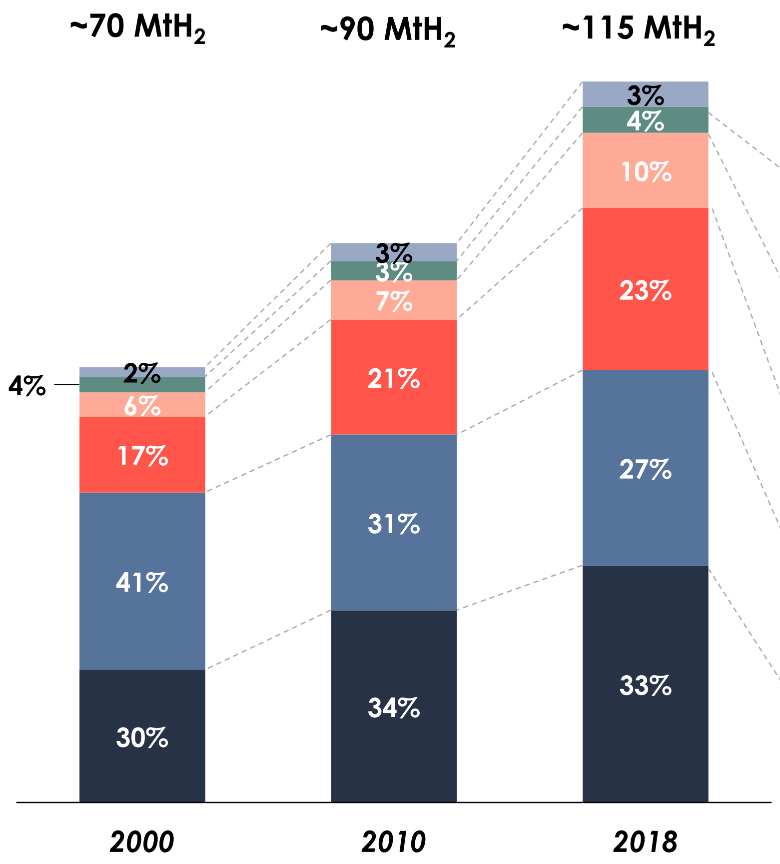
Gas needs to be concentrated (compression, liquefaction) before it can be used

[1] 15 degrees Celsius / 1 bar

Sources: analyse Carbone 4

Worldwide, hydrogen is used exclusively in industry, mainly as a reagent

Worldwide demand for hydrogen by sector (MtH_2)

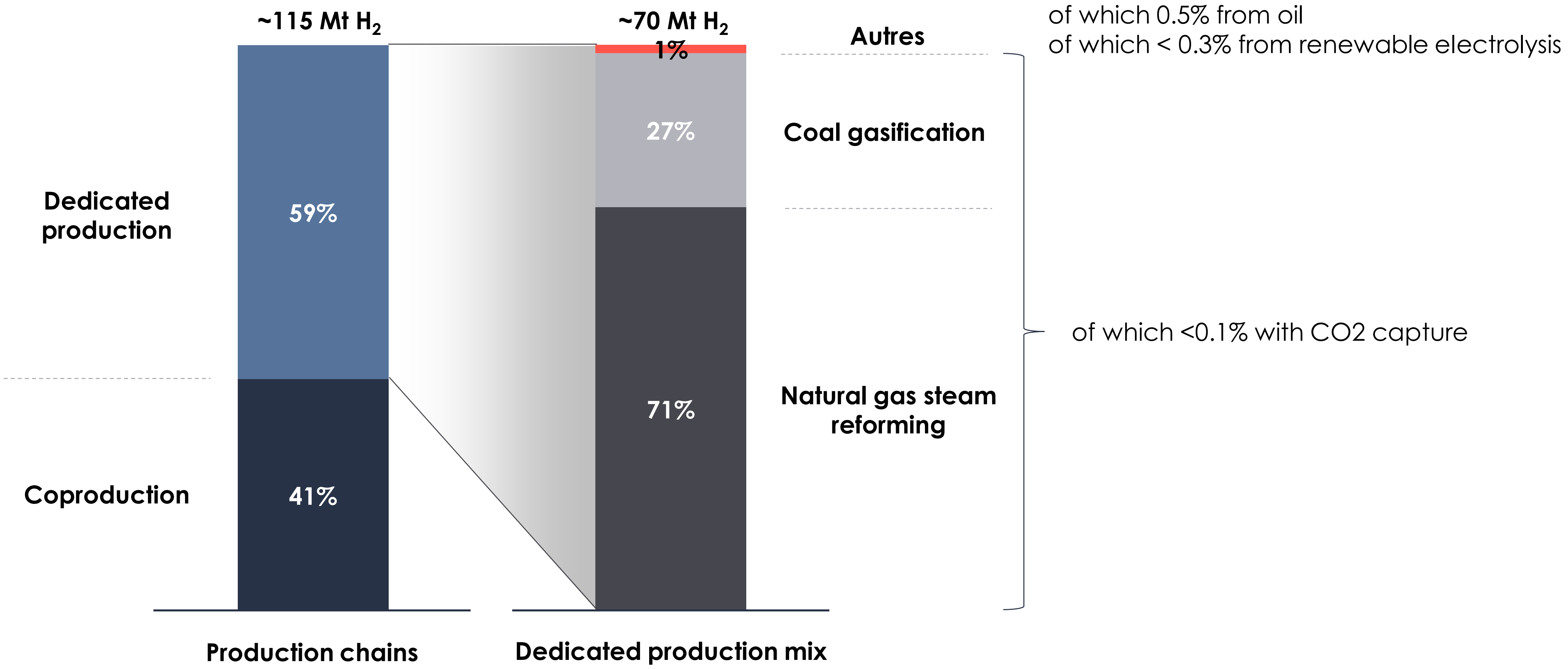


Sector	Uses
Direct iron reduction	Mixture of reducing agents for direct iron reduction
Othersfor pure use	Including chemicals (2%), metallurgy (welding), electronics (semiconductors), glass, food and transport (< 0.01%)
Methanol	Raw material for the manufacture of plastics, synthetic resins, alcohol and various solvents. Also used as fuel.
Others in mix	Mainly heat production, but also electricity (< 3%)
Ammonia	Reagent for the production of ammonia (NH3), ~80% of which is used in the manufacture of fertilizers such as ammonium nitrate
Refinery	For hydrocracking and desulfurization of crude oil and deoxygenation of biofuels

Source: The Future of Hydrogen, AIE 2019

The vast majority of dedicated hydrogen production comes from natural gas and coal

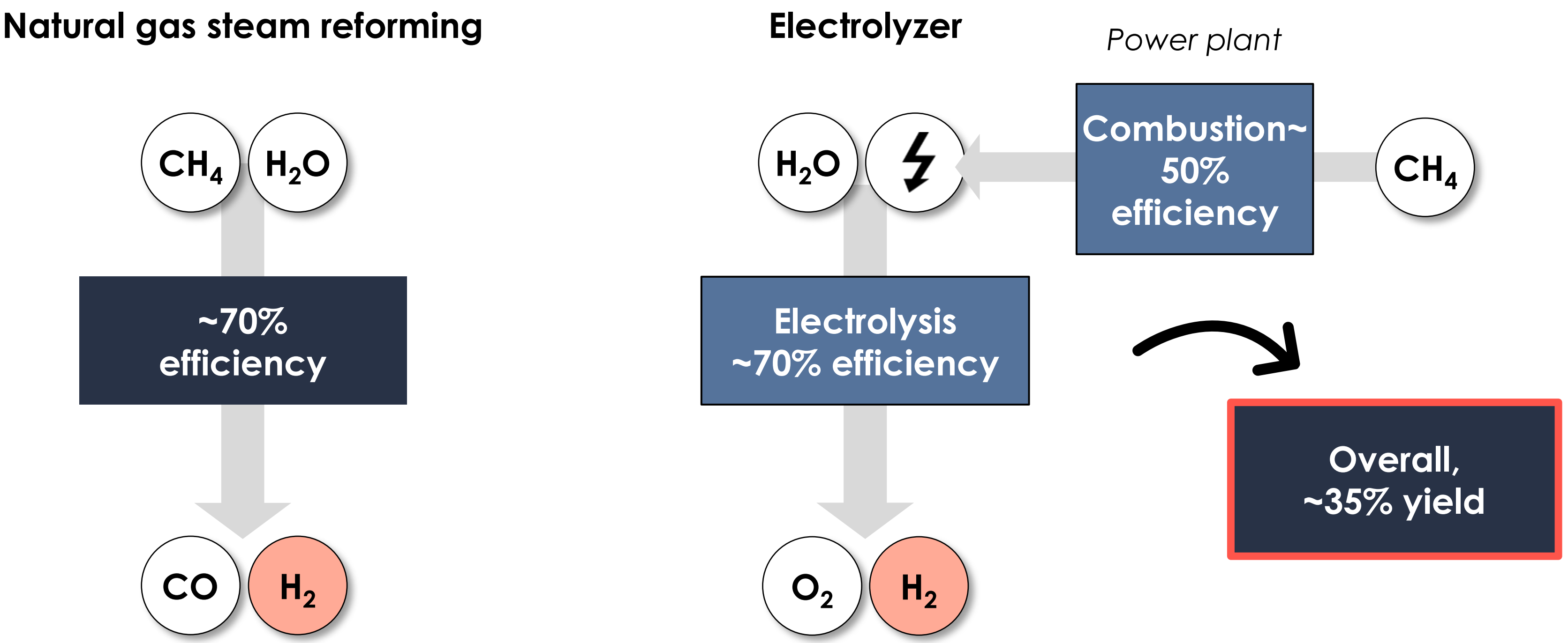
Hydrogen production worldwide in 2018 by sector (MtH_2) **and production mix of the dedicated sector**



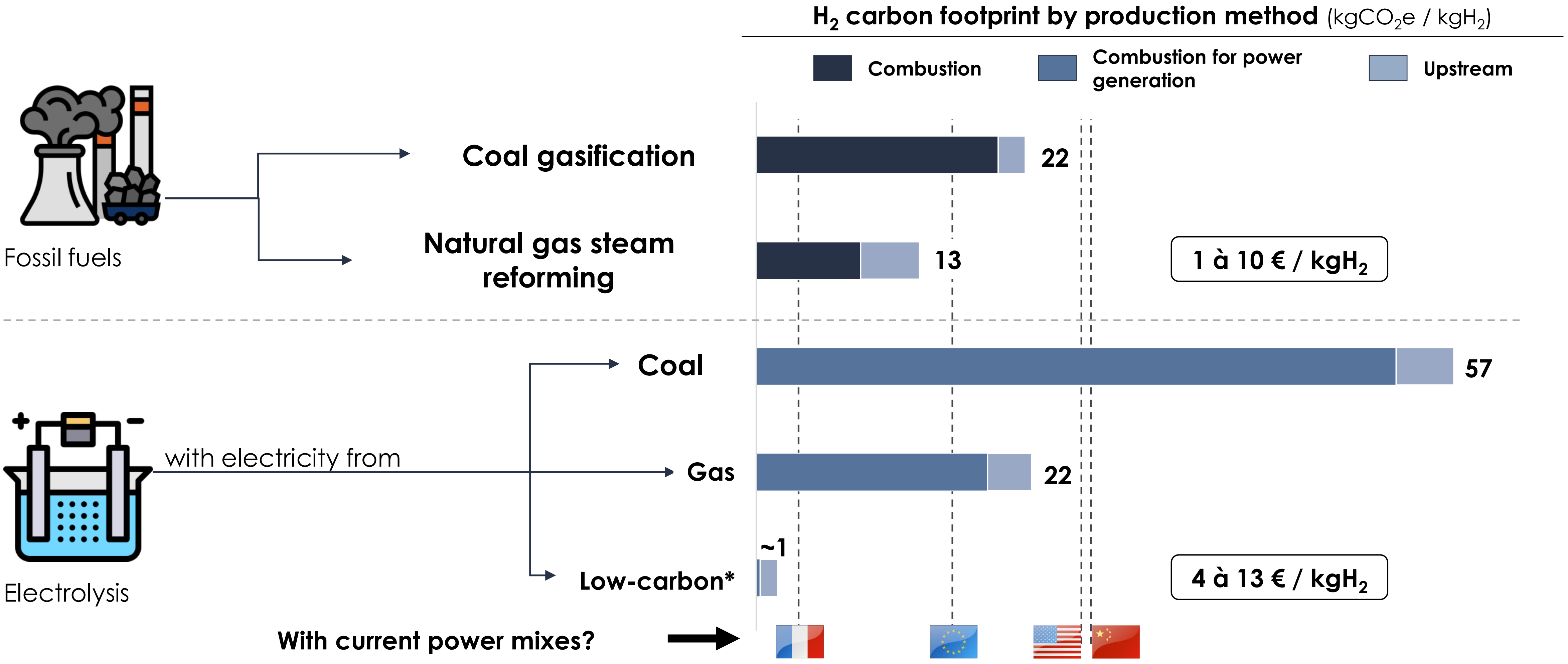
Source: The Future of Hydrogen, AIE 2019

Hydrogen electrolysis is not very energy-efficient

From fossil-fired generation to electricity production



Varying carbon footprints depending on production method



H_2 carbon footprint by production method ($kgCO_2e$ / kgH_2)

- ■ Combustion
- ■ Combustion for power generation
- ■ Upstream

Fossil fuels

Coal gasification

Natural gas steam reforming

1 à 10 € / kgH_2

Electrolysis

with electricity from

Coal

Gas

Low-carbon*

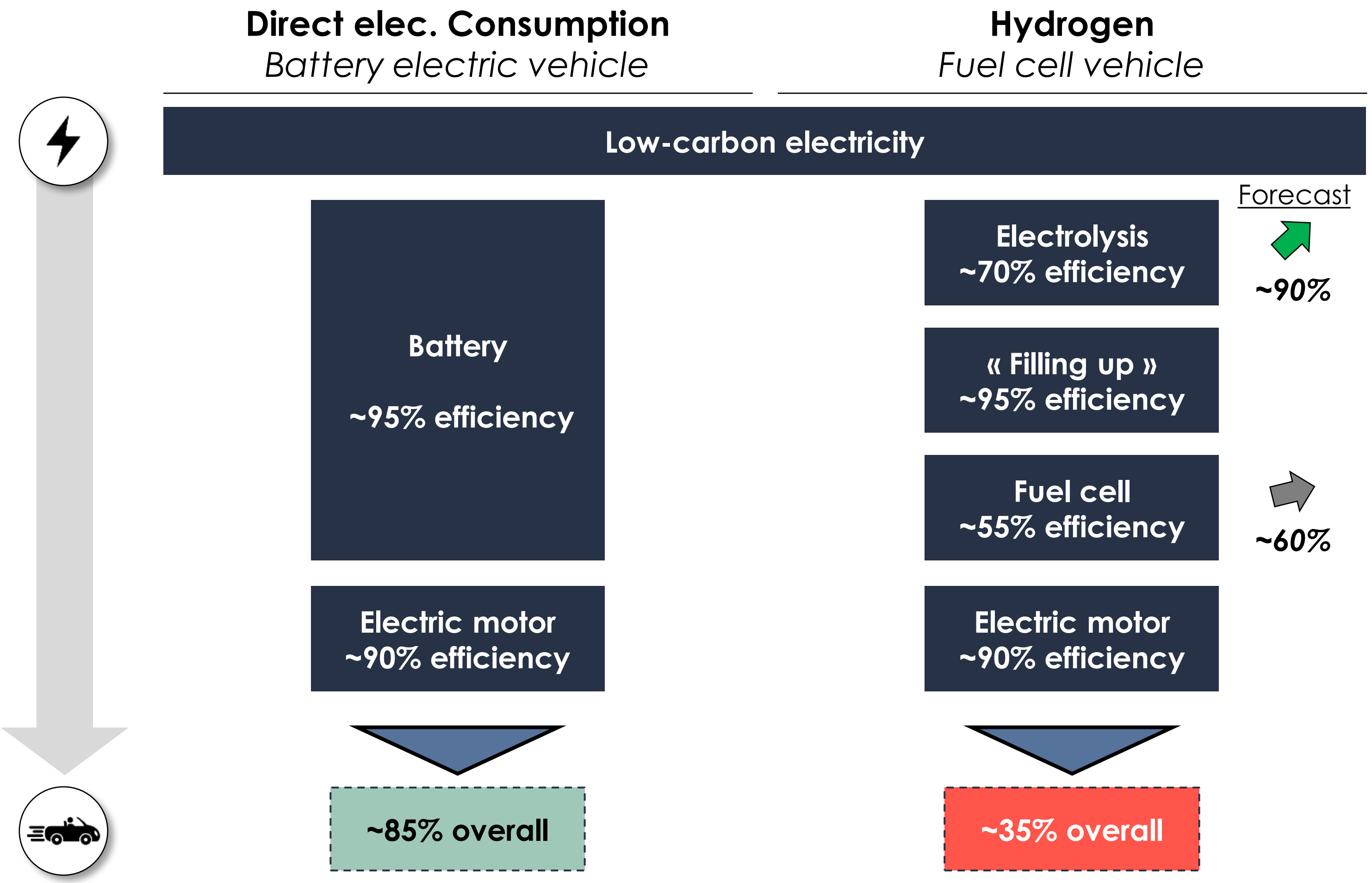
4 à 13 € / kgH_2

With current power mixes?

European taxonomy: Low-carbon H_2 = 3 kgCO2e / kgH2

*Low-carbon: wind, solar PV, hydro, nuclear; sources: ADEME, Carbone 4 analysis

Electric mobility illustration: hydrogen's energy efficiency deteriorates even further when downstream use is included



Direct elec. Consumption
Battery electric vehicle

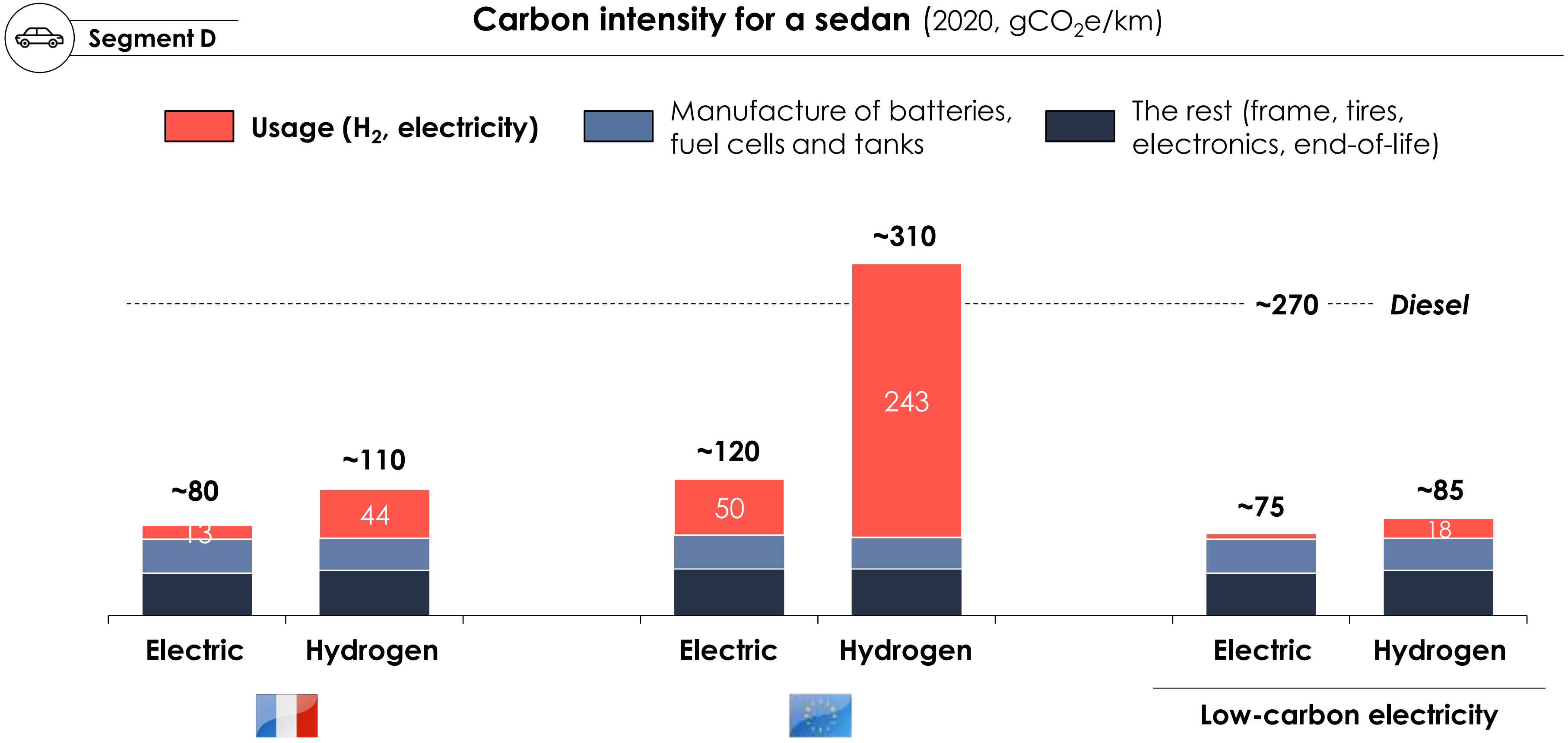
Hydrogen
Fuel cell vehicle

Low-carbon electricity

Direct elec. Consumption	Hydrogen	Forecast
Battery ~95% efficiency	Electrolysis ~70% efficiency	↗ ~90%
	« Filling up » ~95% efficiency	
	Fuel cell ~55% efficiency	→ ~60%
Electric motor ~90% efficiency	Electric motor ~90% efficiency	
~85% overall	~35% overall	

Sources: Transport & Environment, https://www.carbone4.com/publication-hydrogene-bas-carbone

The overall energy inefficiency of H_2 makes the 100% electric alternative, if it exists, even more efficient



Carbon intensity for a sedan (2020, gCO_2e/km)

Note: electric = battery electric car; hydrogen = fuel cell car
Sources: Carbone 4, https://www.carbone4.com/files/wp-content/uploads/2020/12/Transport-Routier-Motorisations-Alternatives-Publication-Carbone-4.pdf

Let's take a look at 11 uses in 3 key sectors

Industry	Transport	Energy
Ammonia production	Sea	Mixed consumption in gas networks
Methanol production	Air	Power system storage
Steel production	Road: trucks	Refinery
Heat use	Rail	

Intra-sector analysis: Industry

The value of low-carbon H2 (3 kgCO2e/kgH_2) is assessed according to the decarbonization potential, the relevant time horizon and the presence or absence of competing solutions with better decarbonization performance.

	Segment	Relevance of low-carbon H_2	Power decarbonation unit[1]	Timeframe[2]	Decarbonizing alternatives, complementary or competing
Industry	Ammonia production	✓	~73%	⌛	• CCS on the production site
	Methanol production	✓	~70%	⌛	
	Acier : DRI à l'H_2	✓	~76%	⌛ ⌛	• CCS on the production site • Scrap recycling with electric furnace • Gas-based direct reduction
	Steel: injection into BF-BOF	✗	~14%	⌛	
	High heat t°C	✓ / ~	~55%	⌛ ⌛	• Direct electricity (e.g. furnace) Biomass

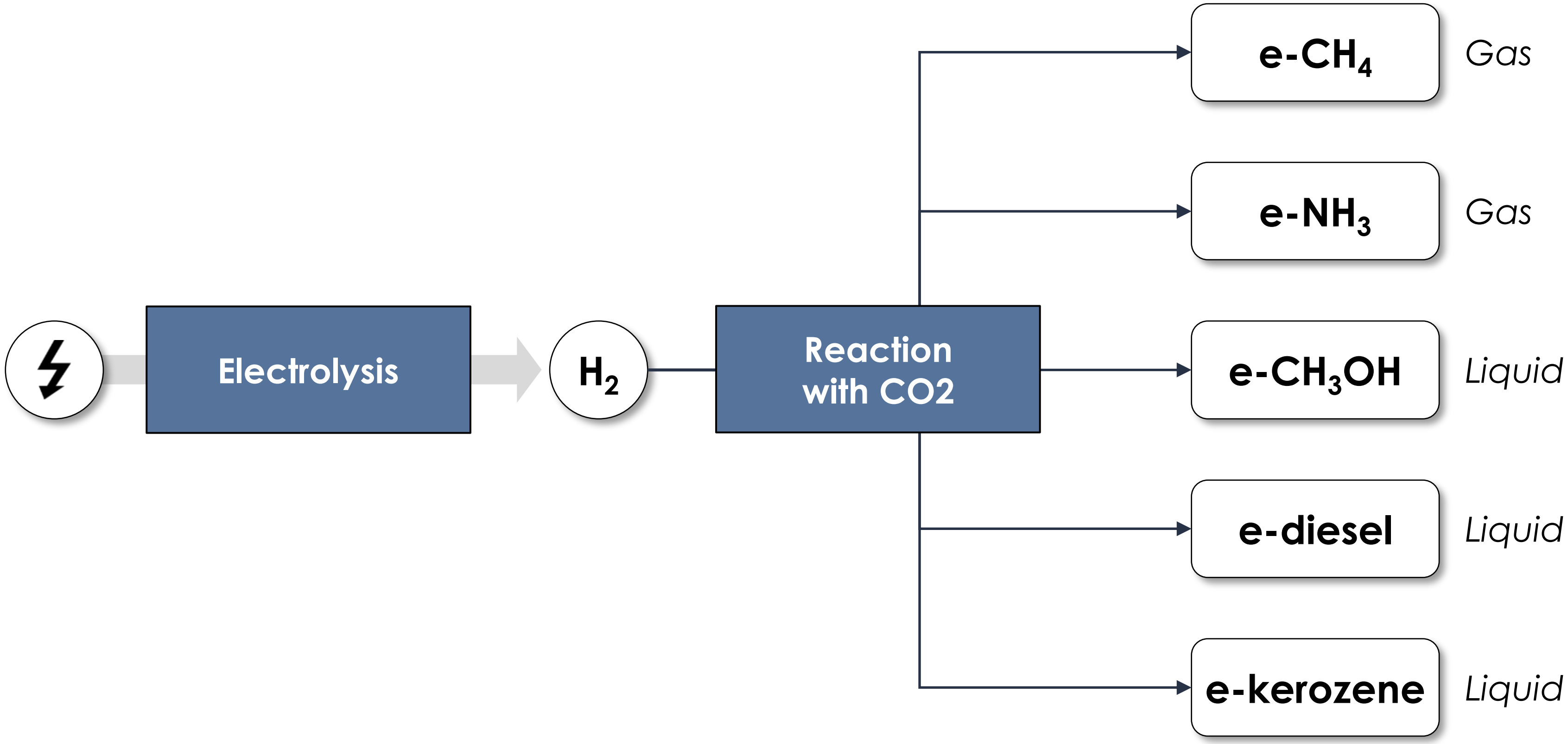
Legend:	⌛	⌛ ⌛	⌛ ⌛ ⌛
Deployable on …	Short term	Medium term	Long term

---

(1) The unit decarbonation power is calculated in relation to a reference situation, which is in the majority within the segment under analysis.

(2) The relevant time horizon is defined according to the technological maturity of the solution associated with the use of H2, but also to the context (e.g.: over time, refinery activity will drop sharply, so the need for low-carbon H2 is defined as transitory).

E-fuels = Power-to-X: a base of electricity, a step through H2, ending up with a molecule that our energy system already consumes



Electrolysis

H_2

Reaction with CO2

e-CH_4 *Gas*

e-NH_3 *Gas*

e-CH_3OH *Liquid*

e-diesel *Liquid*

e-kerozene *Liquid*

Intra-sector analysis: Transport

Legend:	⌛	⌛ ⌛	⌛ ⌛ ⌛
Deployable on …	Short term	Medium term	Long term

The value of low-carbon H2 (3 kgCO2e/kgH_2) is assessed according to the decarbonization potential, the relevant time horizon and the presence or absence of competing solutions with better decarbonization performance.

	Segment	**Relevance of low-carbon H_2**	**Power decarbonation unit**[1]	**Timeframe**[2]	**Decarbonizing alternatives, complementary or competing**
Transport	Rail	✓ / ~	~78%	⌛ ⌛	• Electrification: direct track or batteries
	Trucks	~ / ✗	~70%	⌛ ⌛	• Batteries • Bioenergies: bioGNV, 2G biofuels
	Sea: LH_2	✗	~66%	⌛ ⌛ ⌛	• Bioenergies: liquid biofuels 2G and BioGNL 2G
	Sea: e-ammoniac	~	~39%	⌛ ⌛	
	Sea: e-méthanol	✓	~50%	⌛	
	Sea: e-GNL	✓	~53%	⌛	
	Short to medium-haul air: direct use	✗	~66%	⌛ ⌛ ⌛	• Batteries • 2G biofuels
	Air: e-fuels	✓	~62%	⌛ ⌛	

---

(1) The unit decarbonation power is calculated in relation to a reference situation, which is in the majority within the segment under analysis.

(2) The relevant time horizon is defined according to the technological maturity of the solution associated with the use of H2, but also to the context (e.g.: over time, refinery activity will drop sharply, so the need for low-carbon H2 is defined as transitory).

Intra-sector analysis: Energy

The value of low-carbon H2 (3 $kgCO2e/kgH_2$) is assessed according to the decarbonization potential, the relevant time horizon and the presence or absence of competing solutions with better decarbonization performance.

Segment		Relevance of low-carbon H_2	Power decarbonation unit[1]	Timeframe[2]	Decarbonizing alternatives, complementary or competing
Energy	Refinery	~	~15%	⧗ Transitoire	- CCS on the production site
	Mixed in gas networks	✗	~4%	⧗	- Biomethane and e-methane
	Power system storage	**Required if a lot of variable renewable**	**n.a.**	⧗ ⧗	- Hydraulic reservoirs

Legend:

	⧗	⧗ ⧗	⧗ ⧗ ⧗
Deployable on …	Short term	Medium term	Long term

---

(1) The unit decarbonation power is calculated in relation to a reference situation, which is in the majority within the segment under analysis.

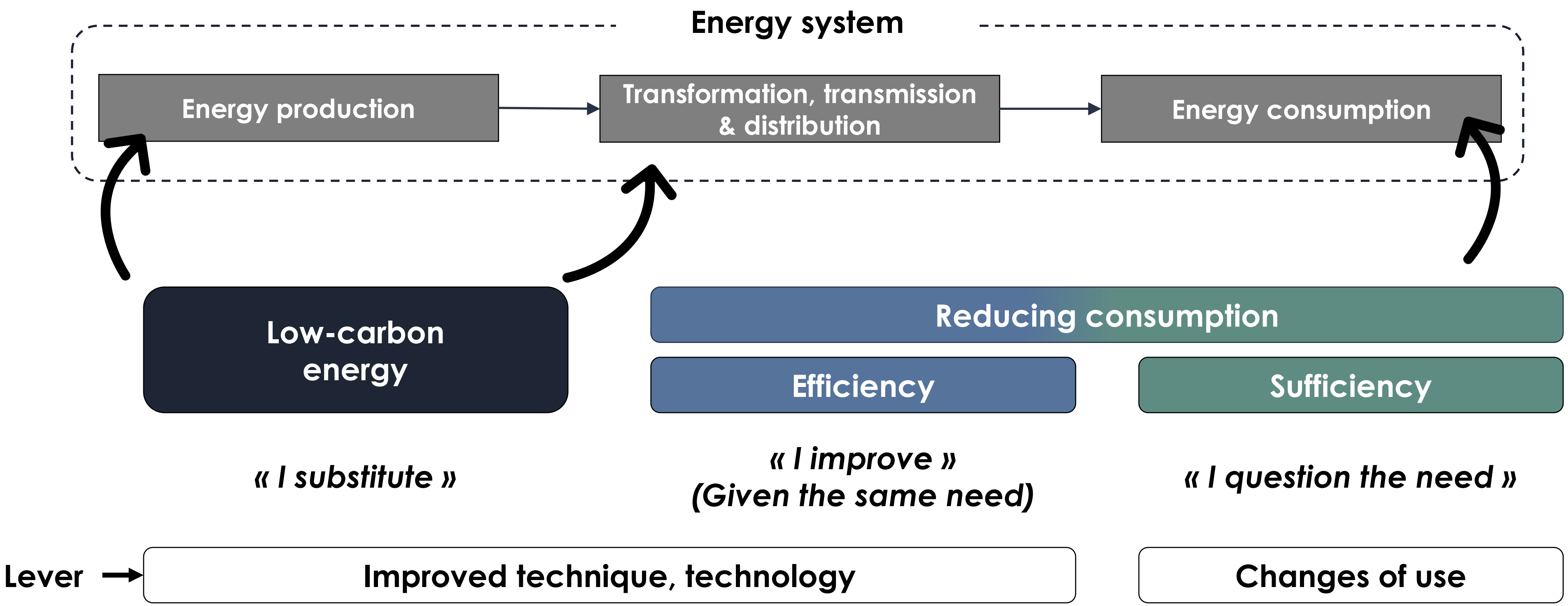
(2) The relevant time horizon is defined according to the technological maturity of the solution associated with the use of H2, but also to the context (e.g.: over time, refinery activity will drop sharply, so the need for low-carbon H2 is defined as transitory).

5-indicator dashboard: hydrogen

Uses →		1 MWh gas	1 MWh H_2	1 MWh heat	1 MWh liq. biofuel	1 MWh gas	1 MWh of electricity	
Indicators *In life cycle*	**Units**	**Natural gas**	**Hydrogen electrolysis**	**Wood**	**Biofuel 2^e Gén.**	**Biomethane**	**Existing nuclear**	**Photovoltaics** (ground, roof)
Greenhouse gases (energy)	$kgCO_2e$	~200	85-100 (leak) Electricity mix Future decline	~20	40 à 150	~40	~10	~40 *Further decline*
Critical materials	Kg	Not significative	**Platinum fuel cell** Electricity mix	Not significative	Not significative	Not significative	Not significative	Next-generation rare earths?
Land occupation (biodiversity, acceptability)	m^2	0,1	0,1 Electricity mix	500	250	250	0,1	10
Total costs	€	40 à 100€	70 à 150€ Electricity mix	40 à 80€	80 à 200€	80 à 100€	40 à 70€	40 à 180€
% « local » added value (local jobs, NRJ dependance)	%	< 50%	> 90% Electricity mix	> 90% *70% for materials*	Not yet mature	> 90%	> 90%	70% *Relocate, recycle?*
Other specific dimensions	-	Local pollution Social	Relevance = uses Ineffective NRJ	Climate : fire, droughts	Climate: yield	Local pollution risk Climate: yield	Accident risk Waste Climate: water	Variable

Sources: ADEME, ONU, IRENA, RTE

Energy mix: just a question of technologies?



Energy system

Energy production

Transformation, transmission & distribution

Energy consumption

Low-carbon energy

Reducing consumption

Efficiency

Sufficiency

« I substitute »

« I improve »
(Given the same need)

« I question the need »

Lever

Improved technique, technology

Changes of use

Energy return on energy invested (EROEI): definitions

Energy produced throughout the life of the asset

$$Energy\ return\ on\ energy\ invested = \frac{energy\ recovered}{invested\ energy}$$

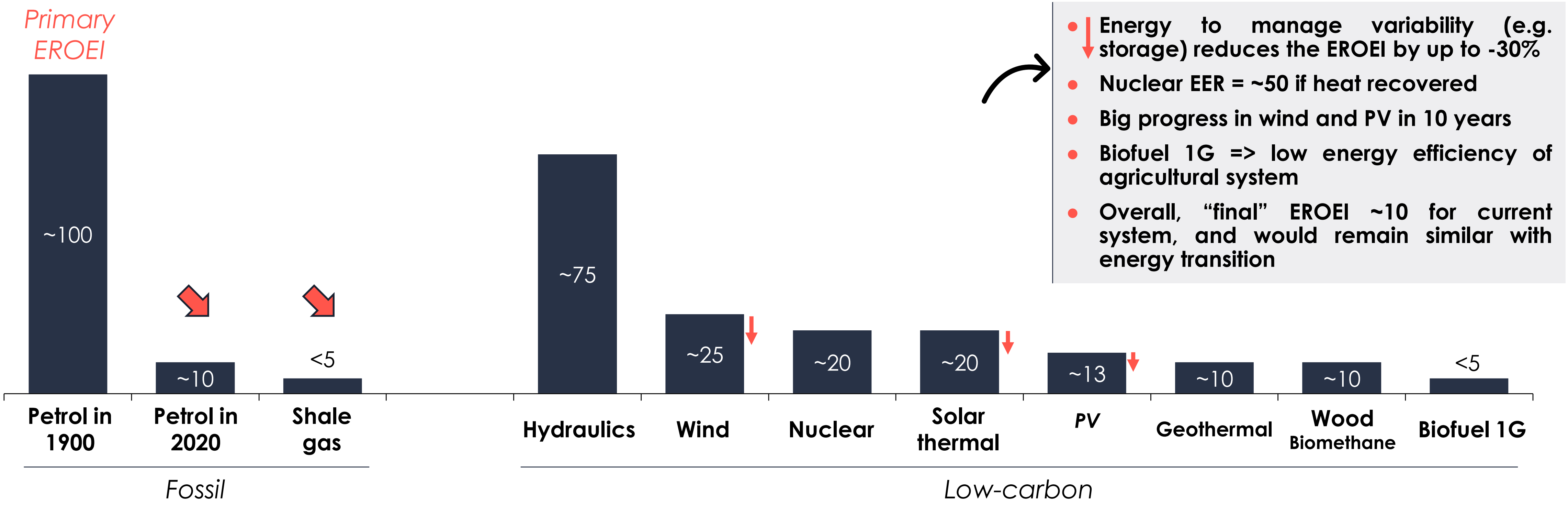
Energy consumed in the life cycle to dig, build, extract, manufacture, etc.

- If EROEI <1, you spend more energy than you recover
- Objective: maximize it by being energy-efficient over the entire life cycle

Energy return on energy invested (EROEI): low-carbon energies now more energy-efficient than fossil fuels

Energy return on energy invested per energy (2020)

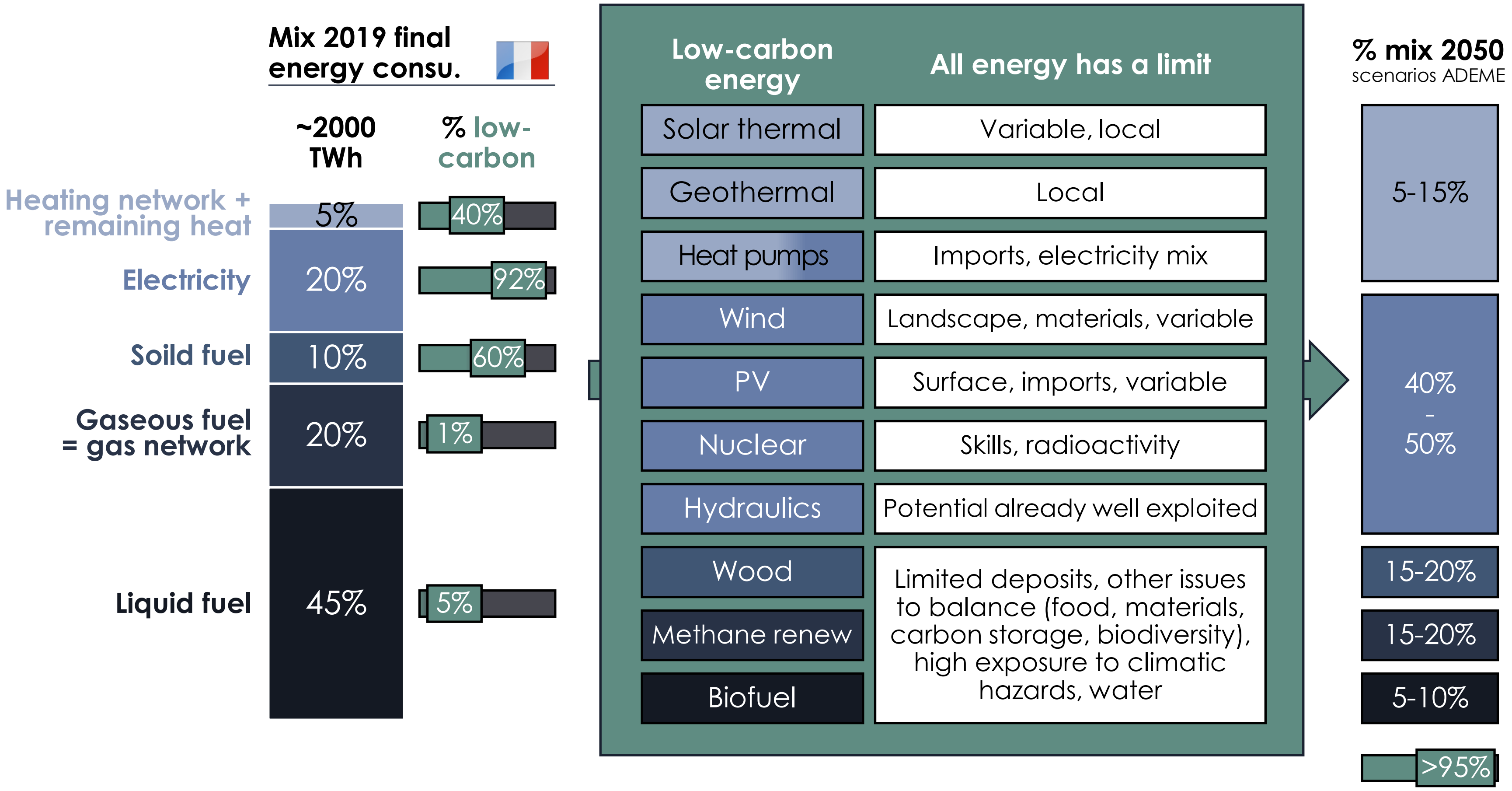
⚠ *Not the same service for each energy; average values* ⚠



- ↓ **Energy to manage variability (e.g. storage) reduces the EROEI by up to -30%**
- **Nuclear EER = ~50 if heat recovered**
- **Big progress in wind and PV in 10 years**
- **Biofuel 1G => low energy efficiency of agricultural system**
- **Overall, "final" EROEI ~10 for current system, and would remain similar with energy transition**

Sources: https://hal.science/hal-03780085/document // Kevin Pahud, Greg de Temmerman. Overview of the EROI, a tool to measure energy availability through the energy transition. 2022 8th International Youth Conference on Energy (IYCE'22), Jul 2022, Eger, Hungary. 10.1109/IYCE54153.2022.9857542. hal-03780085 ; https://www.mdpi.com/2071-1050/14/12/7098 // Energy Return on Investment of Major Energy Carriers: Review and Harmonization ;

2050 mix: >95% low-carbon energies with their limits; major challenges for grids



Mix 2019 final energy consu.

	~2000 TWh	% low-carbon
Heating network + remaining heat	5%	40%
Electricity	20%	92%
Soild fuel	10%	60%
Gaseous fuel = gas network	20%	1%
Liquid fuel	45%	5%

Low-carbon energy	All energy has a limit	% mix 2050 scenarios ADEME
Solar thermal	Variable, local	5-15%
Geothermal	Local	
Heat pumps	Imports, electricity mix	
Wind	Landscape, materials, variable	40% - 50%
PV	Surface, imports, variable	
Nuclear	Skills, radioactivity	
Hydraulics	Potential already well exploited	
Wood	Limited deposits, other issues to balance (food, materials, carbon storage, biodiversity), high exposure to climatic hazards, water	15-20%
Methane renew		15-20%
Biofuel		5-10%
		>95%

How much energy?

Notes: 2050 final energy mix; (1) ADEME S2 and S3 scenarios
Sources: négaWatt ; Transition(s) 2050, ADEME

Mix 2050: what reduction in energy consumption?

Energy mix 2050 – scenarios ADEME

100%	>95% low-carbon energy
5-15%	Heating network + remaining heat
40% - 50% (50-100 TWh H_2)	Electricity
15-20%	Solid fuel
15-20%	Gas network
5-10%	Liquid fuel

S1 GÉNÉRATION FRUGALE	S2 COOPÉRATIONS TERRITORIALES	S3 TECHNOLOGIES VERTES	S4 PARI RÉPARATEUR
• Searching for meaning • Frugality chosen but also constrained • Preference for local products • Nature in sanctuary	• Sustainable evolution of lifestyles • Sharing economy • Equity • Preservation of nature enshrined in law	• More new technologies than sufficiency • Green consumerism for the benefit of solvent populations, connected society • Nature's services optimized	• Maintaining mass consumption • Nature is a resource to be exploited • Confidence in ability to repair damage to ecosystems
~800 TWh **-55%** (VS 2015)	**~825 TWh** **-50%** (VS 2015)	**~1075 TWh** **-40%** (VS 2015)	**~1350 TWh** **-25%** (VS 2015)

+ Suffiency ⟷ **+Techno**

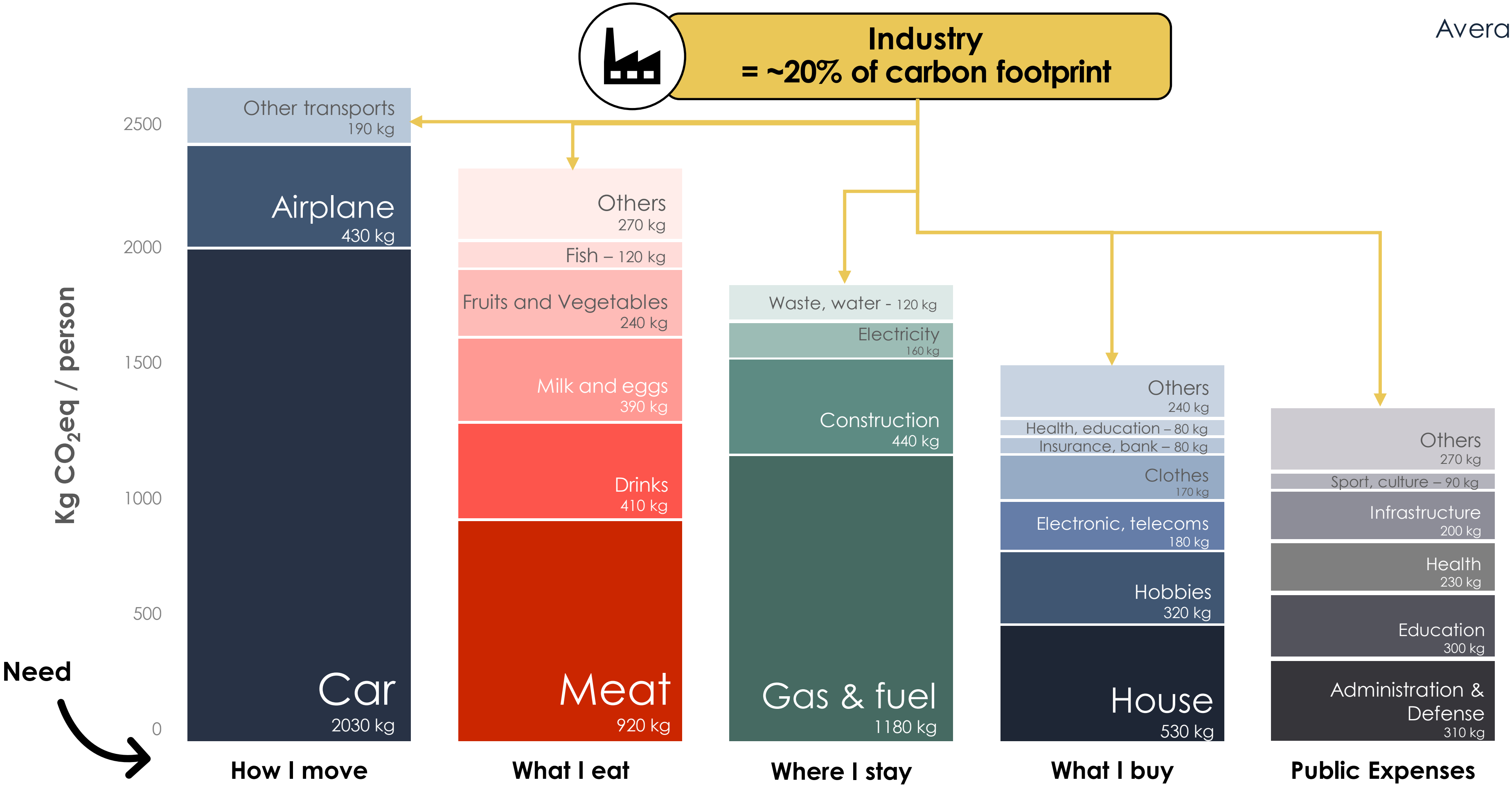
⚠ **Not all scenarios are equivalent: increased water consumption, artificialization, forest exploitation, etc.**

Notes: 2050 final energy mix; Sources: Transition(s) 2050, ADEME

Industry and mass consumption

Average Carbon Footprint in France in 2019

9,9 tCO_2eq / person



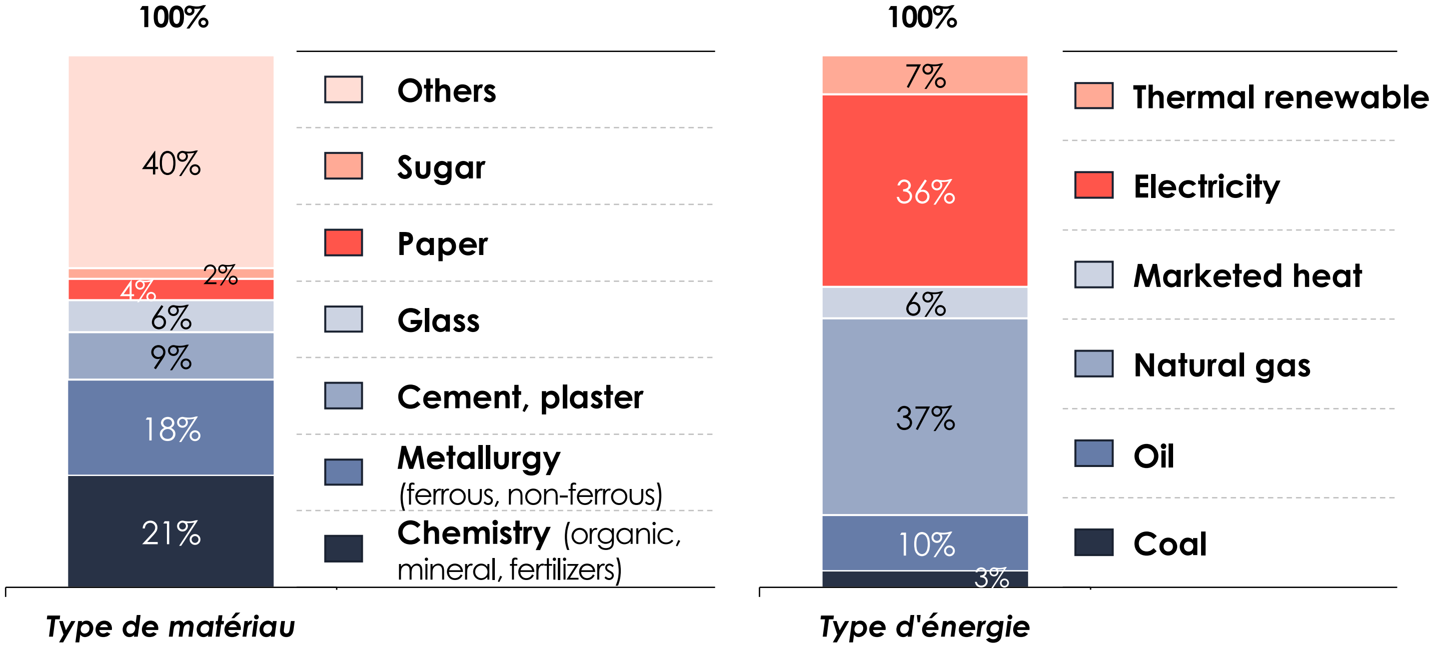
	How I move	What I eat	Where I stay	What I buy	Public Expenses
$\text{kgCO}_2\text{e/person}$	2650 kg	2350 kg	1900 kg	1600 kg	1400 kg
kWh/person	9 000 kWh	3 000 kWh	10 000 kWh	7 000 kWh	7 000 kWh
% low-carbon energy	5%	15%	50%	40%	45%

⚠ **Life cycle data: all the energy and emissions required to satisfy a need**

Gases included: CO2 (excluding LULUCF France), CH4, N2O, HFC, SF6, PFC, H2O (condensation trails).
Source : MyCO2 par Carbone 4 d'après le ministère de la Transition écologique, le Haut Conseil pour le Climat, le CITEPA, Agribalyse V3 et INCA 3.

Industry is the transformation of materials using energy

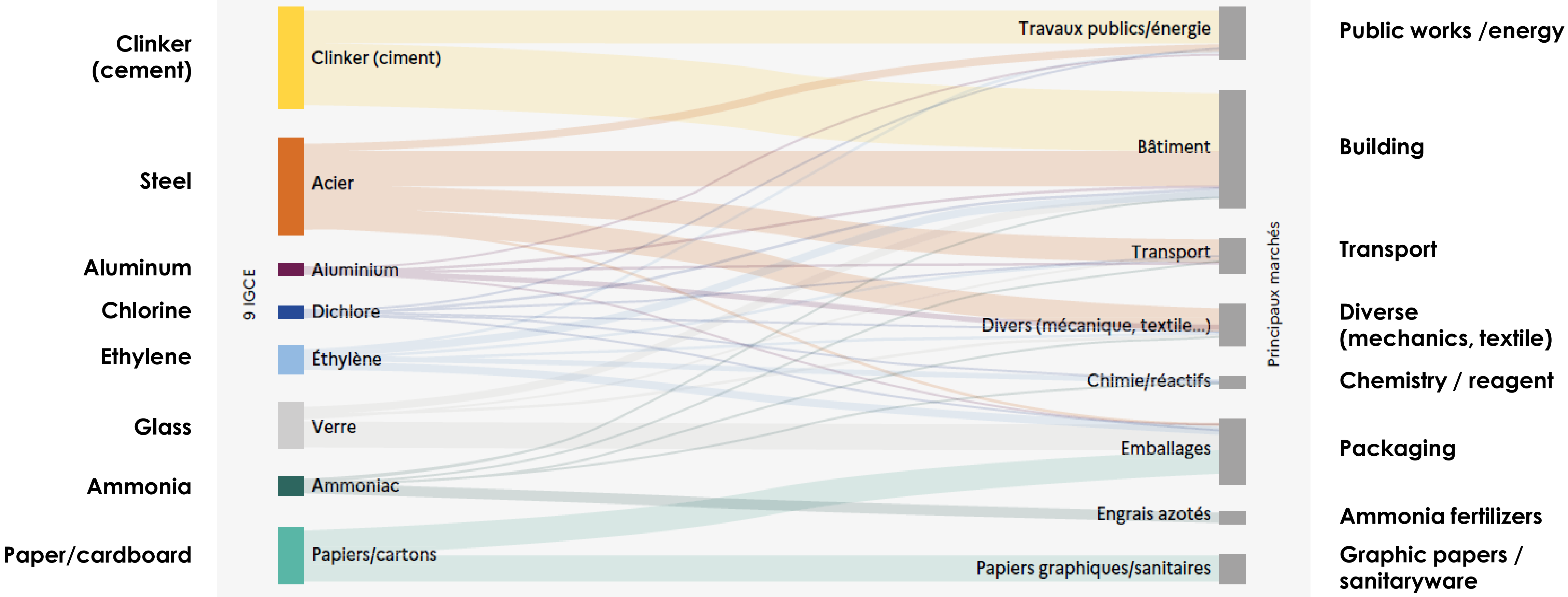
Energy consumption (%)



Note: Segmentation by material dates from 2016, segmentation by energy type from 2021.
Source: Transition(s) 2050, ADEME ; https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-energie-2022/19-bilan-de-lenergie-en-france

These materials are found in all downstream sectors

Figure 4 *Principaux flux de matériaux en provenance de l'industrie lourde (IGCE) en 2014*



Source: Transition(s) 2050, ADEME

Our balance of trade in “industrial” manufactured goods has been in deficit for more than five decades

	Trade balance	Production	Consumption	Prod/Cons.
	Bn €			
Clothing, leather, textiles	🔴 -13,1	22,9	36	0,64
Wood, paper	🔴 -4,1	30	34,1	0,88
Chemistry	🟢 11	73,4	62,4	1,18
Pharmacy	🟢 1,8	38,3	36,5	1,05
Rubber and plastics	🔴 -5,7	34,6	40,3	0,86
Metallurgy and metal products	🔴 -5,8	83,4	89,2	0,93
IT, electronics, optics	🔴 -13,7	36,2	49,9	0,73
Electrical equipment	🔴 -3,8	31,8	35,6	0,89
Machinery and equipment	🔴 -2,1	48,5	50,6	0,96
Automotive	🔴 -4,5	105,5	110	0,96
Other transport equipment	🟢 20,7	52	31,3	1,66
Furniture & others	🔴 -8,1	21,8	29,9	0,73

Tableau 5 - Production, consommation et solde commercial (en milliards d'euros) de plusieurs secteurs de l'industrie française en 2014, et ratio production/consommation (P/C)

Source : INSEE

So what do we do?

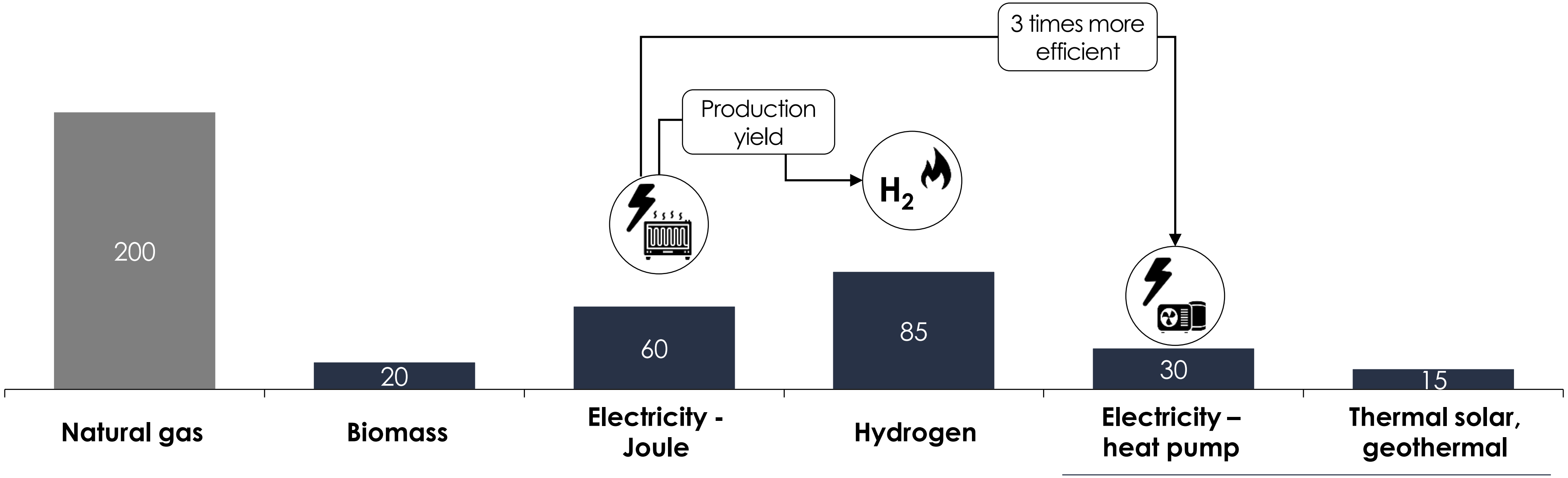
Breakdown of the main levers of emissions (direct and indirect) from a manufactured good

CO_2 = Materials + Manufacturing + Transport + Use + Life time % utilization + End of life

	Materials	Manufacturing	Transport	Use	Life time % utilization	End of life
Low-carbon energy	• Biosourced materials	• Low-carbon energy	• Low-carbon energy	• Electric, elbow grease	-	• Low-carbon energy
Energy efficiency	• Recycled materials	• Process optimization	• Engine upgrade	• Engine upgrade	-	• Recycling
Sufficiency	• Reduce weight	• Sufficient use in the plant	• Train, river • Local • Speed, eco-driving	• Reduce size • Sufficient use of the property	• Robust • Repairable • Shared	• Refuse • Reduce • Reuse

Biomass should be used for high temperaturesAlternative solutions exist for low temperatures

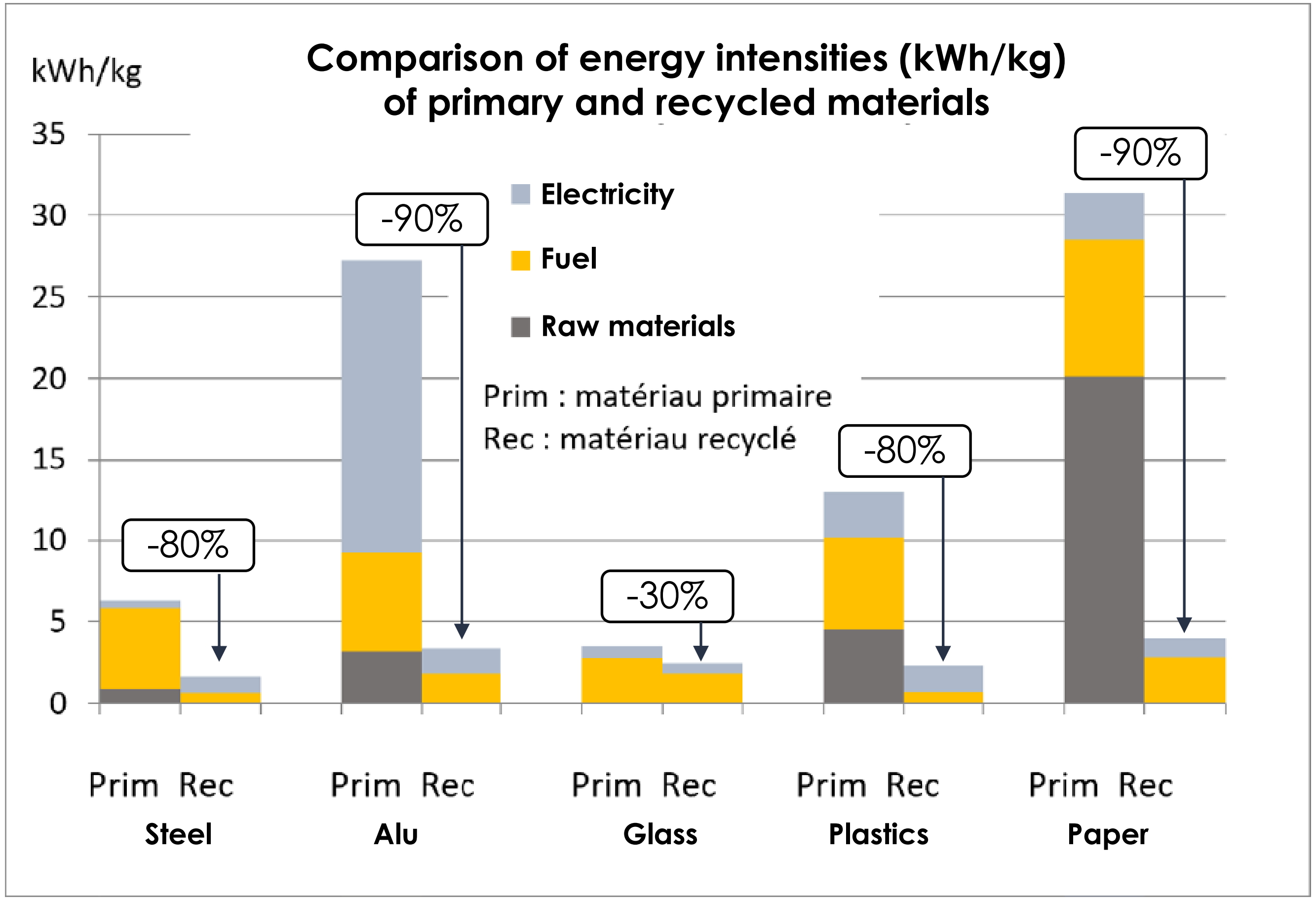
Climate impact by type of energy for heating use (gCO_2e/kWh PCS)



T°C window →	**HIgh**	**Medium-high**	**High**	**Low (<200°C)**
Other limits →	**Limited resources**	**Technology not available for all processes**	**High costs**	**High upfront investment**

Sources: ADEME, AIE, analyses Carbone 4

Recycling enables significant reductions in energy consumption



Comparison of energy intensities (kWh/kg) of primary and recycled materials

Share of recycled materials - négaWatt

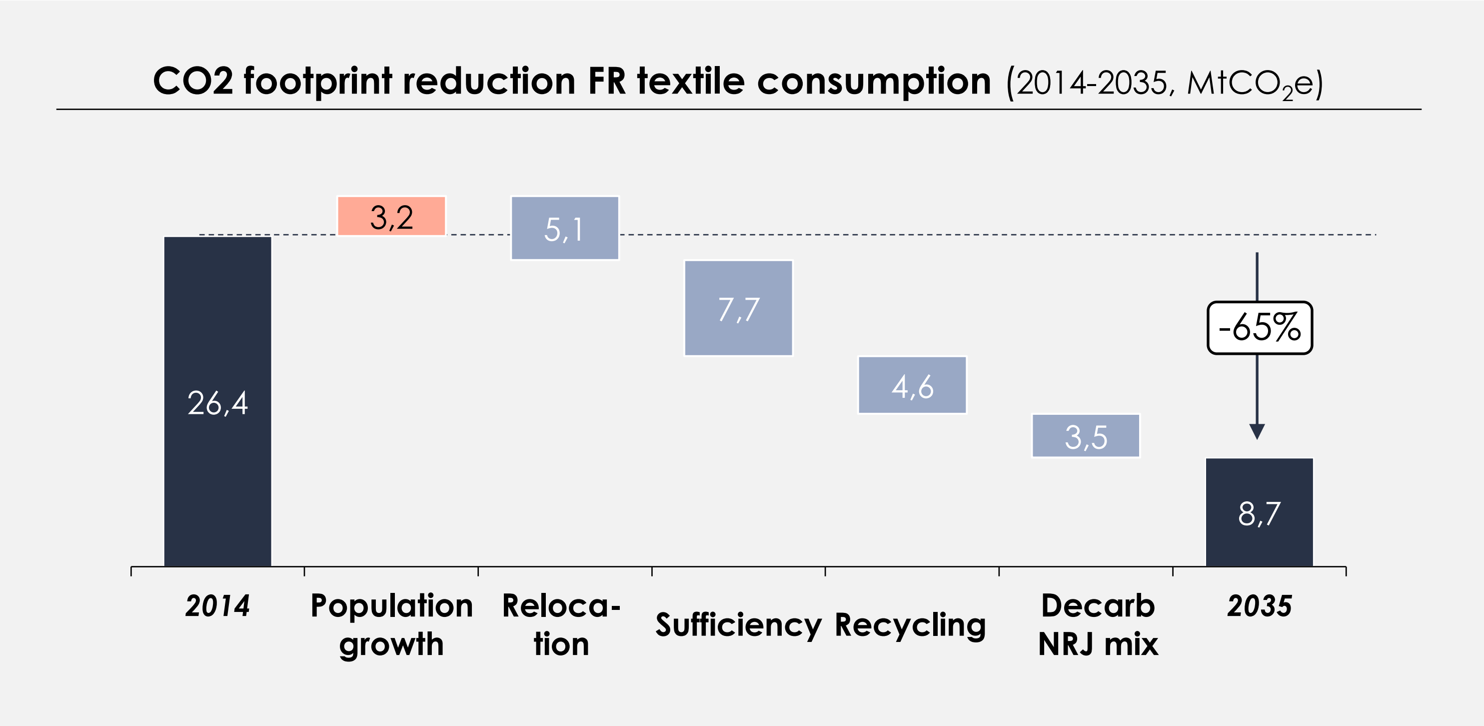
	2014	2050	2050
	Real	Possible	Real
Steel	43%	80%	80%
Alu	55%	85%	68%
Copper	17%	95%	70%
Lithium	0%	90%	77%
Hollow glass	57%	80%	50%
Bitumen	0%	90%	90%
Lubricants	0%	90%	90%
Plastics	6%	90%	41%

Room for improvement, but beware of the 100% myth

- **Not everything can be collected.** Ex: titanium used in toothpaste, paint pigments, etc.
- **Not everything can be recycled.** Ex: metal alloys: "Complicated to recover flour and eggs from a cake"
- **Not everything can be recycled at the right quality level.** Ex: food-soiled cardboard packaging

Source: négaWatt, Bihouix

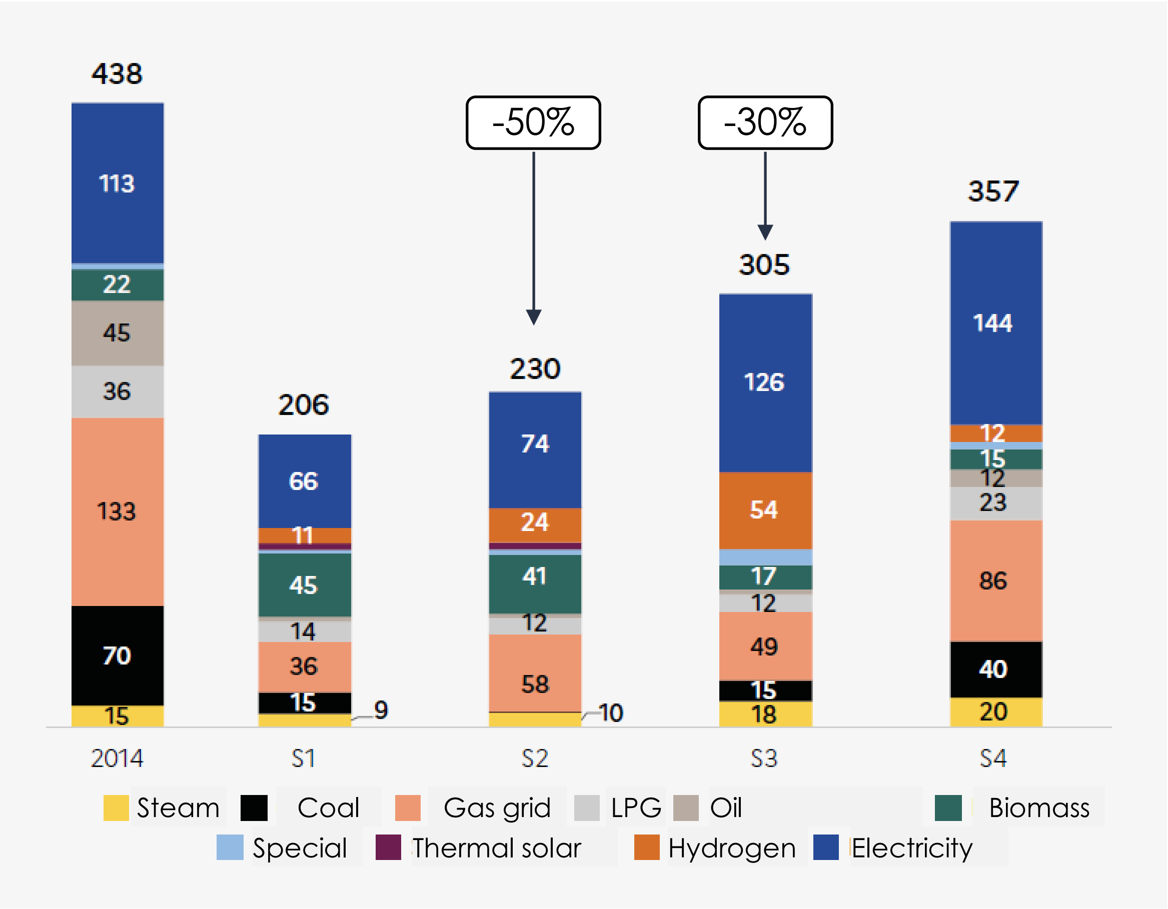
Textiles: négaWatt positions the various levers in this sector



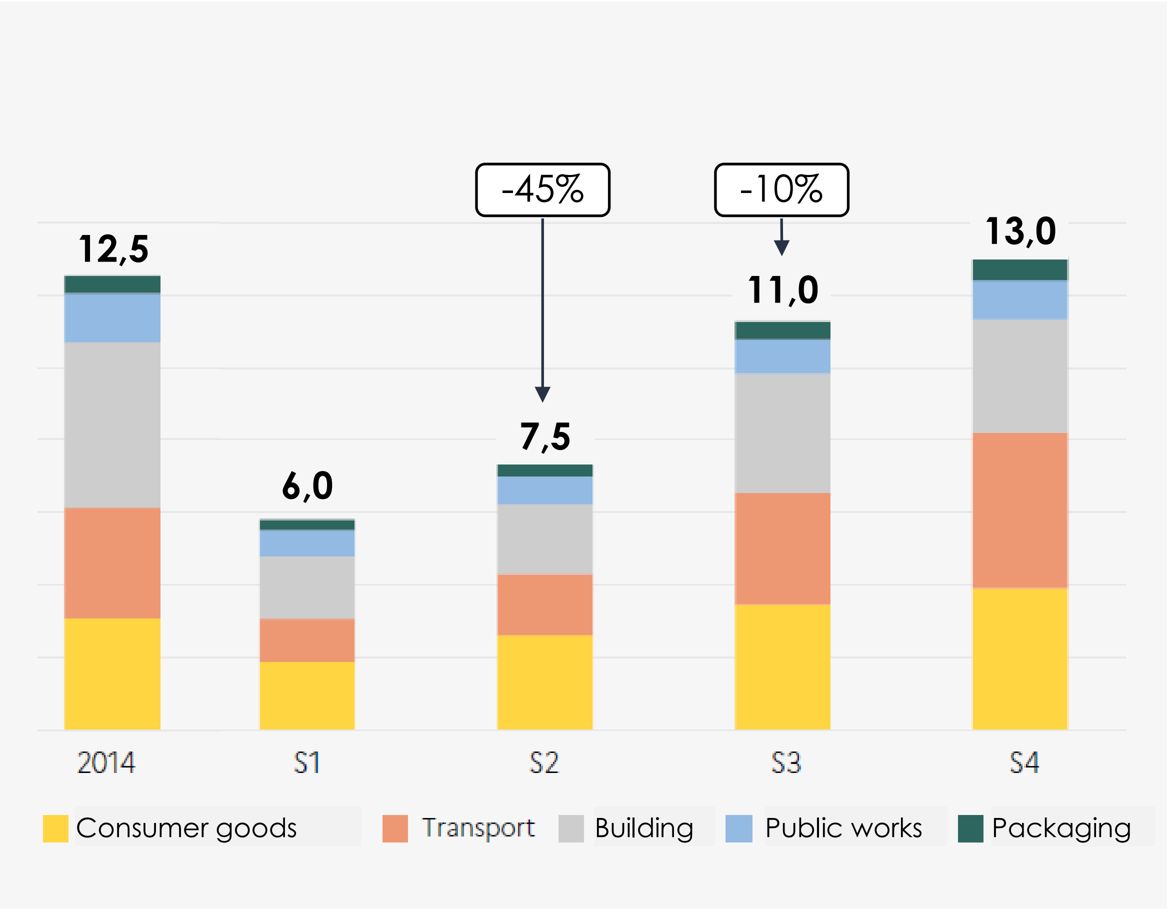
Source: Scénario négaWatt 2022

Industry in 2050: sufficiency and efficiency can reduce consumption by between 30% and 50%

Industrial energy consumption in 2050 (TWh)



Steel demand by sector in 2050 (Mtonnes)



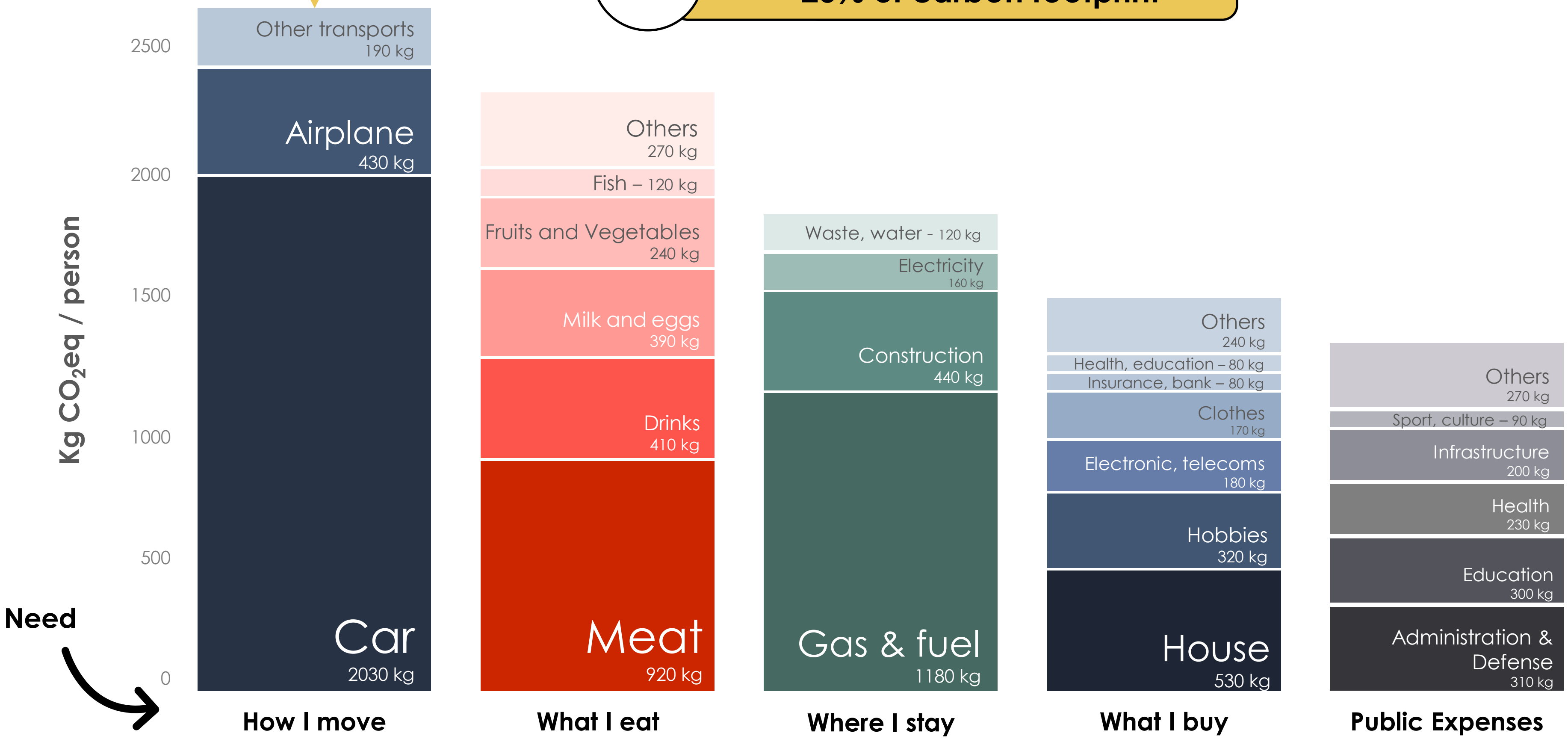
Notes: energy consumption including energy and non-energy uses.
Sources: Transition(s) 2050, ADEME

Short distance passenger mobility

Average Carbon Footprint in France in 2019

9,9 tCO_2eq / person

Passenger mobility = ~25% of carbon footprint

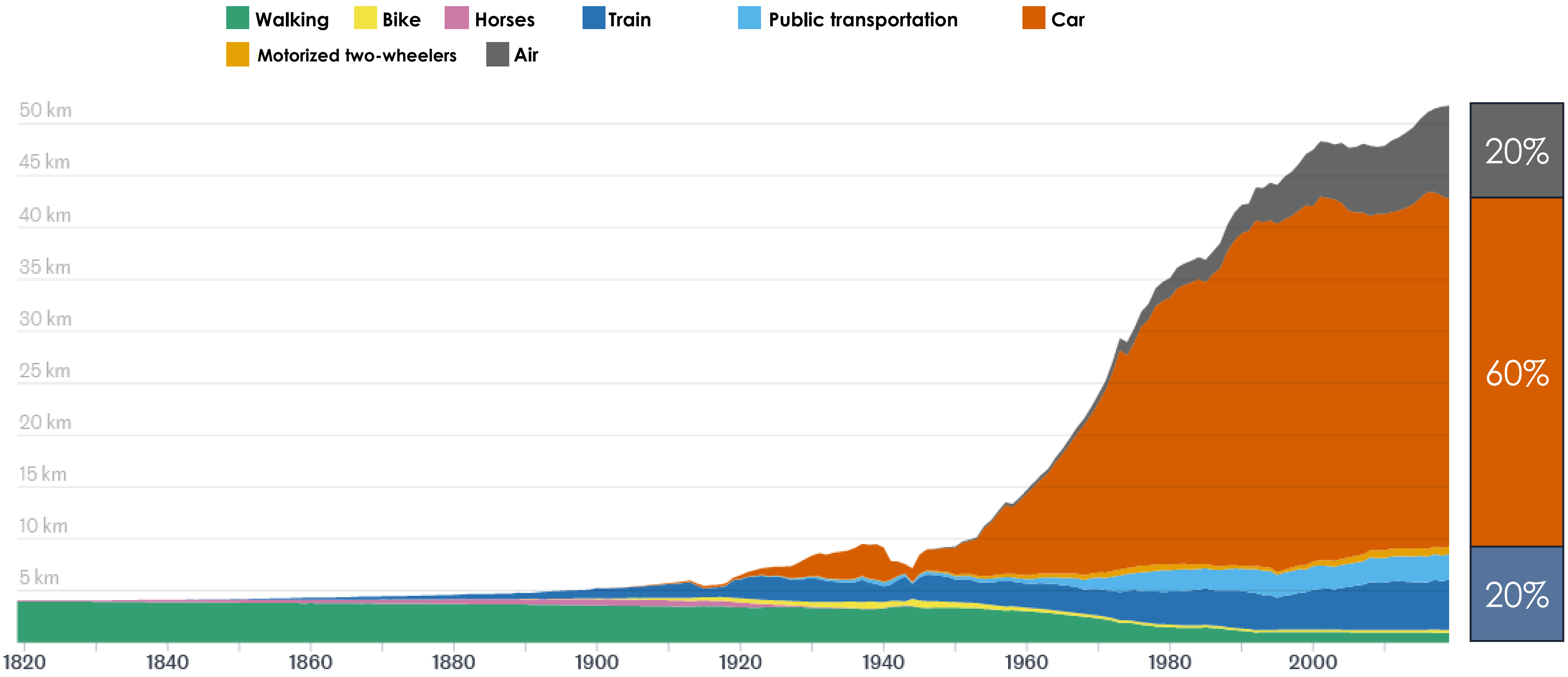


	How I move	**What I eat**	**Where I stay**	**What I buy**	**Public Expenses**
$kgCO_2e$/person	**2650 kg**	**2350 kg**	**1900 kg**	**1600 kg**	**1400 kg**
kWh/person	**9 000 kWh**	**3 000 kWh**	**10 000 kWh**	**7 000 kWh**	**7 000 kWh**
% low-carbon energy	**5%**	**15%**	**50%**	**40%**	**45%**

⚠ **Life cycle data: all the energy and emissions required to satisfy a need**

Gases included: CO2 (excluding LULUCF France), CH4, N2O, HFC, SF6, PFC, H2O (condensation trails).
Source : MyCO2 par Carbone 4 d'après le ministère de la Transition écologique, le Haut Conseil pour le Climat, le CITEPA, Agribalyse V3 et INCA 3.

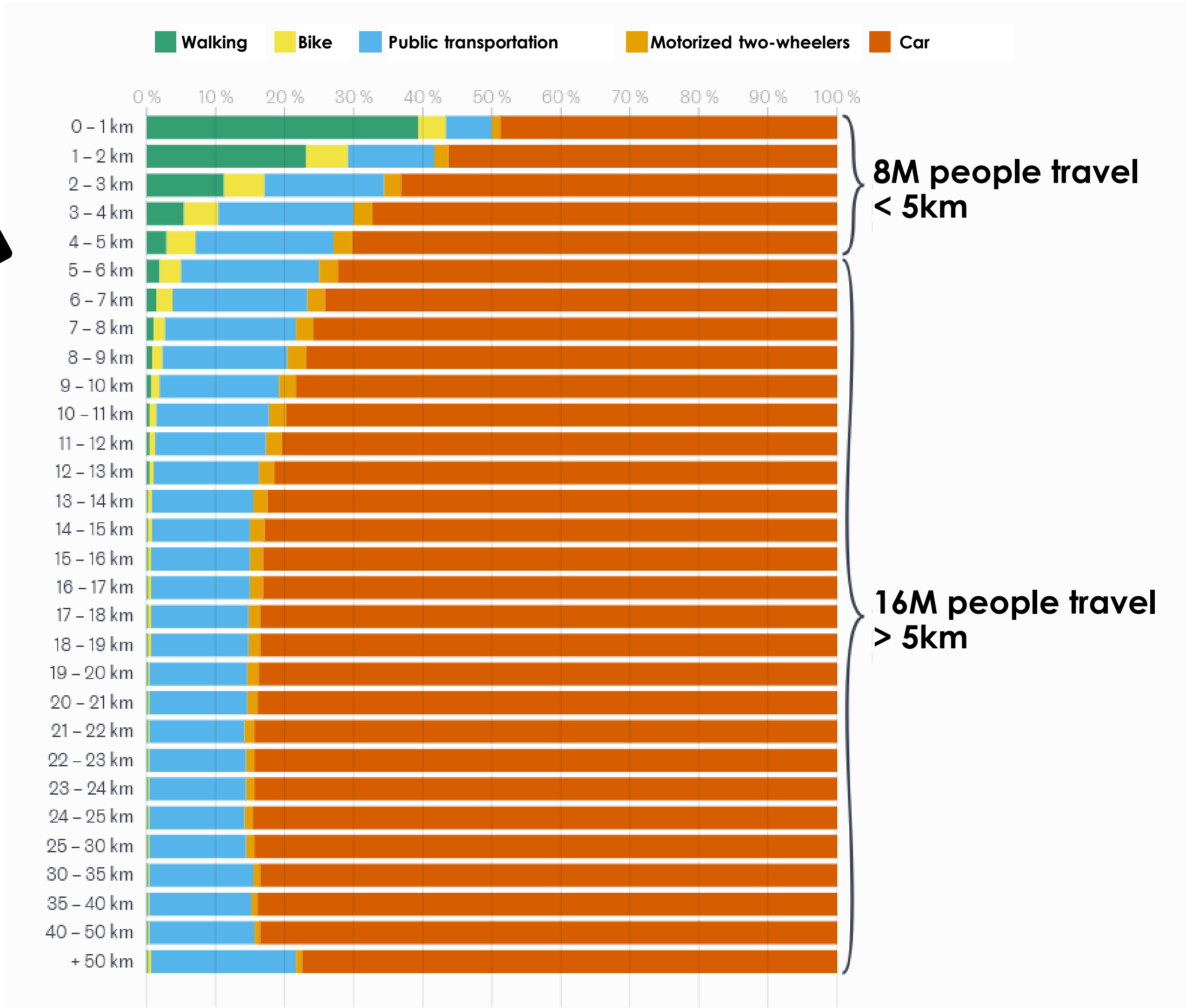
Average distance travelled per person per day, by mode of transport



https://www.lemonde.fr/les-decodeurs/article/2023/01/22/qui-pourrait-se-passer-de-sa-voiture-six-graphiques-pour-analyser-nos-trajets-du-quotidien_6158829_4355770.html#xtor=AL-32280270-[mail]-[ios]

The omnipresence of the car in short-distance travel

<u>Proportion of modes of transport by commuting distance</u> (2019)



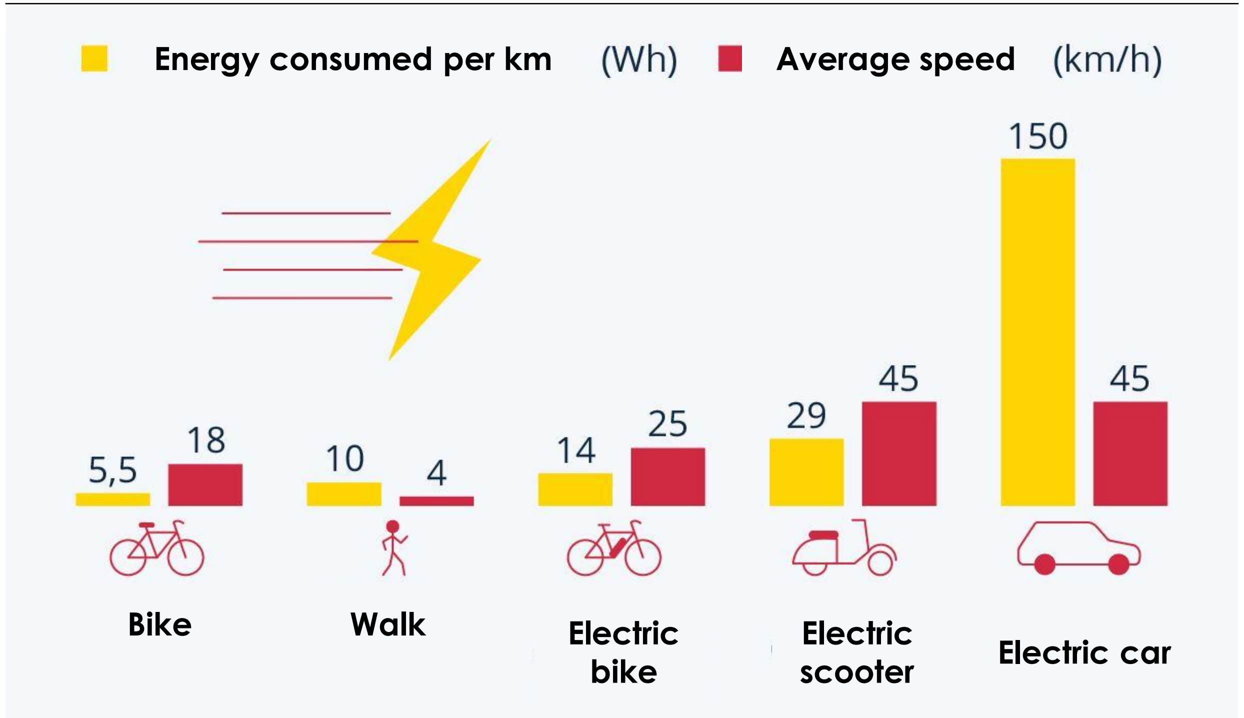
8M people travel < 5km

16M people travel > 5km

https://www.lemonde.fr/les-decodeurs/article/2023/01/22/qui-pourrait-se-passer-de-sa-voiture-six-graphiques-pour-analyser-nos-trajets-du-quotidien_6158829_4355770.html#xtor=AL-32280270-[mail]-[ios]

Cultural marker: “A (bigger and bigger) car for everyone”

The car, queen of energy inefficiency

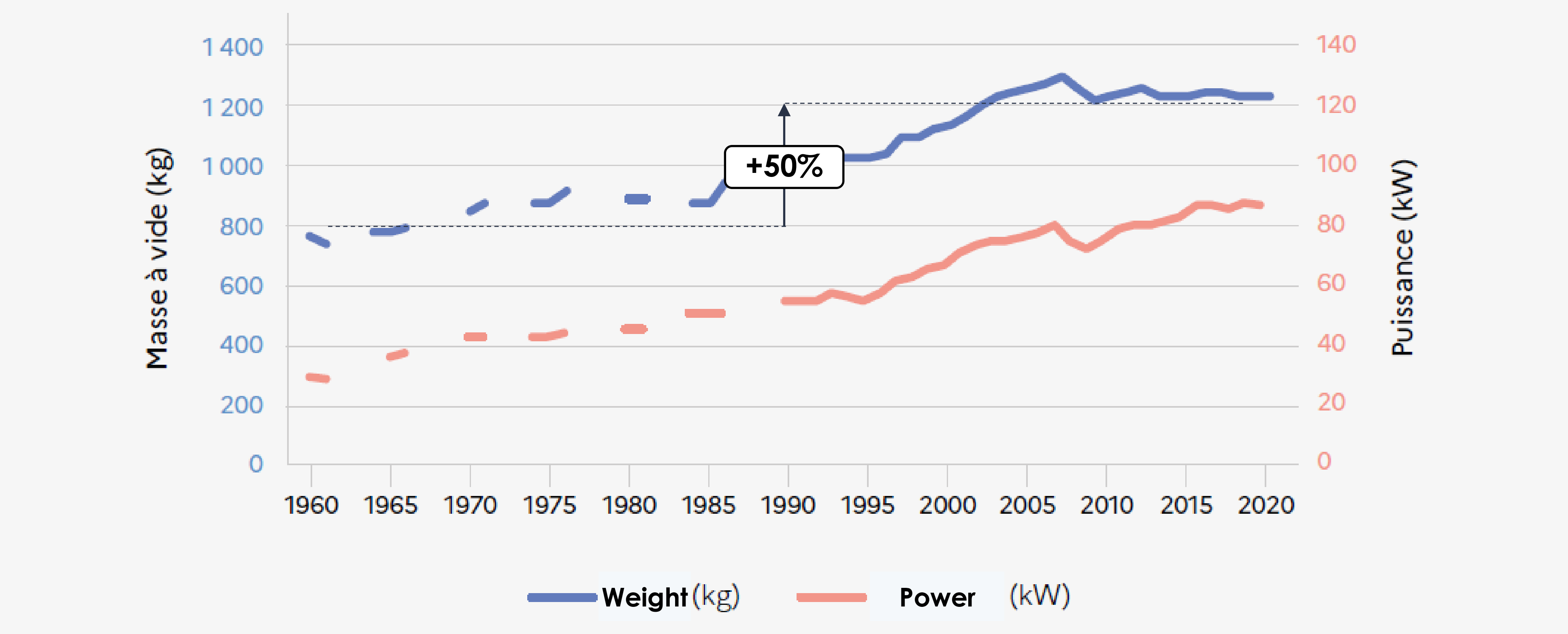


Even worse for internal combustion cars

Sources: Transports urbains – L’avenir des véhicules intermédiaires (n°141, 2022) ; https://www.cc37.org/le-chiffre-du-mois-3-milliards-vs-46-milliards/ ; https://www.vie-publique.fr/eclairage/273112-tableau-du-reseau-routier-francais ; https://www.fntp.fr/data/decryptages/les-amenagements-cyclables-se-deplacer-autrement-et-plus-sobrement ; https://assorail.fr/actualites-ferroviaire/chiffres

Rebound effect: despite these drawbacks, an ever heavier car that wipes out the gains in fuel efficiency

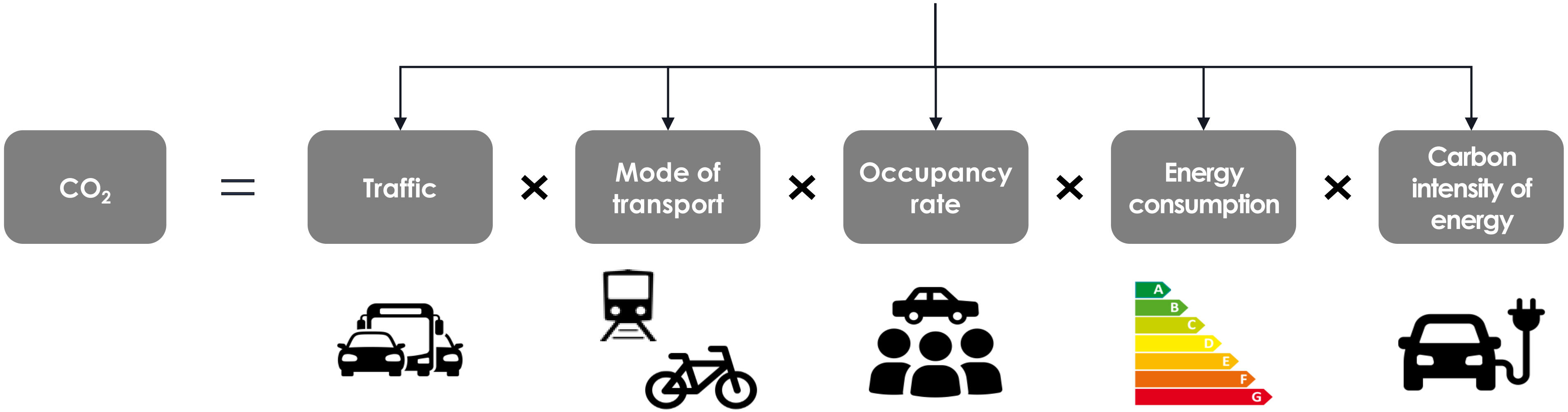
Trends in the characteristics (weight, power) of new passenger cars in France (1960-2020)



Sources: Transition(s) 2050, ADEME

So what do we do?

Breakdown of <u>direct</u> emissions from passenger transport

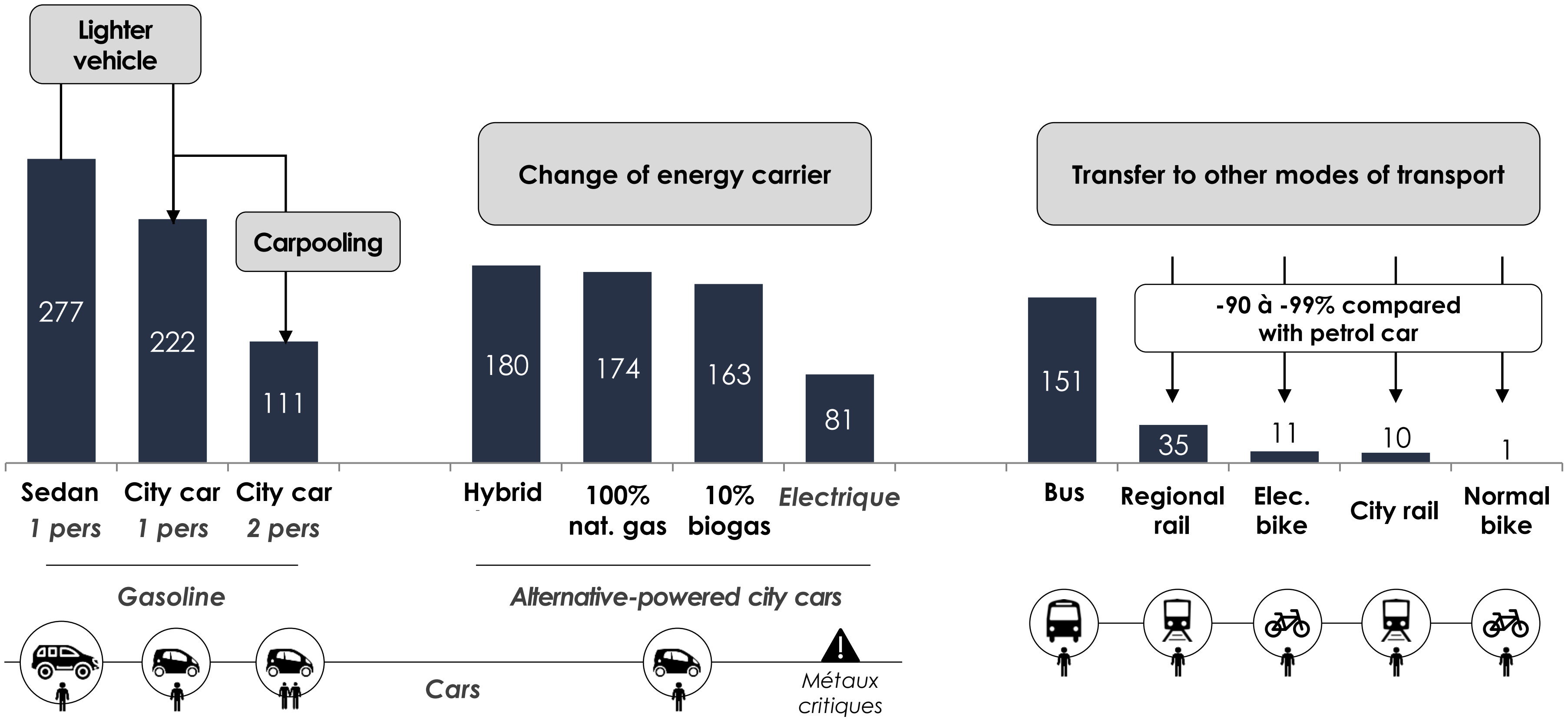


CO_2 = Traffic × Mode of transport × Occupancy rate × Energy consumption × Carbon intensity of energy

- **Traffic**: *Number of vehicles on the road and distances travelled*
- **Mode of transport**: *Trains and bicycles consume less energy to transport a person*
- **Occupancy rate**: *The fuller the vehicle, the lower the energy consumption per person*
- **Energy consumption**: *The more efficient the engine, the lighter the vehicle, the lower the speed, the lower the energy consumption*
- **Carbon intensity of energy**: *The more decarbonized the energy, the lower the emissions (e.g. electricity)*

Trains and bicycles are the least carbon-intensive modes of transport

Emissions generated by mode of transport (2018, gCO_2e/passager.km)



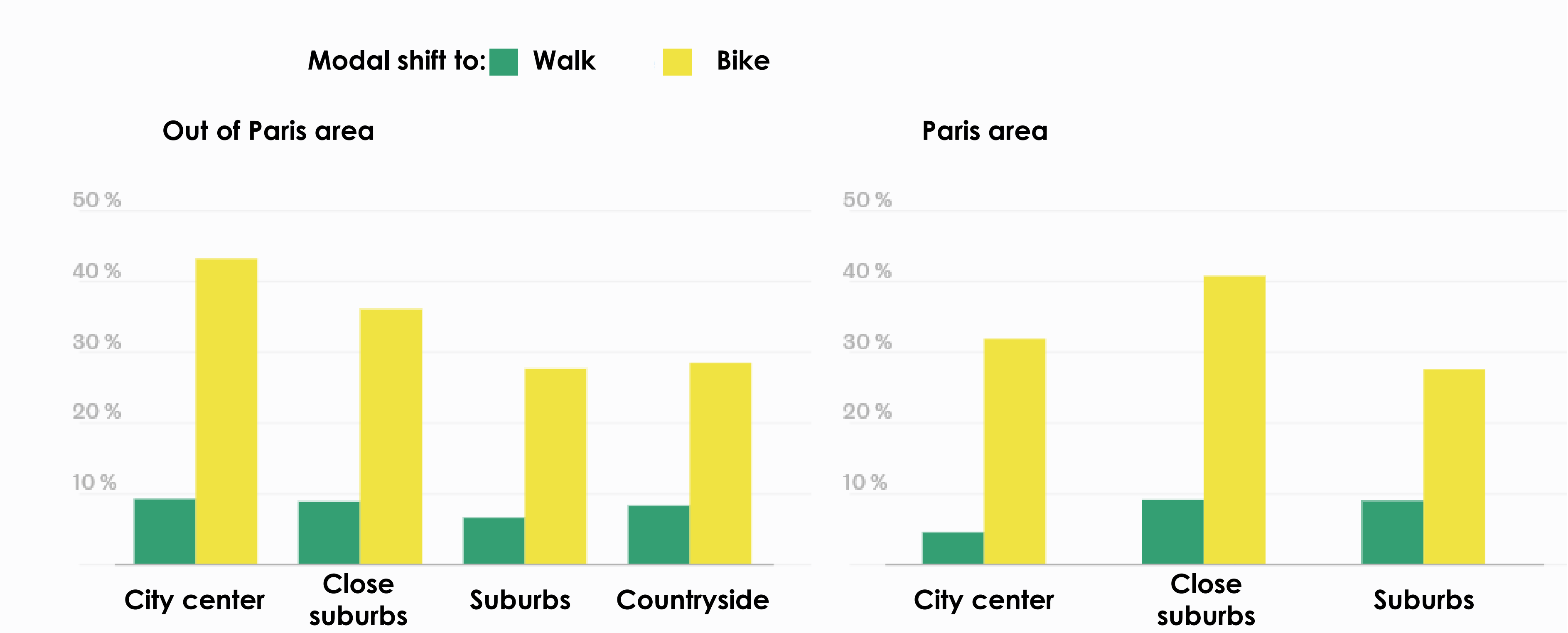
Other sufficiency measures

- **110 km/h instead of 130 km/h means 25% energy savings**
- **Reduce distances: work closer together, consolidate journeys, etc.**

Sources: Carbone 4, ADEME, négaWatt

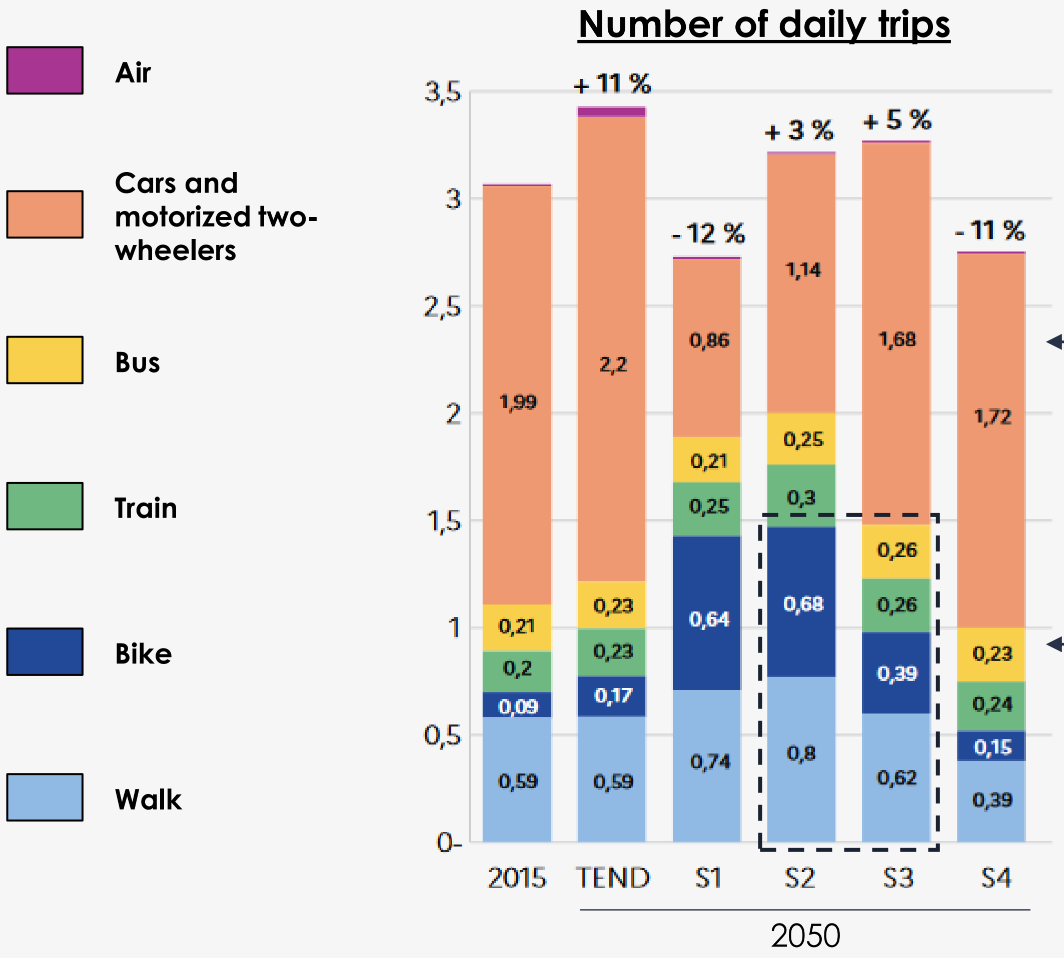
Bicycles: a theoretical modal shift of more than a third everywhere

Portion of journeys that could be made other than by car



Sources: https://www.lemonde.fr/les-decodeurs/article/2023/01/22/qui-pourrait-se-passer-de-sa-voiture-six-graphiques-pour-analyser-nos-trajets-du-quotidien_6158829_4355770.html#xtor=AL-32280270-[mail]-[ios] ; CEREMA, 2019 pour le graphique ; *Pourquoi pas le vélo ?*, Stein Van Oosteren

Short-distance mobility in 2050: the rise of the bicycle, a more moderate role for the 90% electric car



Low-carbon energy

90% electric vehicles

Sufficiency

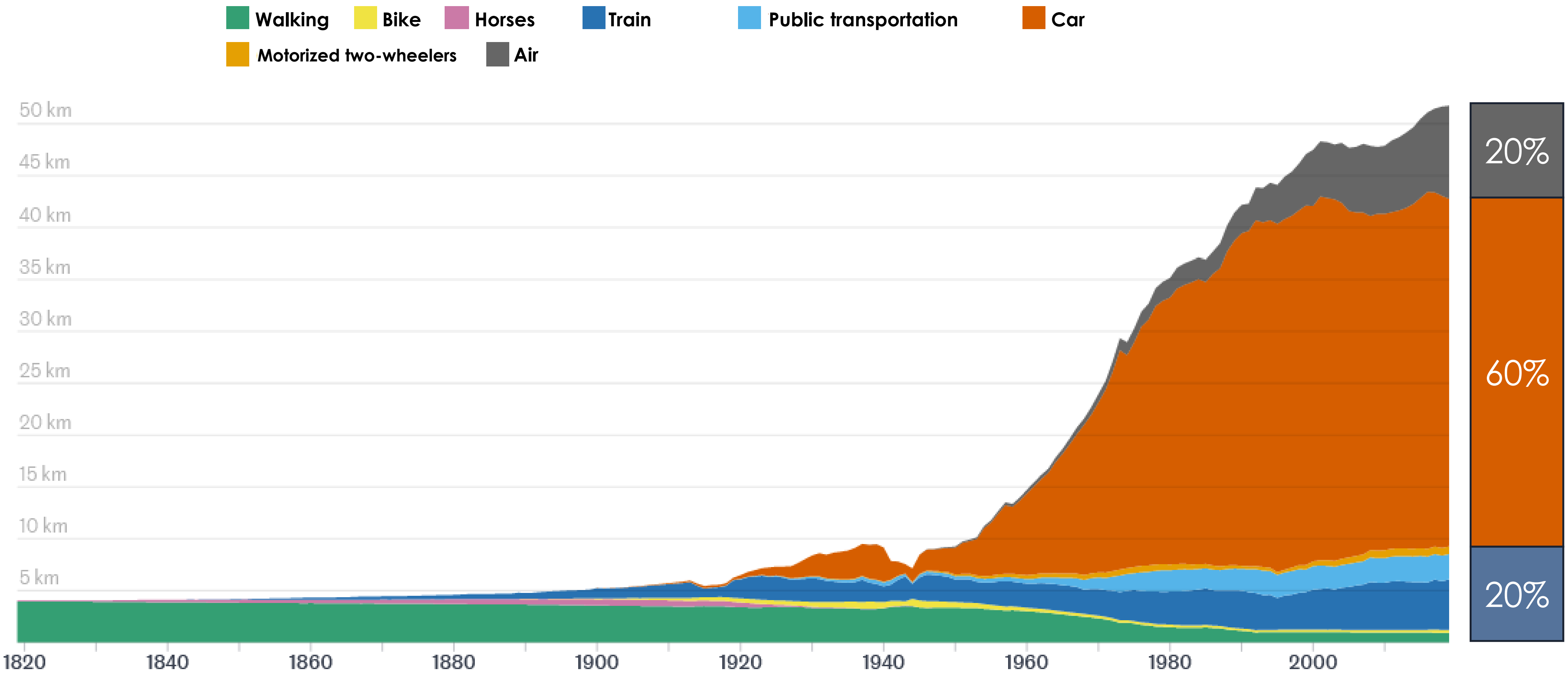
Efficiency

Significant modal shift to walking and cycling

Sources: Transition(s) 2050, ADEME ; https://www.carbone4.com/analyse-faq-voiture-electrique

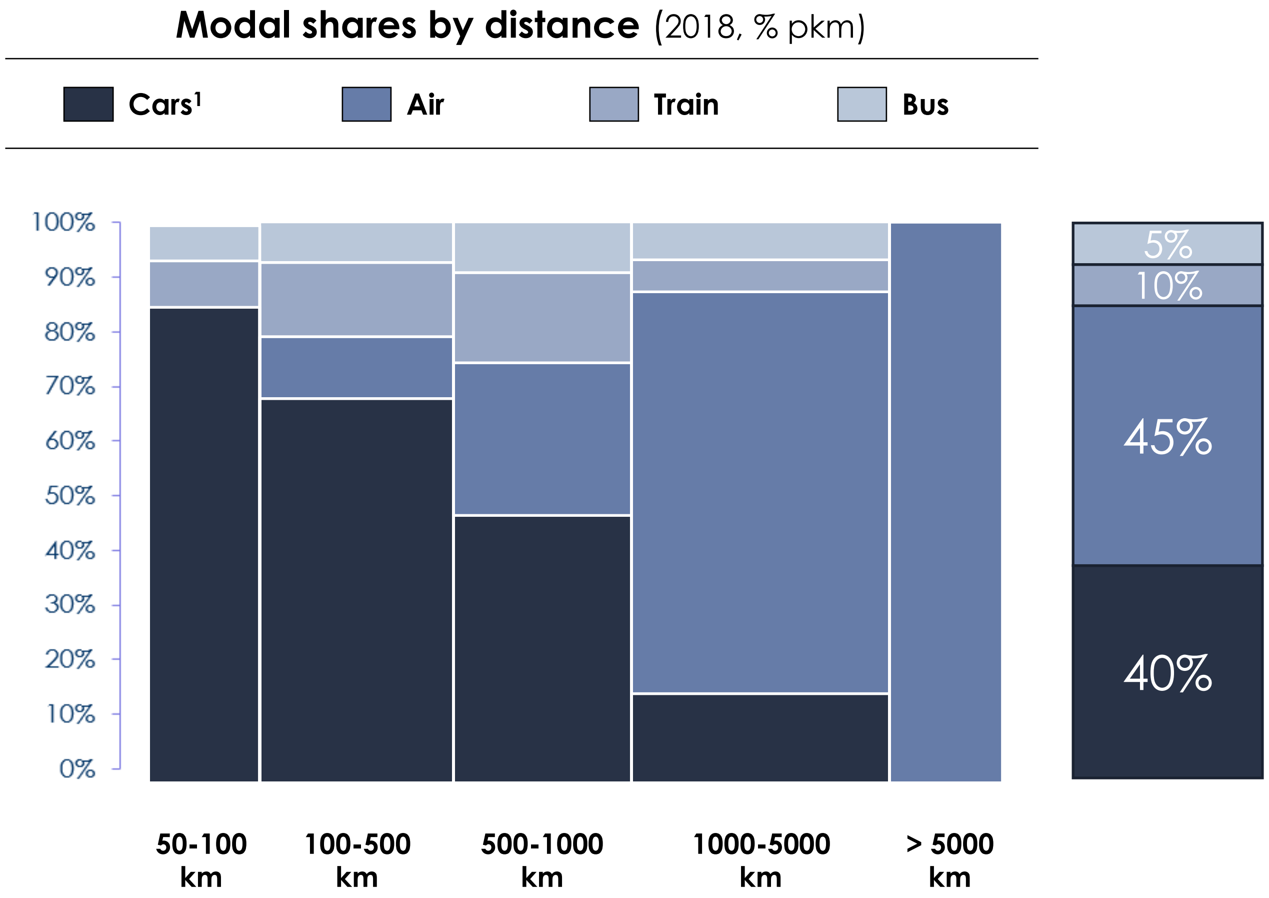
Long-distance passenger mobility

Average distance travelled per person per day, by mode of transport



https://www.lemonde.fr/les-decodeurs/article/2023/01/22/qui-pourrait-se-passer-de-sa-voiture-six-graphiques-pour-analyser-nos-trajets-du-quotidien_6158829_4355770.html#xtor=AL-32280270-[mail]-[ios]

Long-distance travel is mainly by plane and car

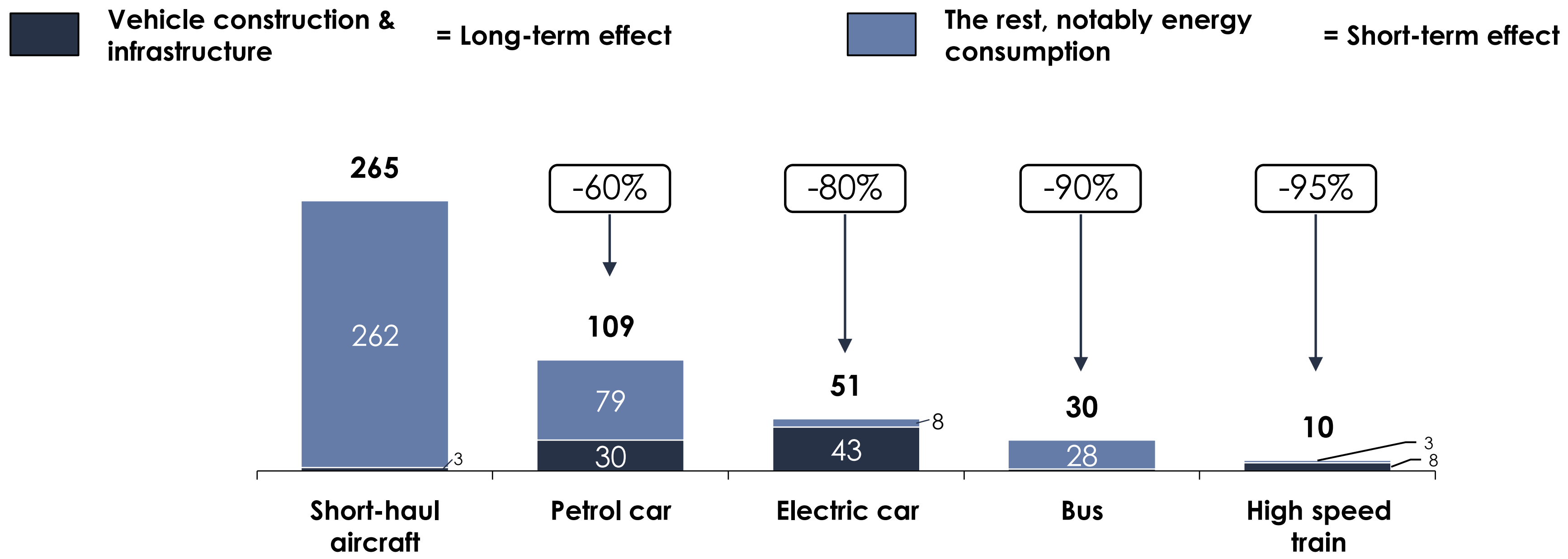


Modal shares by distance (2018, % pkm)

Notes: (1) including 2-wheelers and 3-wheelers
Sources: ENTD, ICCT, Carbone 4

For equivalent distances, air travel emits 60 to 95% more emissions than other modes of transport

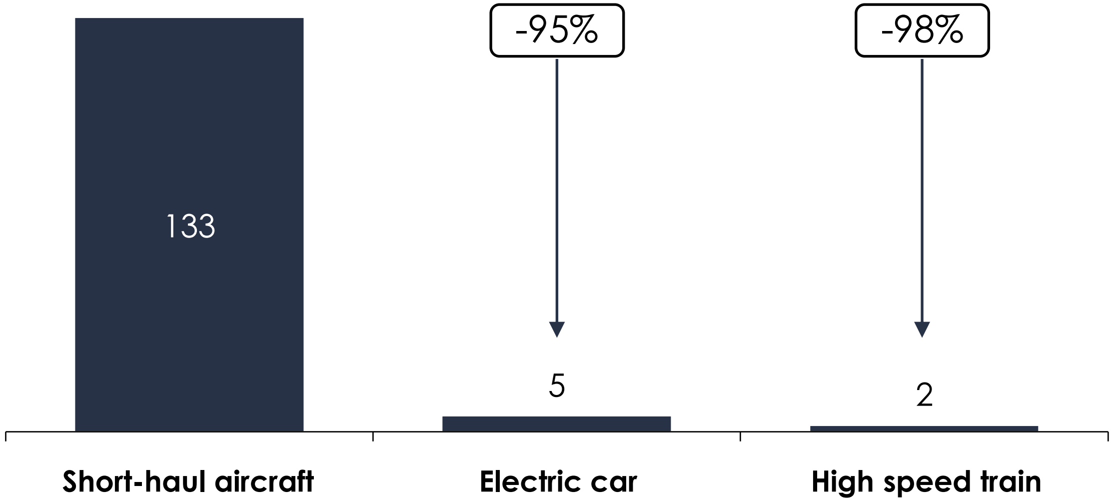
Carbon intensity of a trip, by mode of transport (2021, gCO_2e/passager.km)



Notes : taux d'occupation moyen de 2,2 personnes pour la voiture ; effet des trainées de condensation pris en compte pour l'aviation
Source : https://www.carbone4.com/analyse-faq-aviation-climat

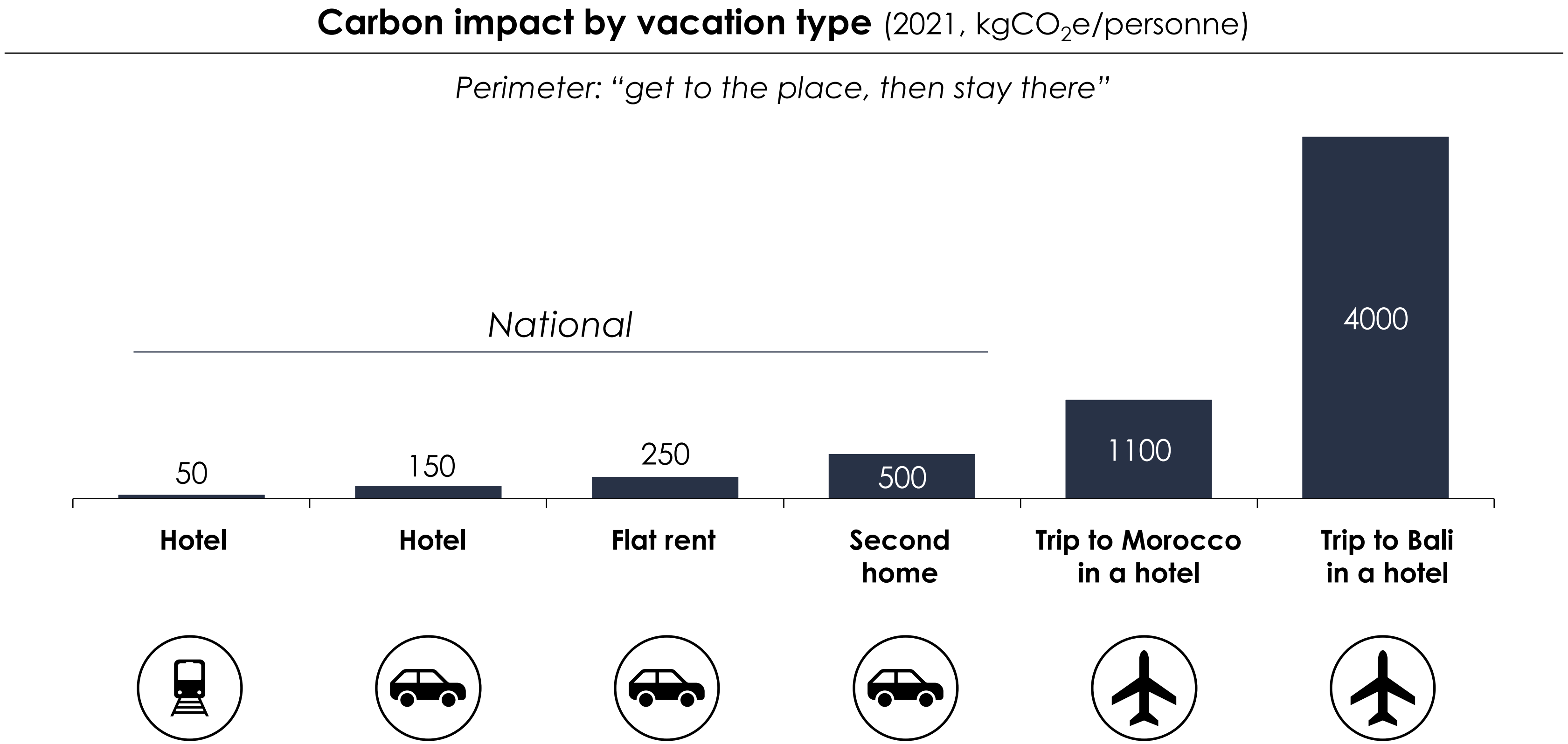
For <u>equivalent journey times</u>, air travel emits 95% more emissions than other modes of transport

Carbon intensity of a <u>one-hour</u> journey, by mode of transport (2021, kgCO$_2$e/passager)



Notes: average occupancy rate of 2.2 people for cars; effect of condensation trails taken into account for aviation.
Source: Carbone 4, analyses Alexandre Joly

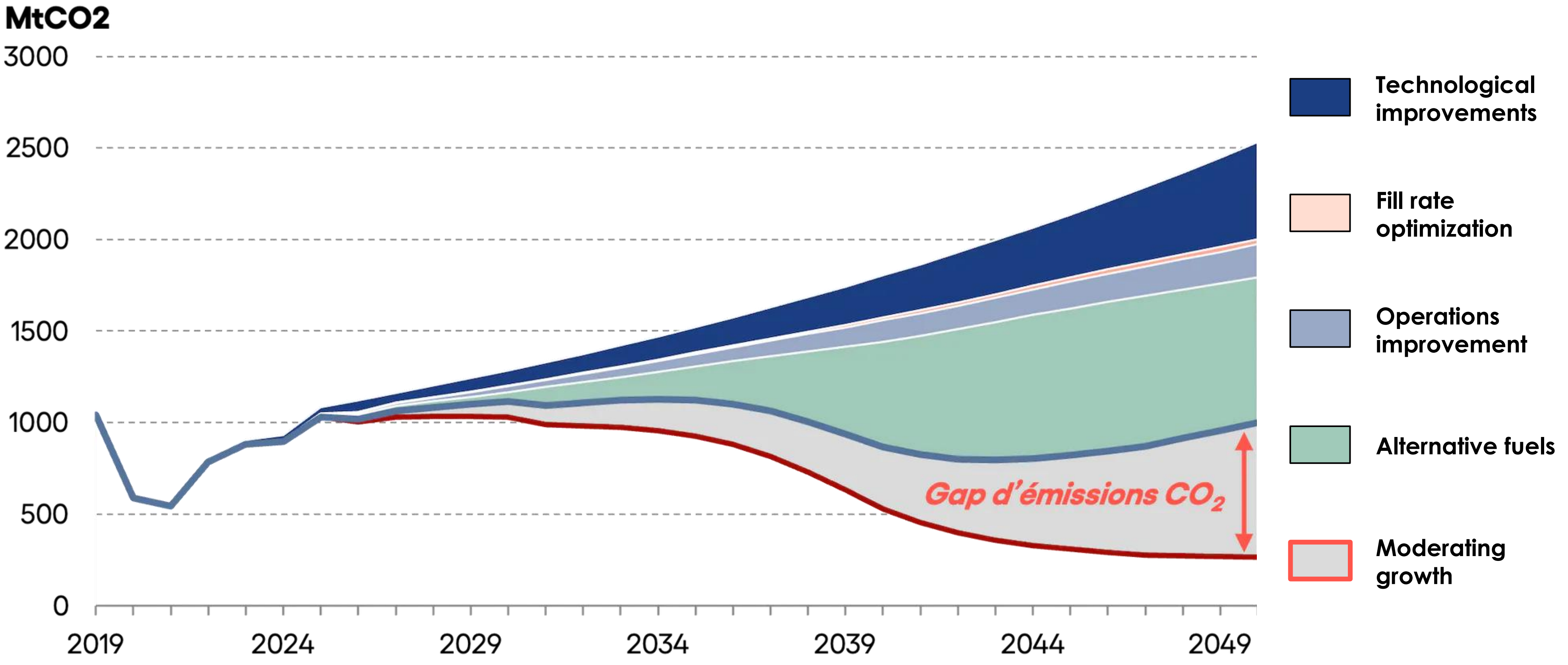
In absolute terms, long-distance travel emits 10 times more than domestic travel



Sources: ADEME, analyses Alexandre Joly

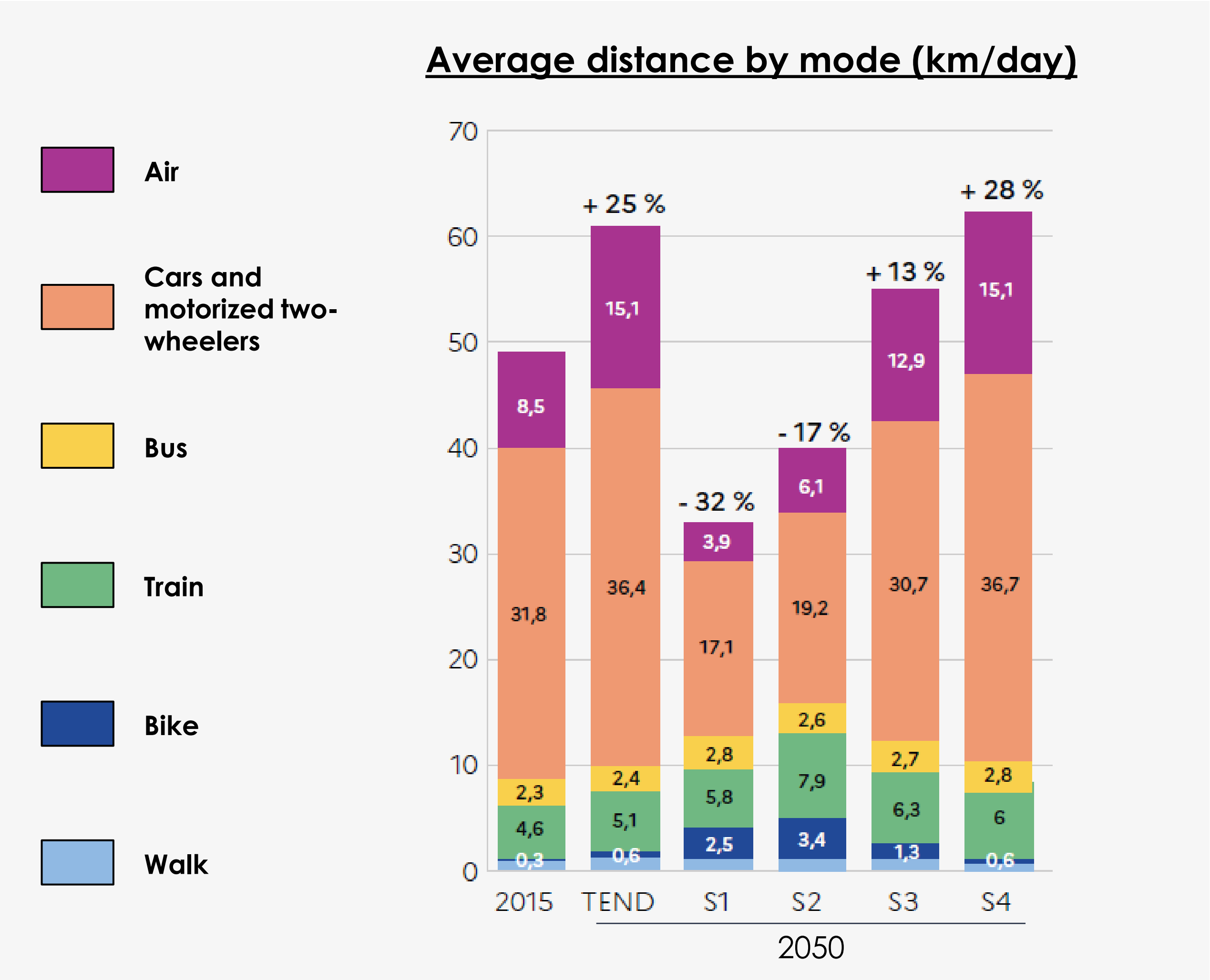
Without moderating traffic growth, aviation will not be compatible with the Paris Agreement

Evolution of CO2 emissions from global air transport, respecting a 2°C budget (2019-2050, $MtCO_2$)



Note: the scope corresponds to upstream and combustion emissions for CO2, and covers global transport excluding regional transport, 2°C budget defined by ISAE Supaéro.
Source: https://www.carbone4.com/analyse-faq-aviation-climat

Long-distance mobility in 2050: shorter distances, less use of aviation, a revolutionized rail network



Average distance by mode (km/day)

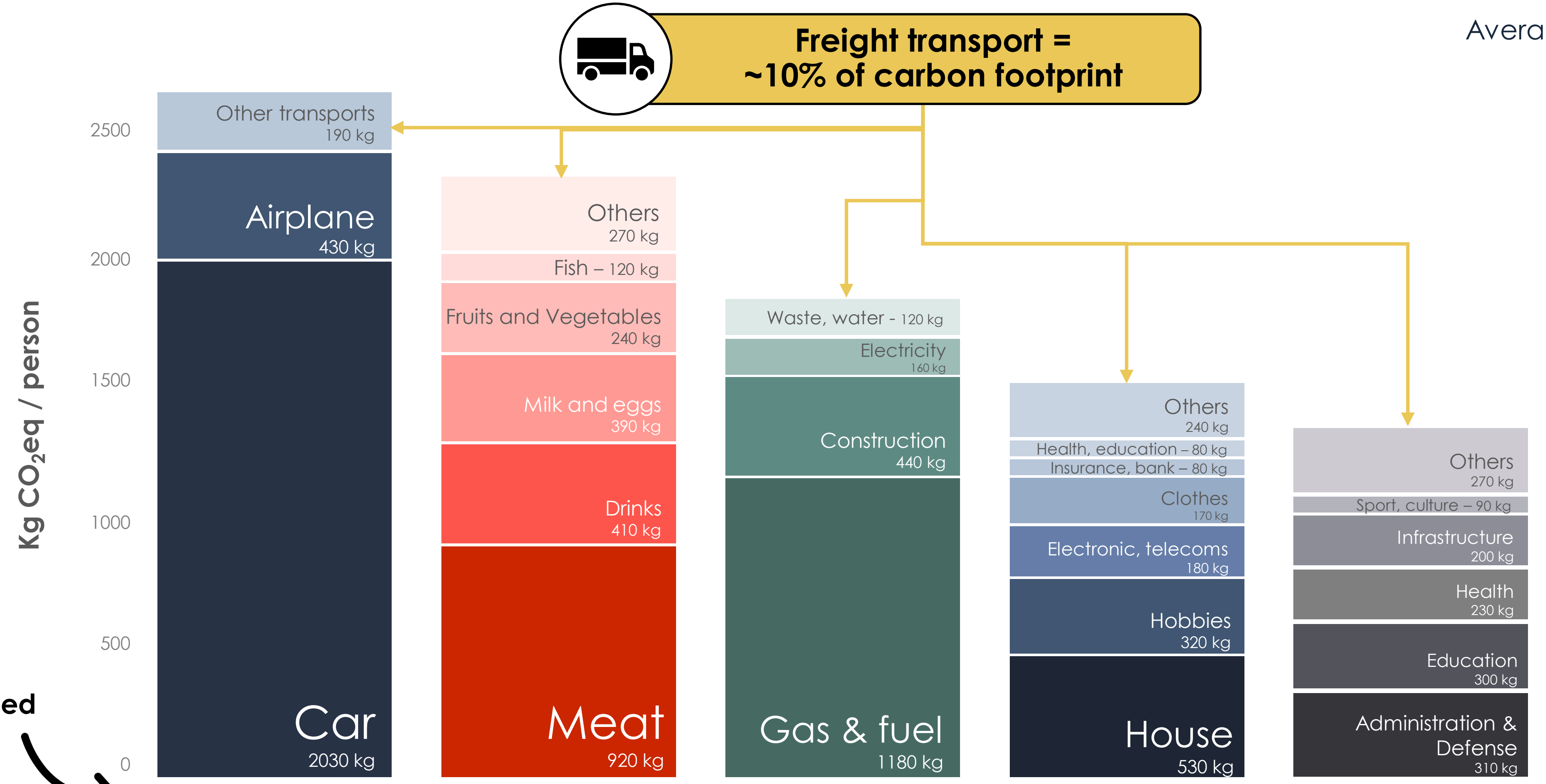
Sources: Transition(s) 2050, ADEME

Freight transportation

Average Carbon Footprint in France in 2019

9,9 tCO_2eq / person

Freight transport = ~10% of carbon footprint



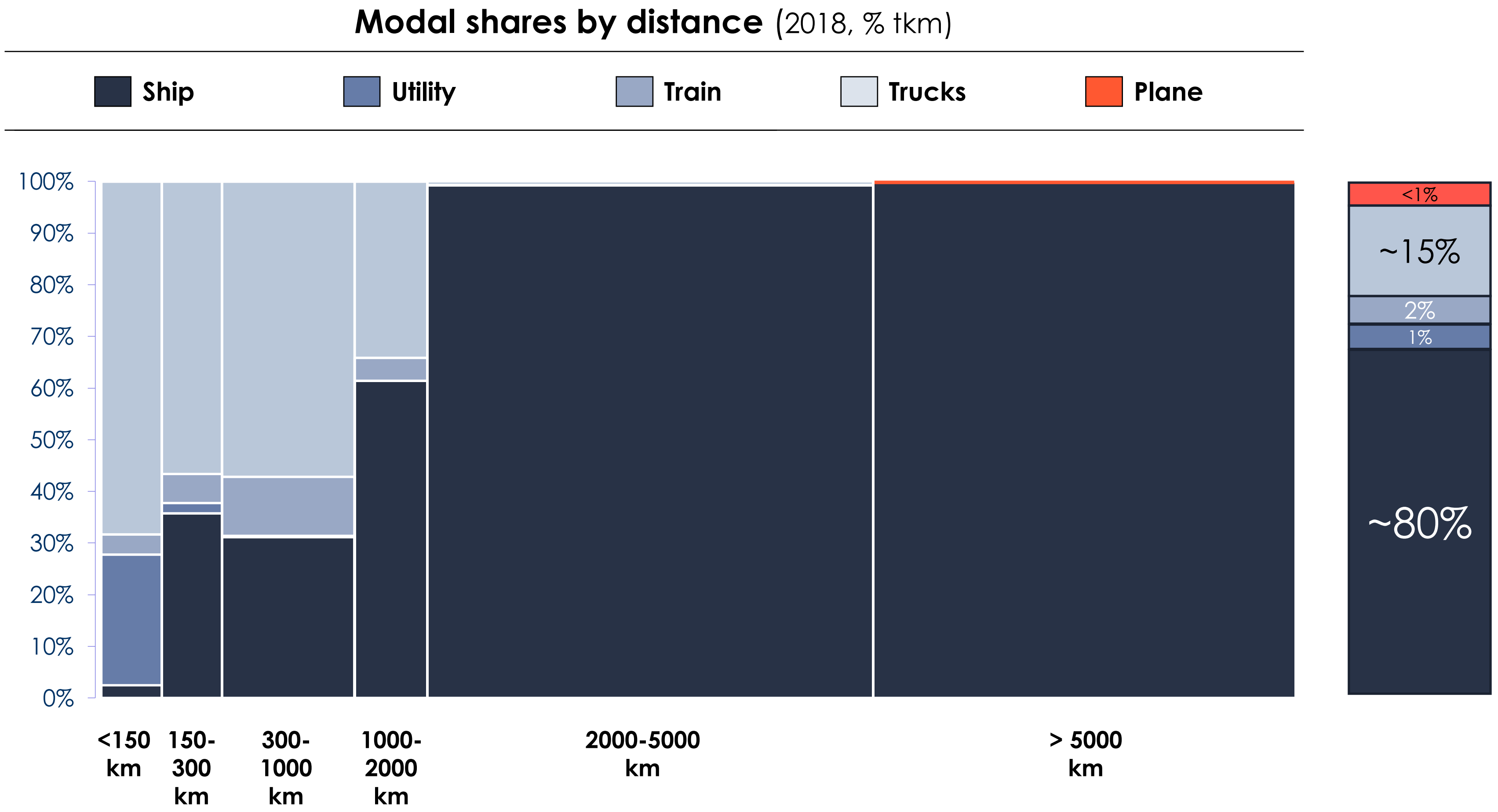
Need

	How I move	What I eat	Where I stay	What I buy	Public Expenses
$kgCO_2e$/person	2650 kg	2350 kg	1900 kg	1600 kg	1400 kg
kWh/person	9 000 kWh	3 000 kWh	10 000 kWh	7 000 kWh	7 000 kWh
% low-carbon energy	5%	15%	50%	40%	45%

Life cycle data: all the energy and emissions required to satisfy a need

Gases included: CO2 (excluding LULUCF France), CH4, N2O, HFC, SF6, PFC, H2O (condensation trails).
Source : MyCO2 par Carbone 4 d'après le ministère de la Transition écologique, le Haut Conseil pour le Climat, le CITEPA, Agribalyse V3 et INCA 3.

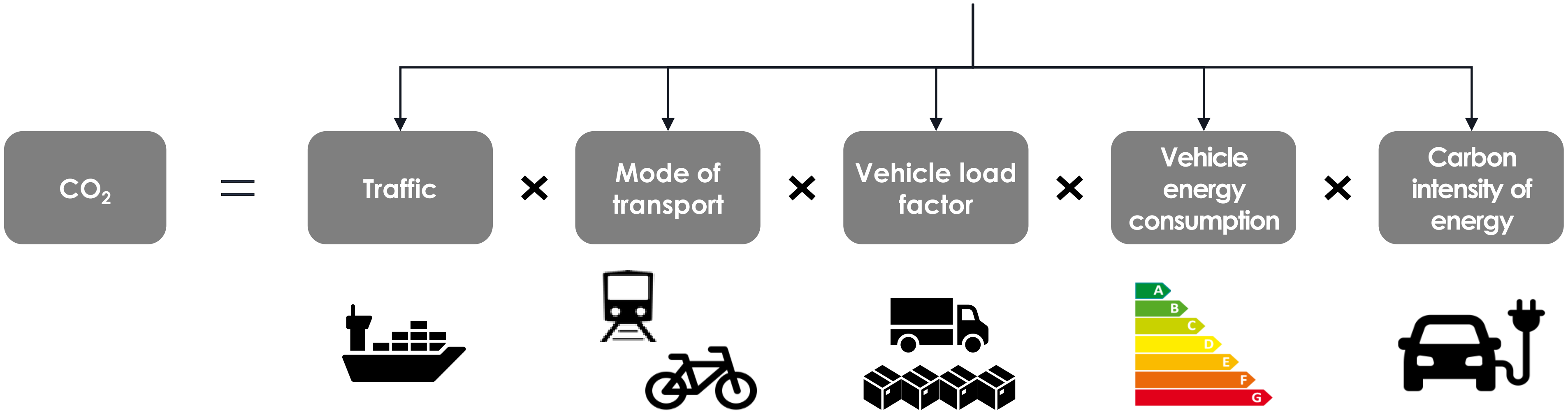
Long-distance is mainly by boat and truck



Scope: European Union
Sources: Eurostat, ICCT, Carbone 4

So what do we do?

Breakdown of <u>direct</u> emissions from freight transport

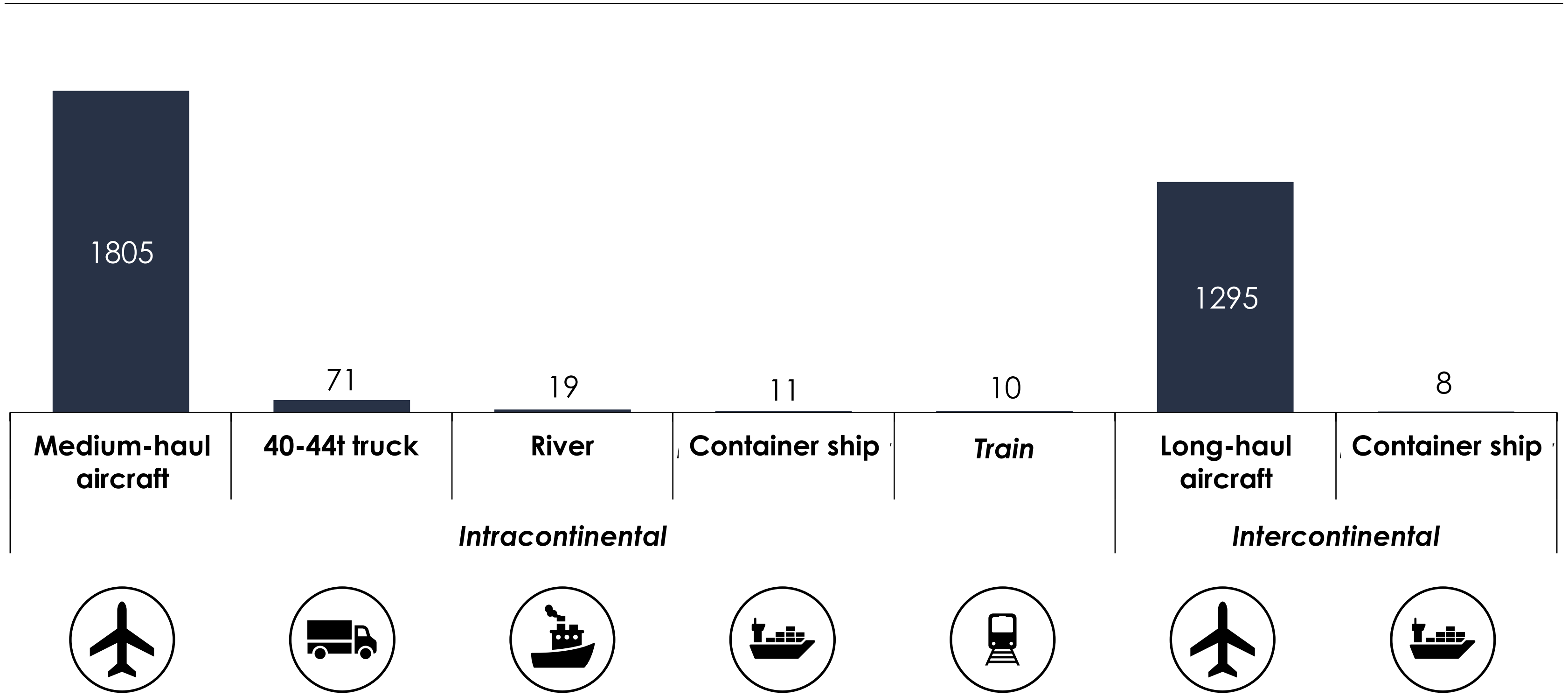


CO_2 = **Traffic** × **Mode of transport** × **Vehicle load factor** × **Vehicle energy consumption** × **Carbon intensity of energy**

Quantity of goods transported and distances covered	*Trains, inland waterways and bicycles consume less energy to transport goods*	*The fuller the vehicle, the lower the energy consumption per load*	*The more efficient the engine, the lighter the vehicle, the lower the speed, the lower the energy consumption*	*The more decarbonized the energy, the lower the emissions (e.g. electricity)*

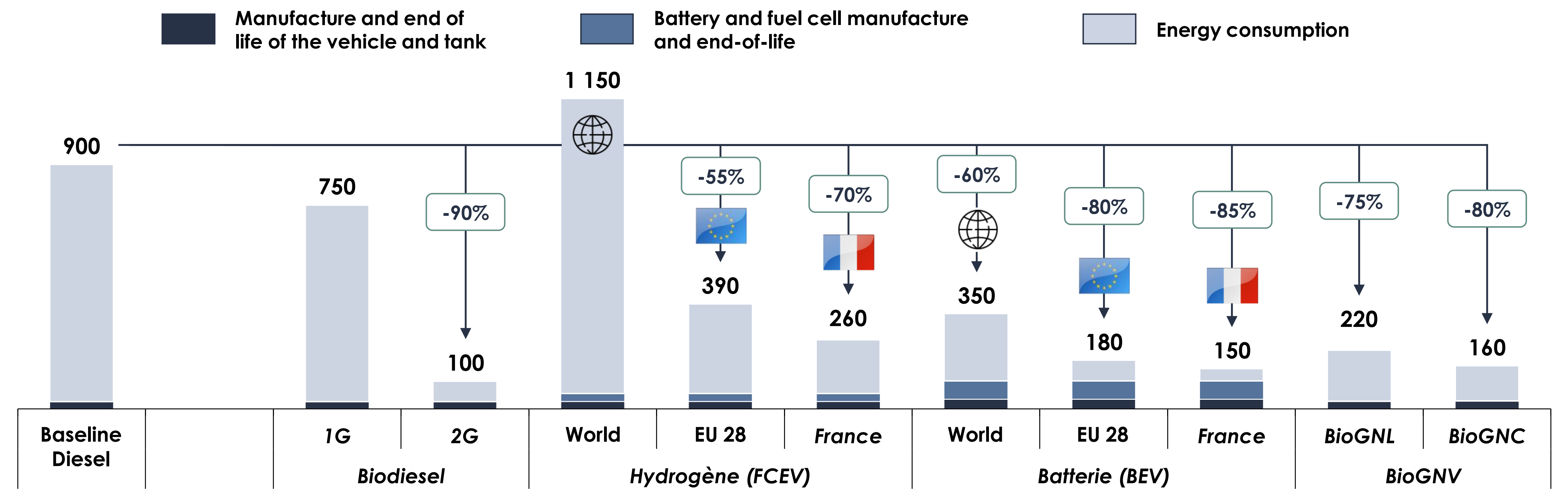
Planes emit 100 times more than trains and boats; trucks 7 times more

Carbon intensity by freight transport mode (2021, gCO_2e/tonne.km)



Source: https://www.carbone4.com/analyse-faq-aviation-climat

Four major alternatives to fossil fuels: 2G biodiesel, hydrogen, battery electric, biomethane



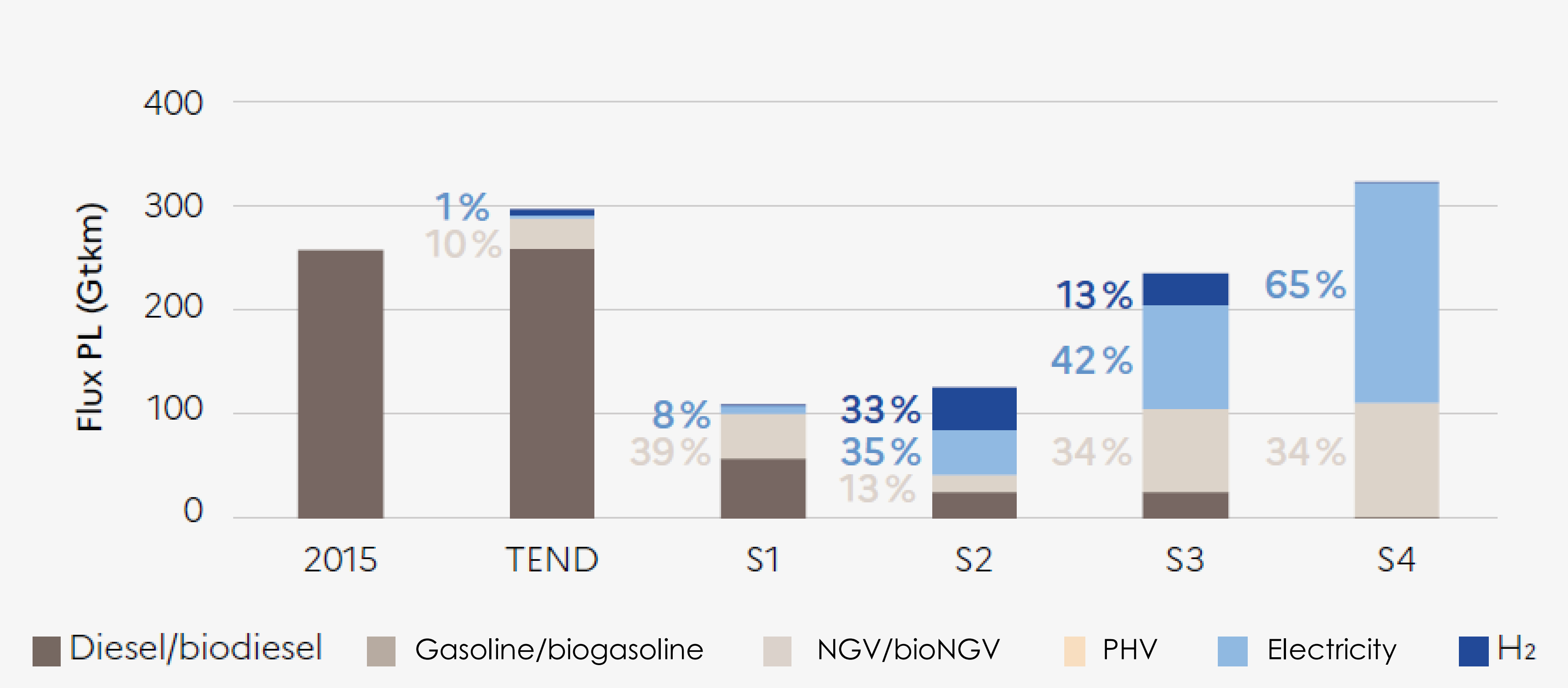
Carbon footprint of a truck (road tractor) purchased in 2030, by engine and geography (gCO_2e/km)

Other limits →	Limited resources	Energy inefficiency	Critical metals	Limited resources

Sigles : BEV pour *Battery Electric Vehicle* ; FCEV pour *Fuel Cell Electric Vehicle* ; GNV pour *Gaz Naturel Véhicule*, GNC pour *Gaz Naturel Comprimé*, GNL pour *Gaz Naturel Liquéfié*.
Sources: https://www.carbone4.com/files/Carbone_4_Etude_Hydrogene.pdf

Freight transport in 2050: a varied mix, with bioNGV and battery electricity the most popular technologies

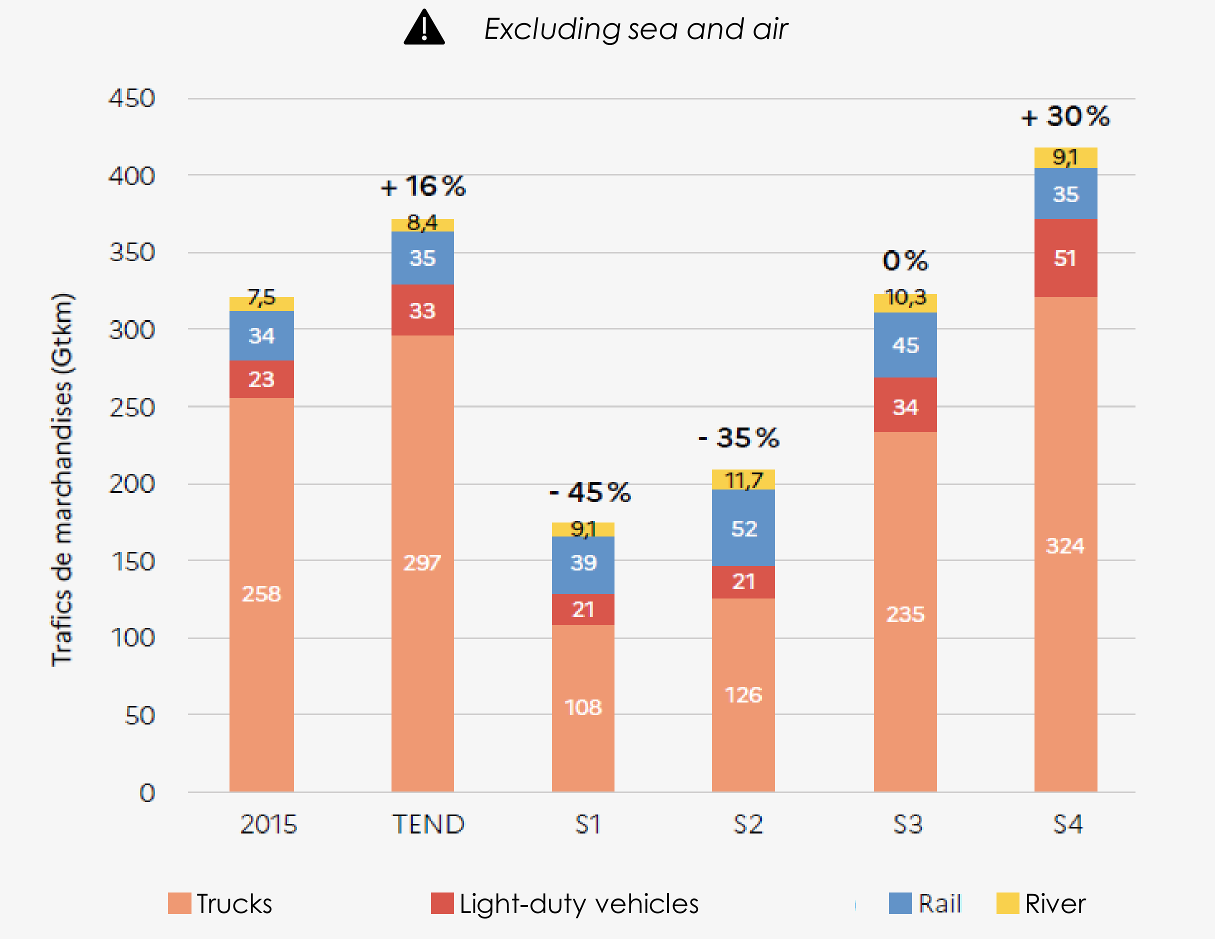
Breakdown of energy carriers for heavy goods vehicles in 2050 - scenarios ADEME (%, Gtkm)

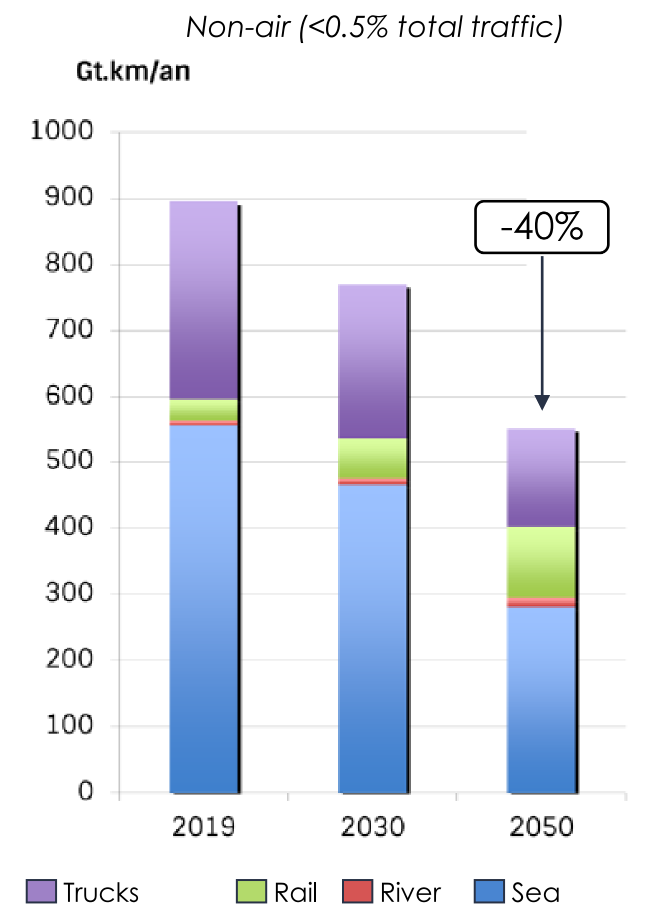


Note: PHV = Plug-in Hybrid Vehicle
Sources: Transition(s) 2050, ADEME

Freight transport in 2050: traffic under control, with a shift from road to rail

Freight transport by mode (2015/19-2050, Gtkm)





Source: Transition(s) 2050, **ADEME**

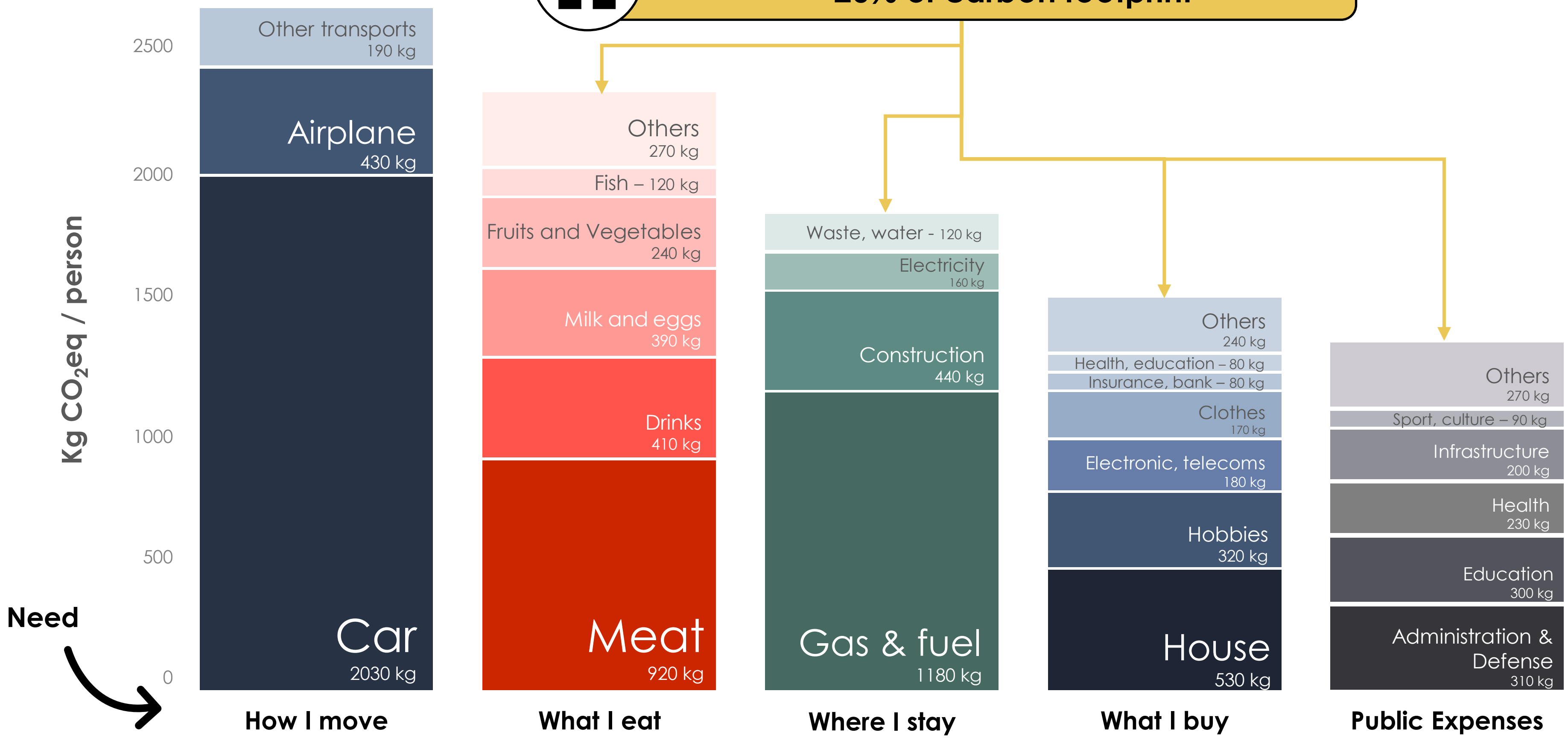
Source: Scénario 2022, **négaWatt**

Use of buildings

Average Carbon Footprint in France in 2019

9,9 tCO_2eq / person

Direct building energy (use) = ~20% of carbon footprint



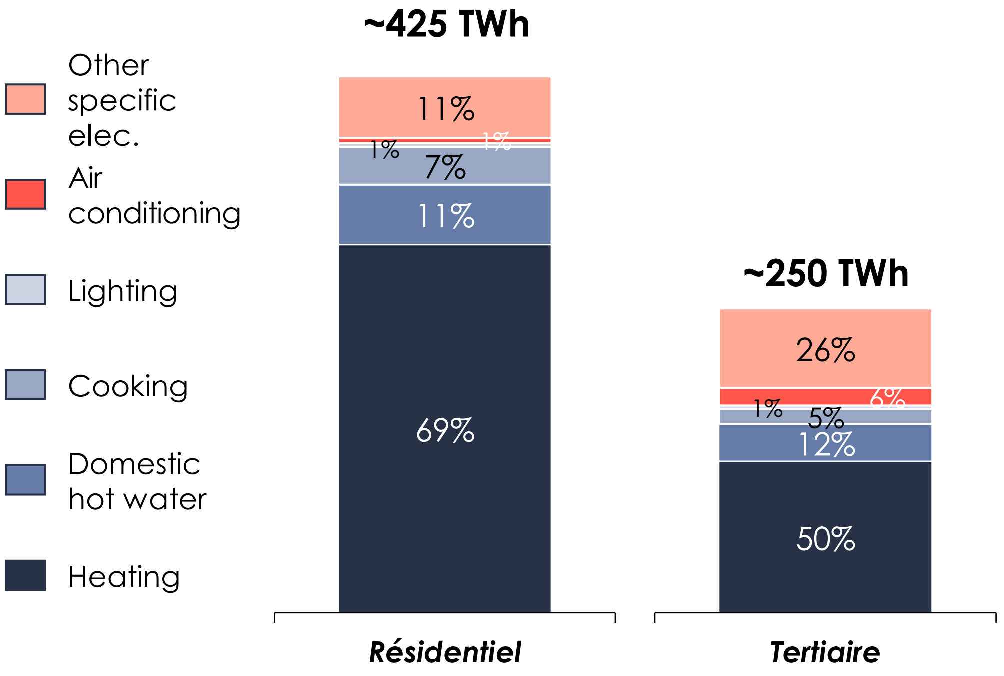
	How I move	What I eat	Where I stay	What I buy	Public Expenses
$kgCO_2e$/person	**2650 kg**	**2350 kg**	**1900 kg**	**1600 kg**	**1400 kg**
kWh/person	**9 000 kWh**	**3 000 kWh**	**10 000 kWh**	**7 000 kWh**	**7 000 kWh**
% low-carbon energy	**5%**	**15%**	**50%**	**40%**	**45%**

Life cycle data: all the energy and emissions required to satisfy a need

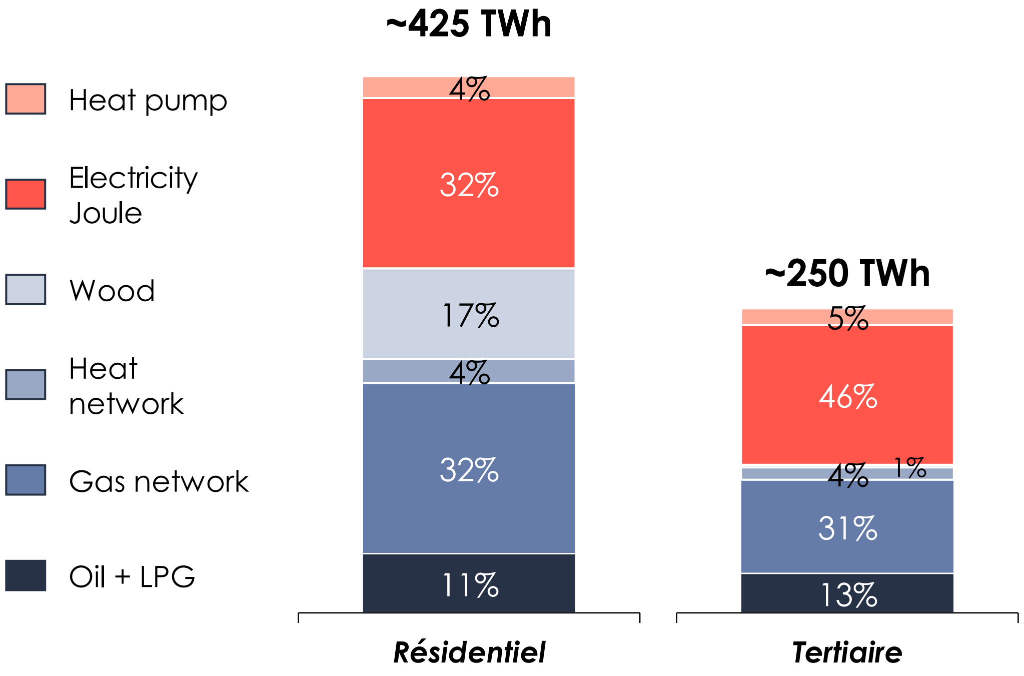
Gases included: CO2 (excluding LULUCF France), CH4, N2O, HFC, SF6, PFC, H2O (condensation trails).
Source : MyCO2 par Carbone 4 d'après le ministère de la Transition écologique, le Haut Conseil pour le Climat, le CITEPA, Agribalyse V3 et INCA 3.

Direct energy: heating as primary use, and still 40% fossil fuels

Energy consumption by use (2020, TWh)



Energy consumption by energy type (2020, TWh)

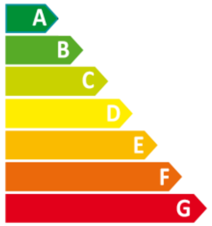


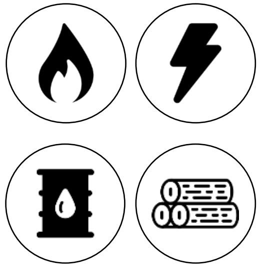
Notes: in PCS final energy
Source: Transition(s) 2050, ADEME

So what do we do?

Breakdown of direct emissions from the residential sector

CO$_2$ = **Total surface area of occupied units** (m^2) × **Energy consumption** (kWh/m^2) × **Carbon intensity of energy** (CO$_2$e/kWh)





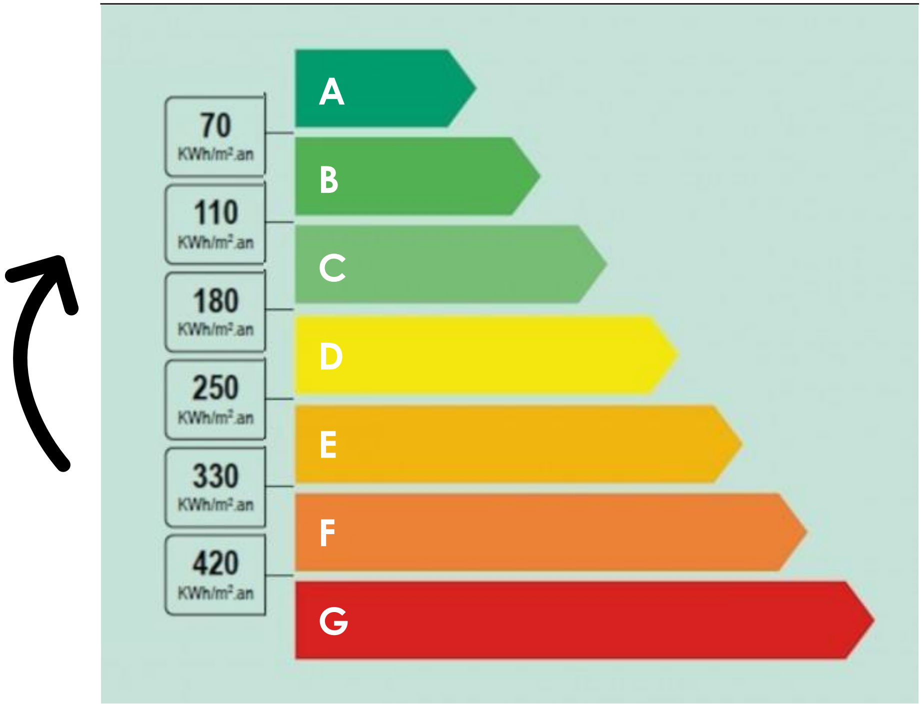
- *New build requirements*
  - *Population*
  - *Surface area per inhabitant*
  - *No. of inhabitants per dwelling*
  - *Second home*
- *Demolition*

- *NRJ building performance (DPE)*
- *Sufficiency in use*

- *Heat pump*
- *Wood-burning stoves*
- *Geothermal*
- *Solar thermal*

The key challenge is to massively scale up high-performance renovations

Housing energy label



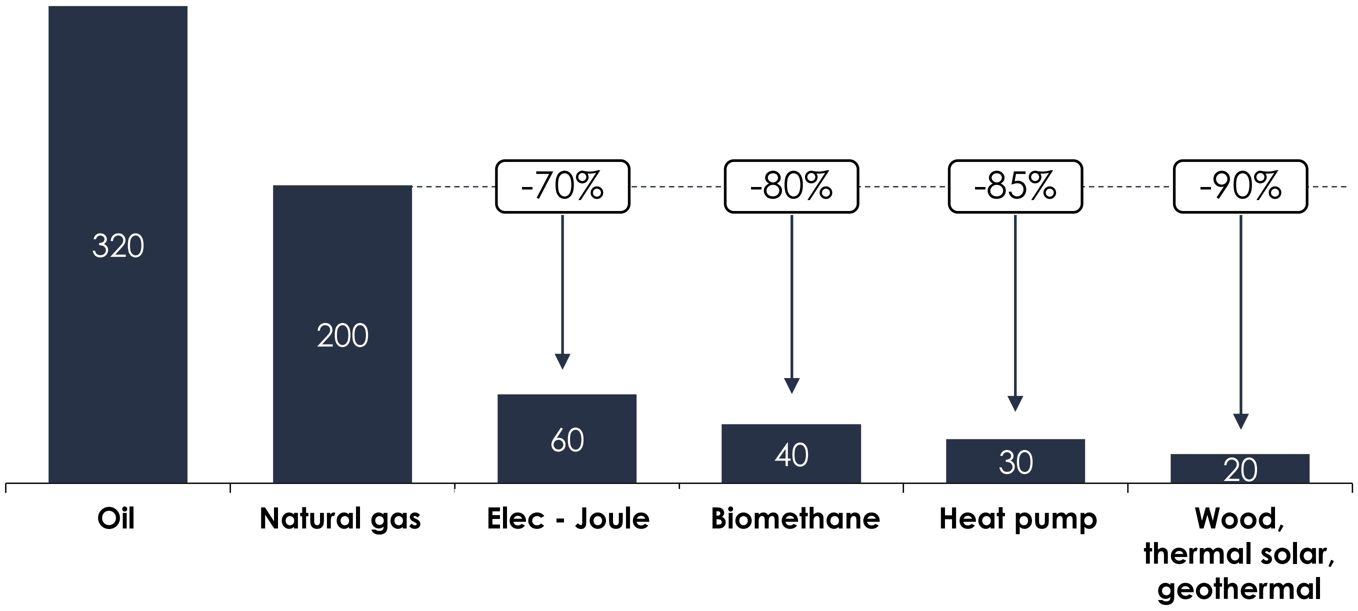
Nb of units
2%
3%
14%
34%
29%
13%
5%

95% of energy consumption

Sources : https://www.carbone4.com/files/wp-content/uploads/2021/03/LEtat-franc%CC%A7ais-se-donne-t-il-les-moyens-de-son-ambition-climat.pdf

Once insulated, the home can be heated using various alternatives to fossil fuels

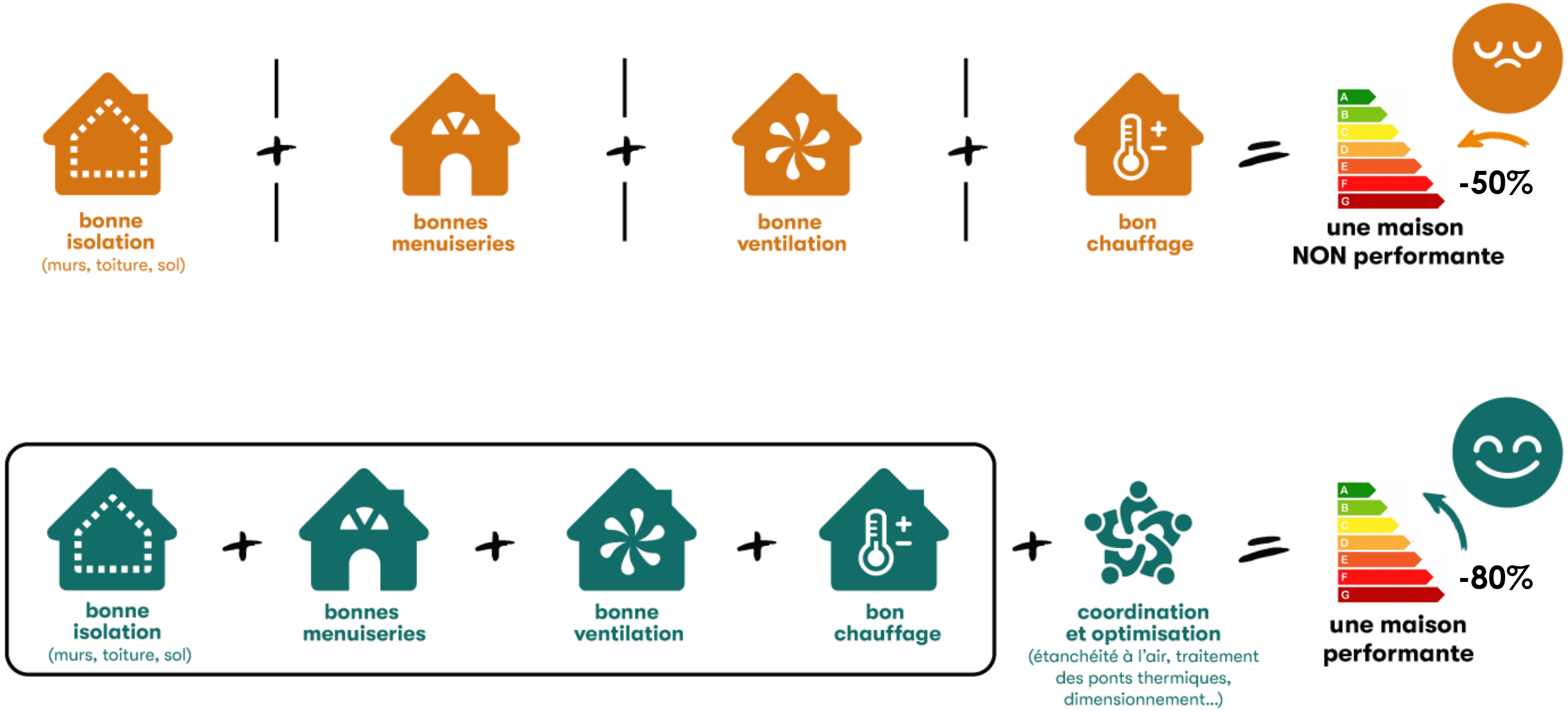
Carbon intensity of different residential heating systems (gCO_2e/kWh)



Limited resources? →	Yes	Yes, wood

Source: ADEME, analyses C4

Dorémi: coordinating trades for in-depth, high-performance energy renovation



bonne isolation (murs, toiture, sol) + bonnes menuiseries + bonne ventilation + bon chauffage = une maison NON performante

-50%

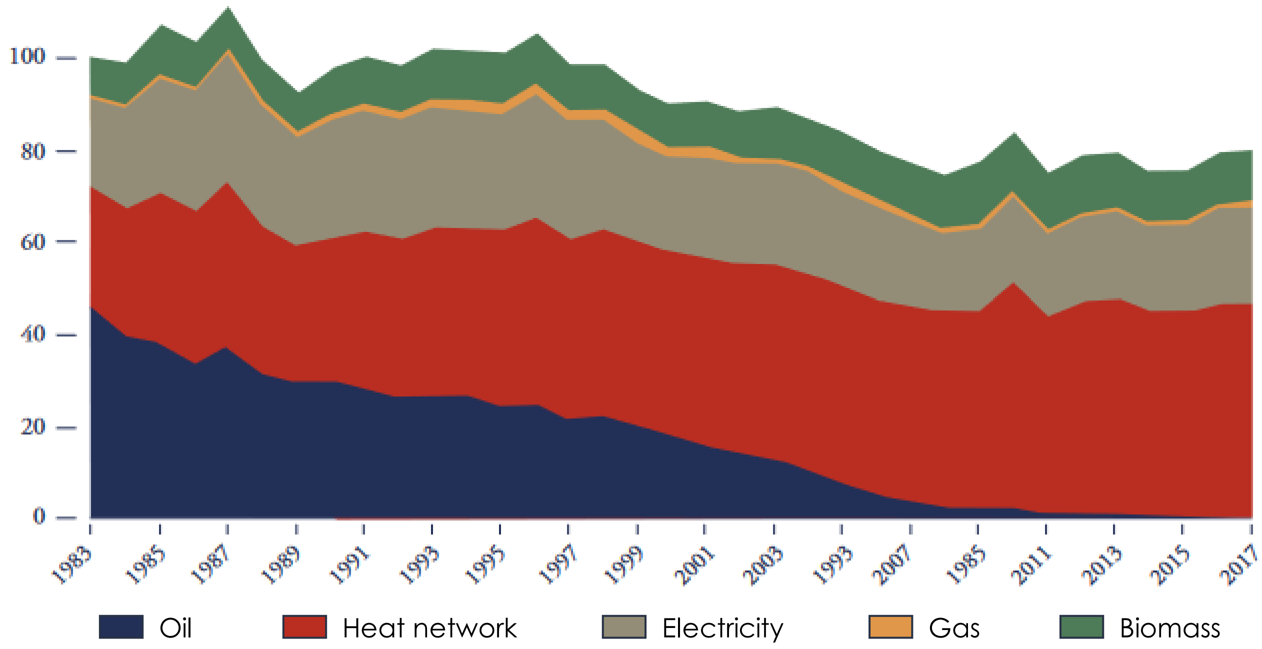
bonne isolation (murs, toiture, sol) + bonnes menuiseries + bonne ventilation + bon chauffage + coordination et optimisation (étanchéité à l'air, traitement des ponts thermiques, dimensionnement...) = une maison performante

-80%

Source: https://www.renovation-doremi.com/fr/

Energy and carbon performance of buildings: focus on Sweden

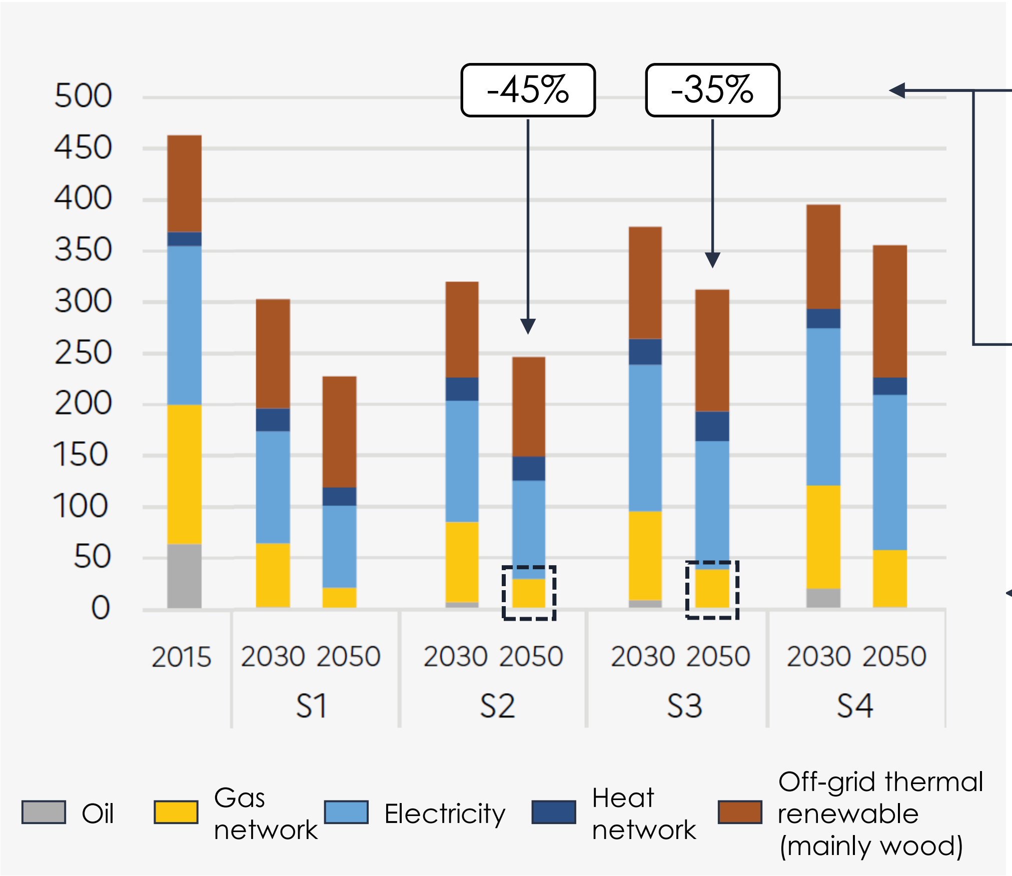
Energy consumption of Swedish buildings (heating and domestic hot water, TWh)



Source: HCC, « RÉNOVER MIEUX : LEÇONS D'EUROPE », https://www.hautconseilclimat.fr/wp-content/uploads/2020/11/hcc_rapport_renover_mieux_lecons_deurope.pdf

The residential sector in 2050: renovation and sobriety to reduce energy consumption, with virtually no fossil fuel use

Residential energy consumption (2015-30-50, TWh)



Sufficiency

Behavioral changes
(e.g. setpoint t°C)

Efficiency

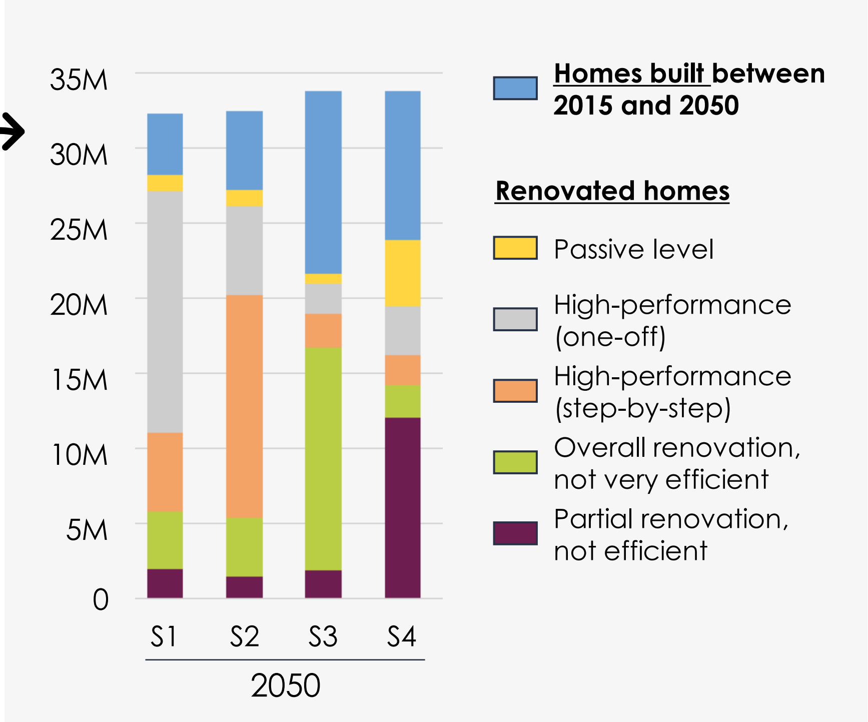
Massive renovations
(> 90% of stock)

Low-carbon energy

Fossil fuel phase-out

Housing energy performance (2050, en millions)

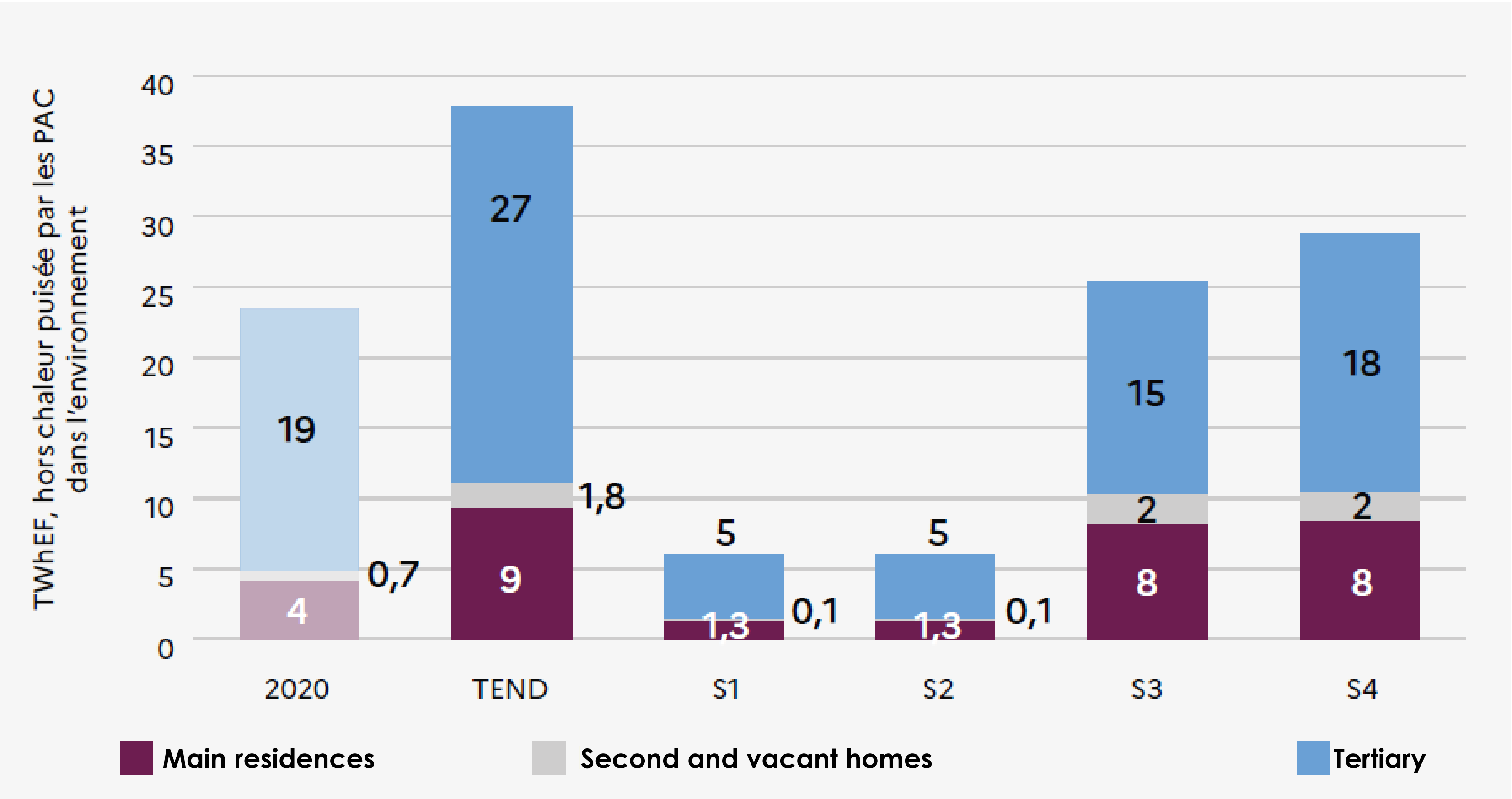
> 700,000 renovations / year between 2015 and 2050



Source: Transition(s) 2050, ADEME

Air-conditioning: insulation and heat pumps to control electricity consumption

Electricity consumption for air conditioning (2020-50, TWh)



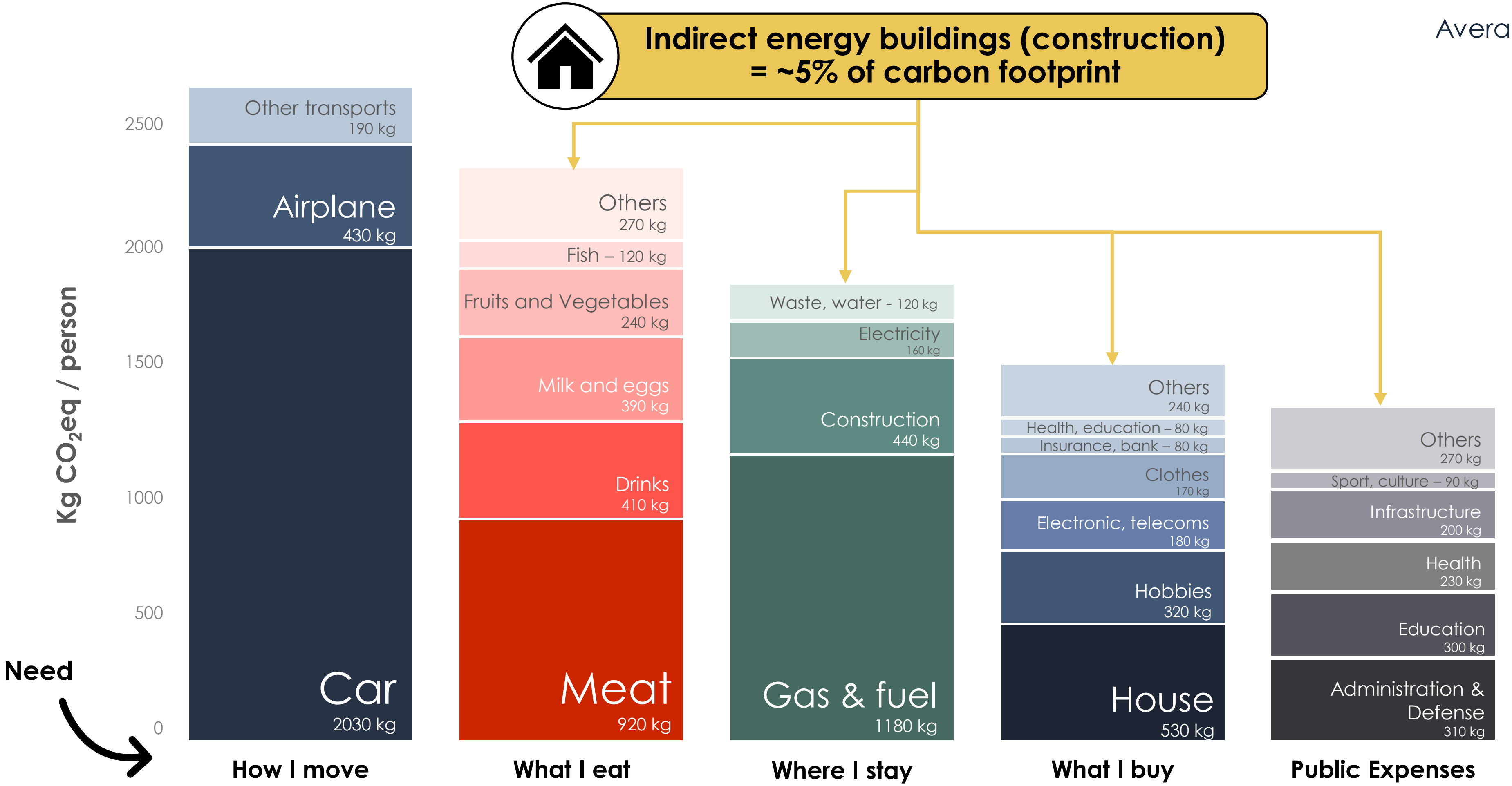
Source: Transition(s) 2050, ADEME

Construction of buildings

Average Carbon Footprint in France in 2019

9,9 tCO_2eq / person

Indirect energy buildings (construction) = ~5% of carbon footprint



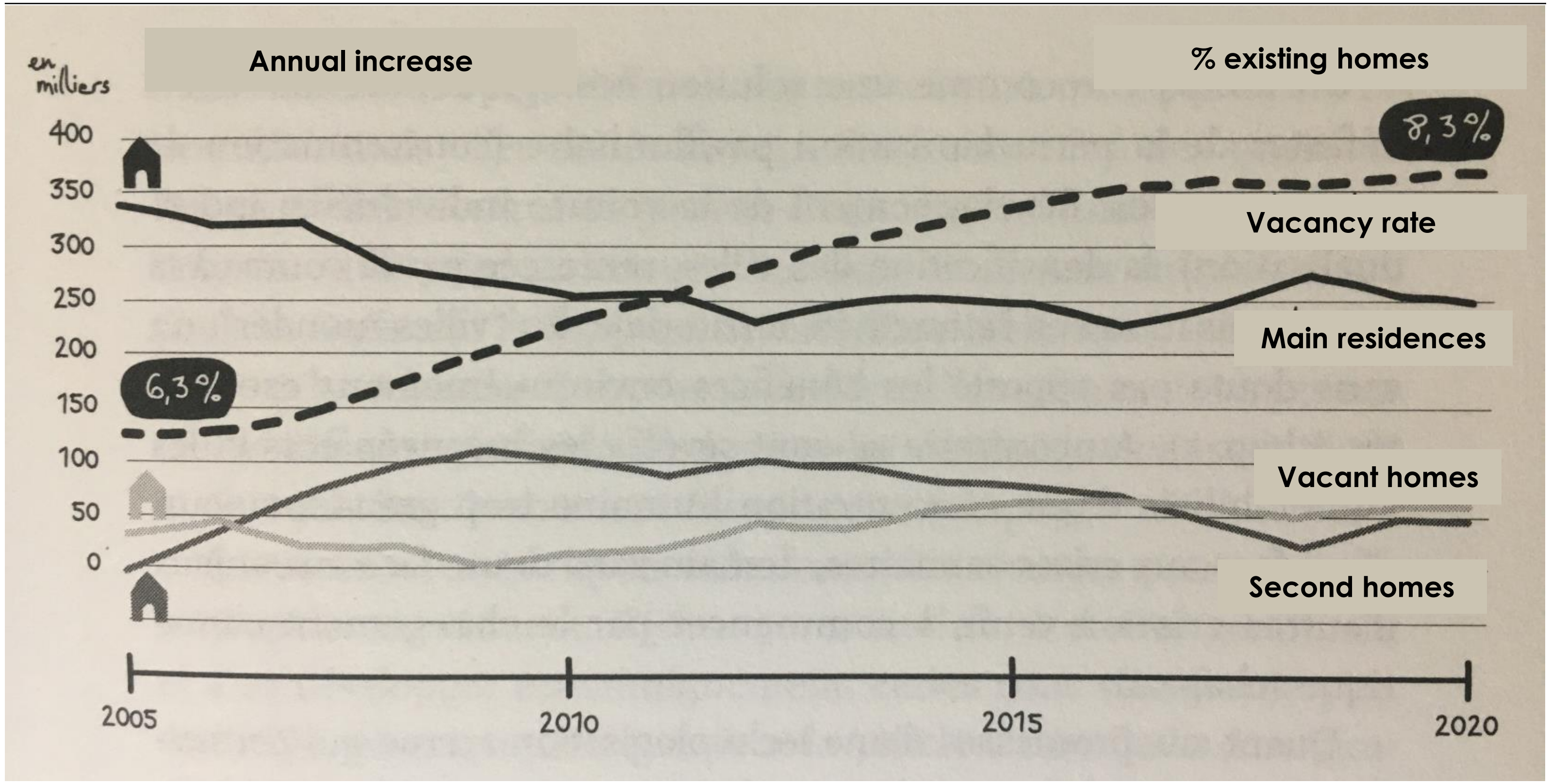
	How I move	**What I eat**	**Where I stay**	**What I buy**	**Public Expenses**
$kgCO_2e$/person	**2650 kg**	**2350 kg**	**1900 kg**	**1600 kg**	**1400 kg**
kWh/person	**9 000 kWh**	**3 000 kWh**	**10 000 kWh**	**7 000 kWh**	**7 000 kWh**
% low-carbon energy	**5%**	**15%**	**50%**	**40%**	**45%**

Life cycle data: all the energy and emissions required to satisfy a need

Gases included: CO2 (excluding LULUCF France), CH4, N2O, HFC, SF6, PFC, H2O (condensation trails).
Source : MyCO2 par Carbone 4 d'après le ministère de la Transition écologique, le Haut Conseil pour le Climat, le CITEPA, Agribalyse V3 et INCA 3.

In France, we build more than we need in primary residences

Annual change in housing stock and vacancy rate

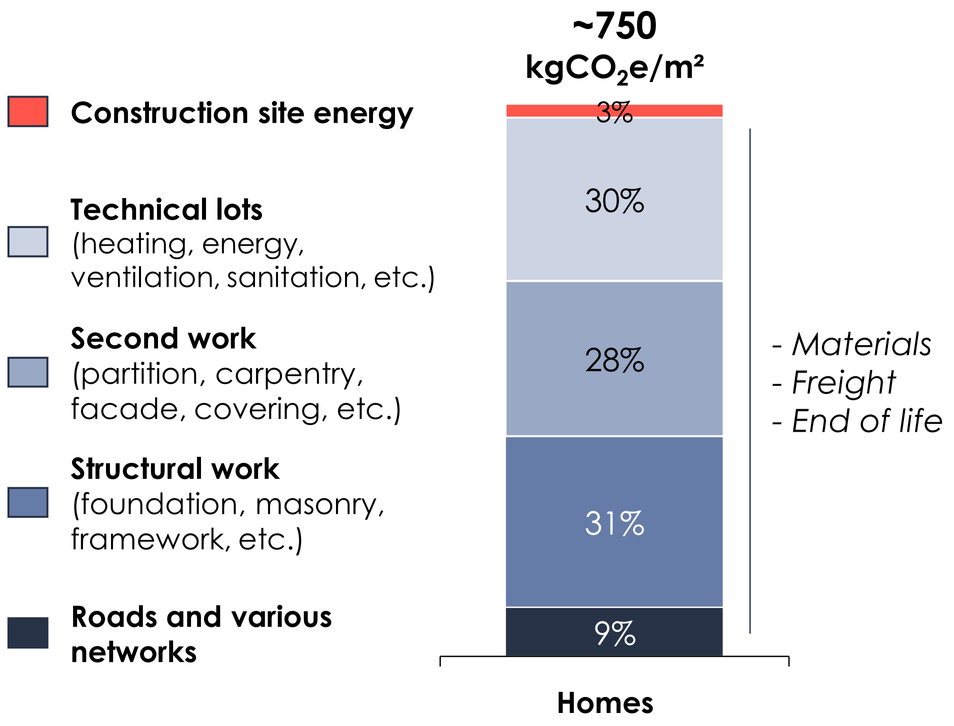


Sources: *La ville stationnaire*, Philippe Bihouix, Sophie Jeantet, Clémence de Selva ; https://www.statistiques.developpement-durable.gouv.fr/chiffres-cles-du-logement-edition-2022

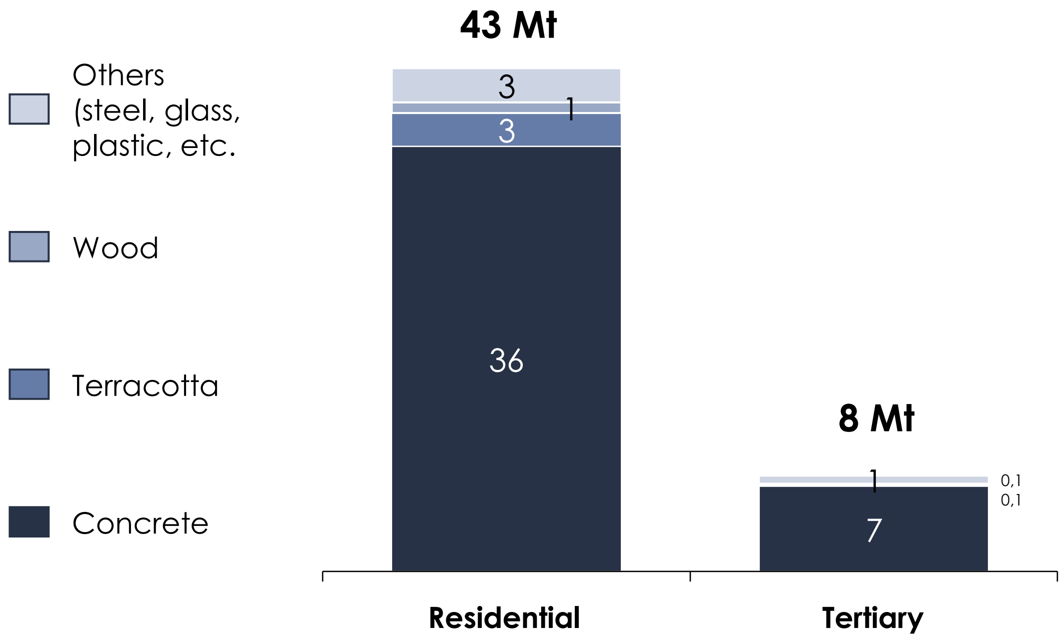
Indirect energy: 97% of construction-related emissions are generated off-site; concrete is the main material used

Emissions linked to new construction (2018, $kgCO_2e/m^2$)

Excluding energy and water consumption



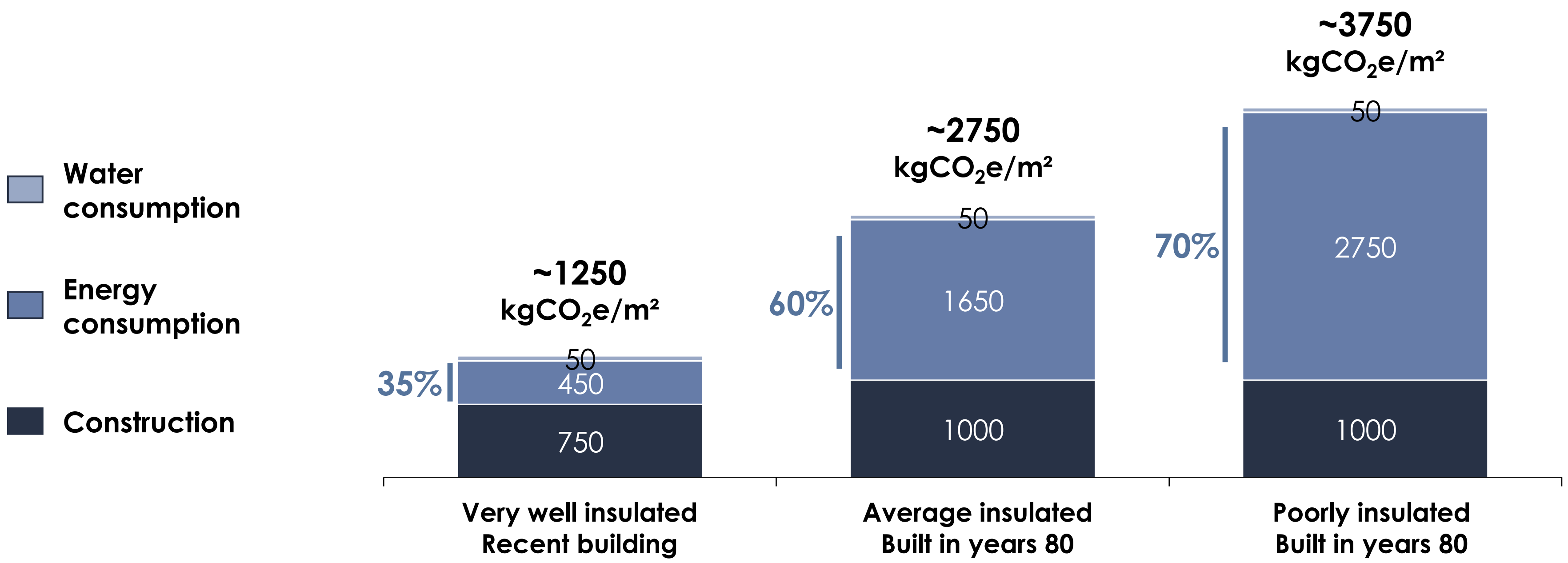
Material consumption (2015, Mtonnes)



Note: refrigerants included with technical batches
Sources: Hub des prescripteurs, « Brief Filière » ; Transition(s) 2050, ADEME

The share of emissions linked to energy consumption strongly depends on the level of insulation

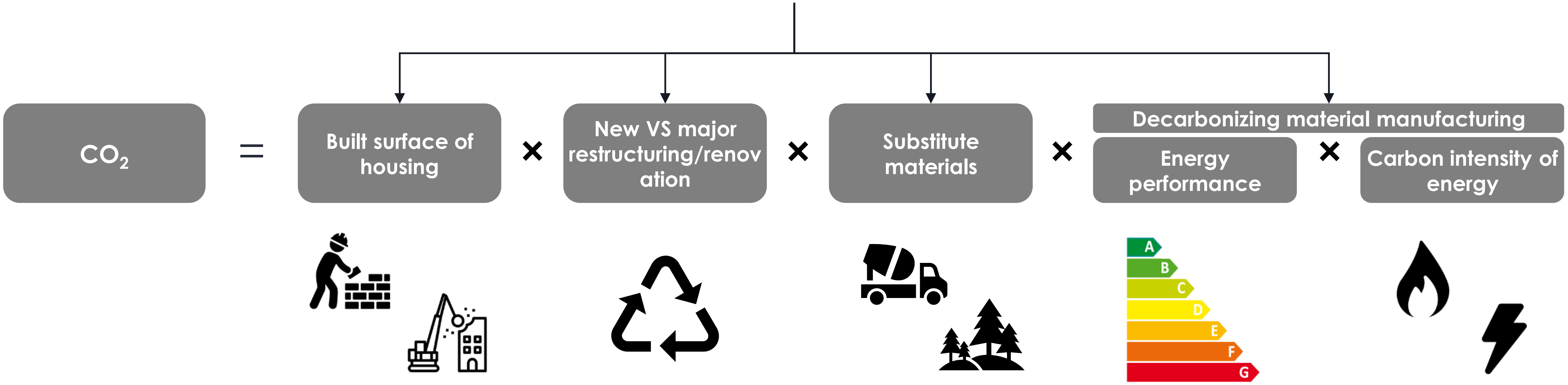
Carbon footprint over 50 years of housing (2018, $kgCO_2e/m^2$)



Sources: Hub des prescripteurs, « Brief Filière » ; analyses Alexandre Joly

So what to do?

Breakdown of indirect residential emissions levers



- *Need new construction*
  - *Population*
  - *Area per inhabitant*
  - *Number of inhabitants / accommodation*
  - *Secondary homes*

- *New on already artificialized soil*
- *Reuse of structure*

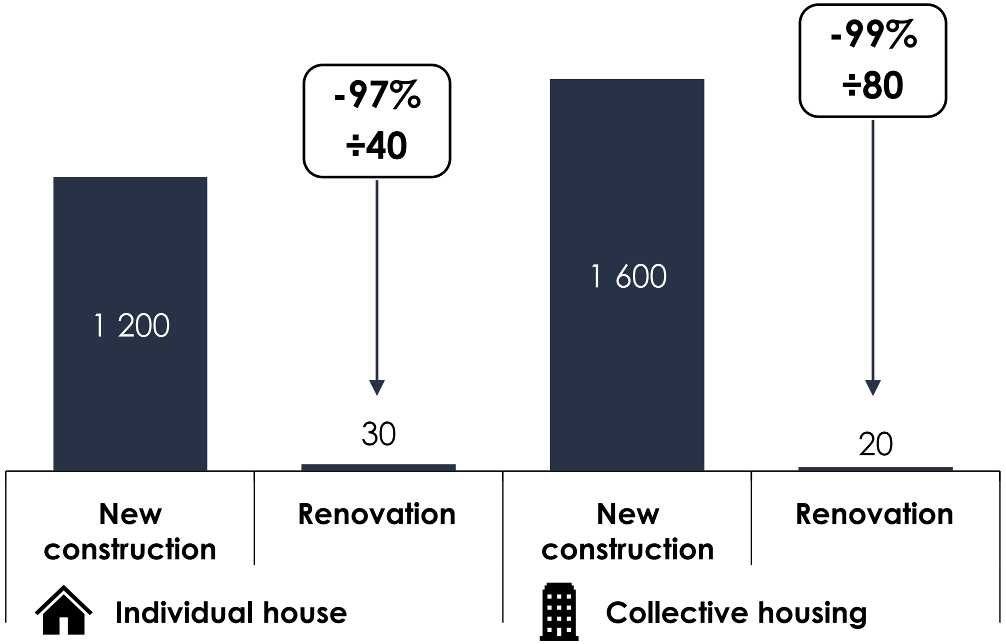
- *Slightly lower-carbon cement*
- *Wood, biosourced*
- *Earth, geosourced*
- *Recycled steel*

- *Materials manufacturing process efficiency*
- *Efficiency on construction site energy*

- *Use of low-carbon energy in the factory, transport, and on the construction site*

New construction consumes 40 to 80 times more materials than renovation

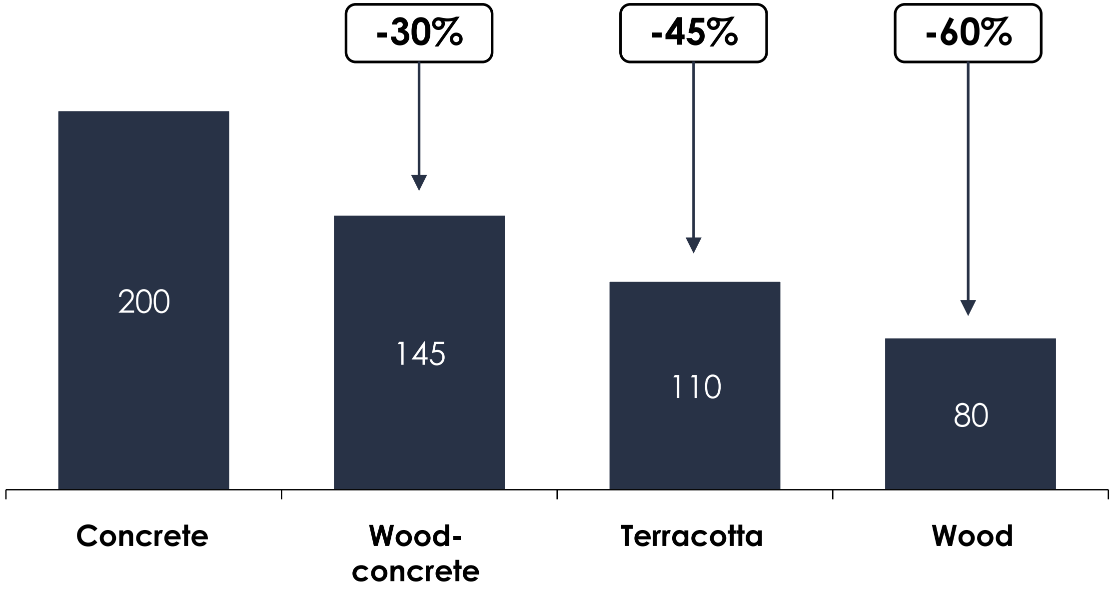
Construction VS renovation: consumption of materials (2015, kg / m²)



Source: ADEME, https://presse.ademe.fr/2019/12/etude-la-construction-neuve-beaucoup-plus-consommatrice-de-materiaux-que-la-renovation.html

The introduction of wood makes it possible to reduce emissions linked to the construction of the building structure by 30 to 60% today

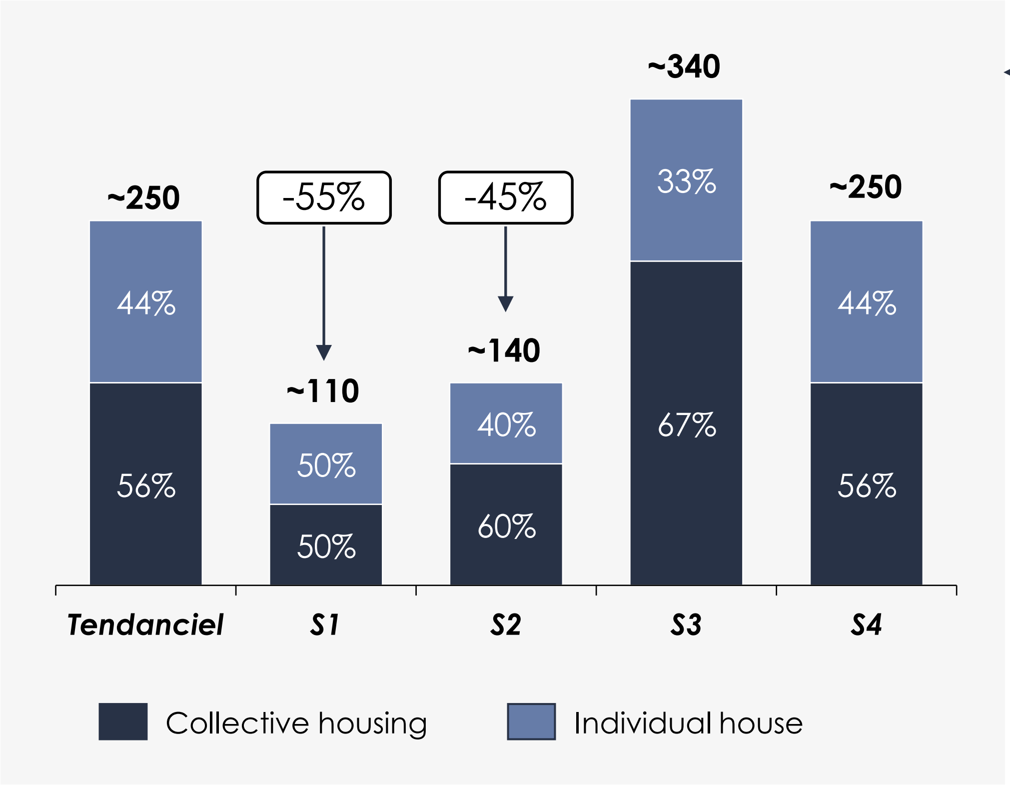
Carbon footprint for building structure (2018, kgCO2e / m²)



Note: the scope concerns collective housing
Sources: *La ville stationnaire*, Philippe Bihouix, Sophie Jeantet, Clémence de Selva ; IFPEB, Brief biosourcés, https://www.ifpeb.fr/restitution-des-messages-clefs-de-lapi-materiaux-biosources-du-hub-des-prescripteurs-bas-carbone/

Residential in 2050: renovation and sobriety to reduce our energy consumption, almost no more fossil energy

Annual average of the number of new housing units built between 2015 and 2050 (Thousands of housing units, per year)



Sufficiency

- Less new construction (secondary residences, vacant, under-occupied)

- More collective housing

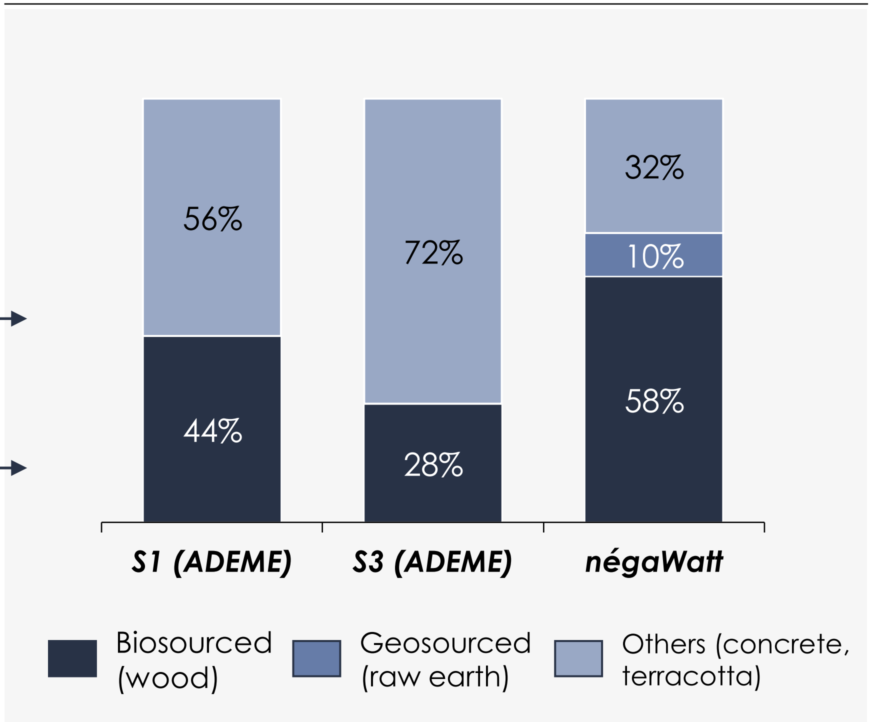
Efficiency

Optimized process

Energy and low-carbon materials

Biosourced + geosourced

Share of construction methods (2050, %)

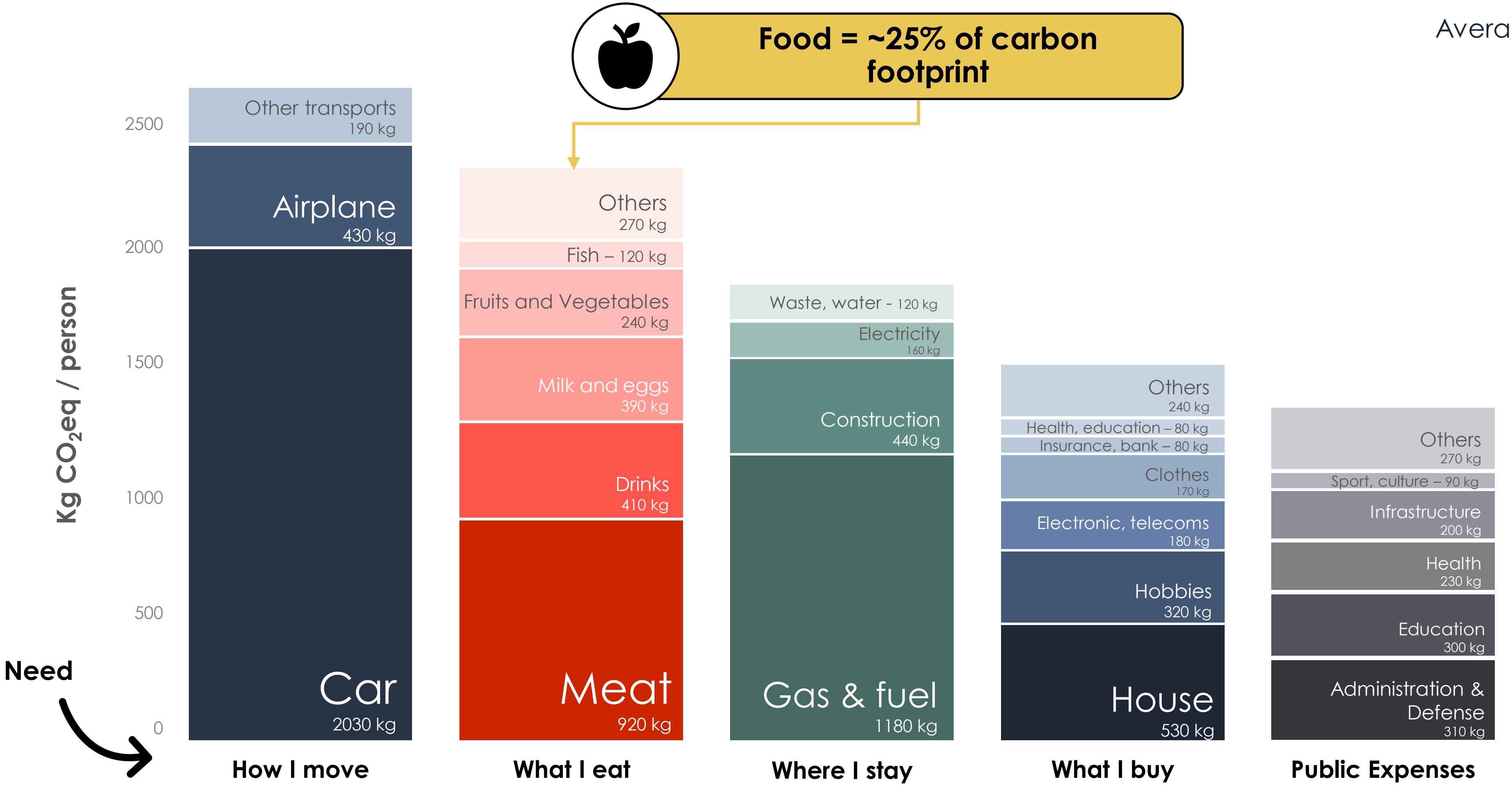


Source: Transition(s) 2050, ADEME ; scénario 2022 négaWatt

Food

Average Carbon Footprint in France in 2019

9,9 tCO_2eq / person



Food = ~25% of carbon footprint

	How I move	**What I eat**	**Where I stay**	**What I buy**	**Public Expenses**
$kgCO_2e$/person	**2650 kg**	**2350 kg**	**1900 kg**	**1600 kg**	**1400 kg**
kWh/person	**9 000 kWh**	**3 000 kWh**	**10 000 kWh**	**7 000 kWh**	**7 000 kWh**
% low-carbon energy	**5%**	**15%**	**50%**	**40%**	**45%**

Life cycle data: all the energy and emissions required to satisfy a need

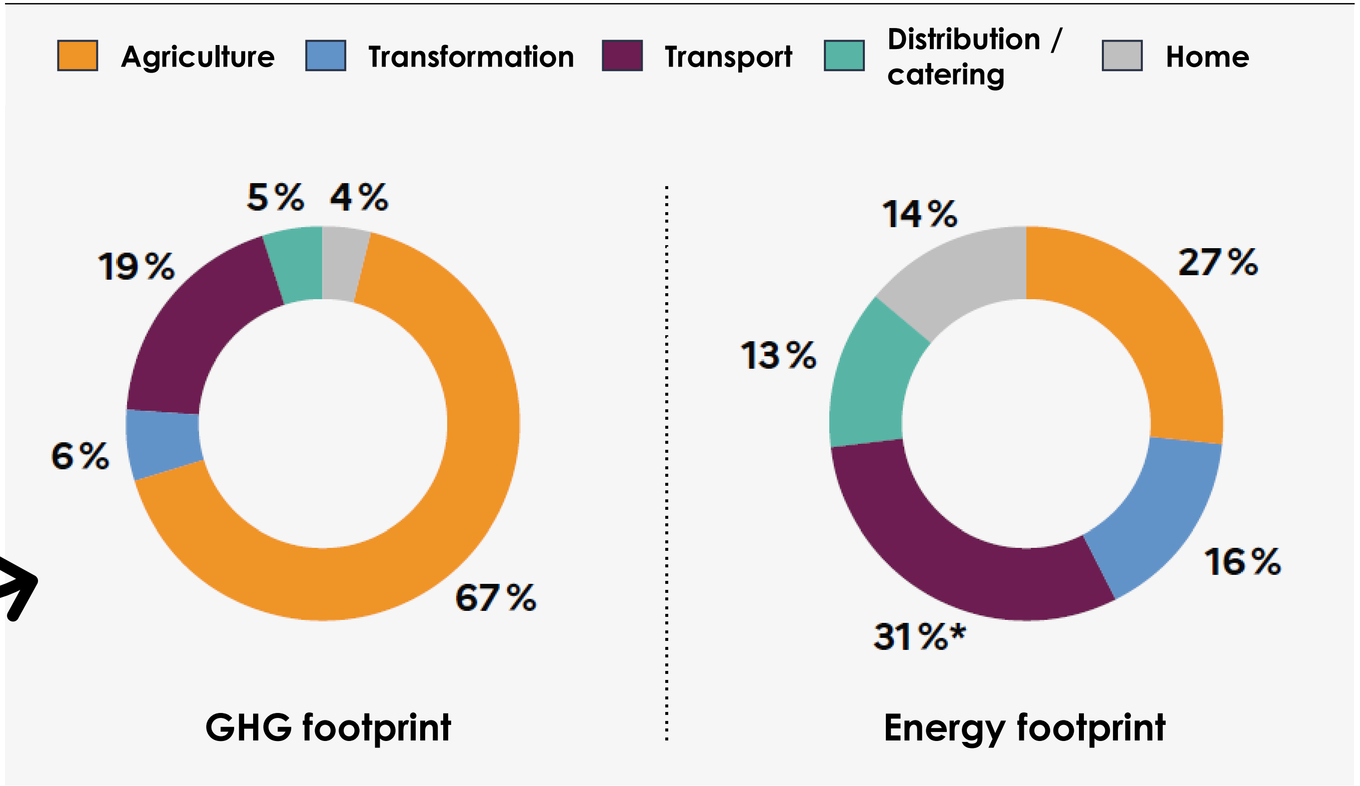
Gases included: CO2 (excluding LULUCF France), CH4, N2O, HFC, SF6, PFC, H2O (condensation trails).
Source : MyCO2 par Carbone 4 d'après le ministère de la Transition écologique, le Haut Conseil pour le Climat, le CITEPA, Agribalyse V3 et INCA 3.

Greenhouse gas footprint and energy: two different distributions in food

3 greenhouse gases in the field

- **45% = CH4 = fermentation** (digestive system, manure/slurry)
  - **90% = cattle**
- **40% = N2O = the use of mineral nitrogen fertilizers**
- **15% CO2 = energy (buildings, tractors)**

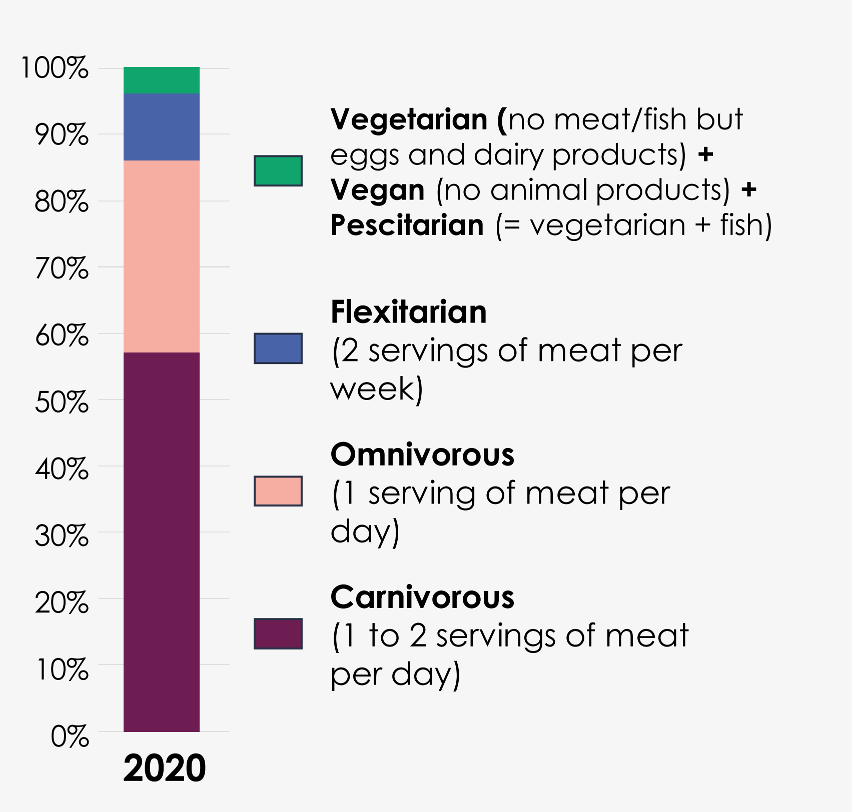
Greenhouse gas (GHG) and energy footprint - French food supply



Note: (*) including household travel for 9%
Source: Transition(s) 2050, ADEME

15% low-meat diets

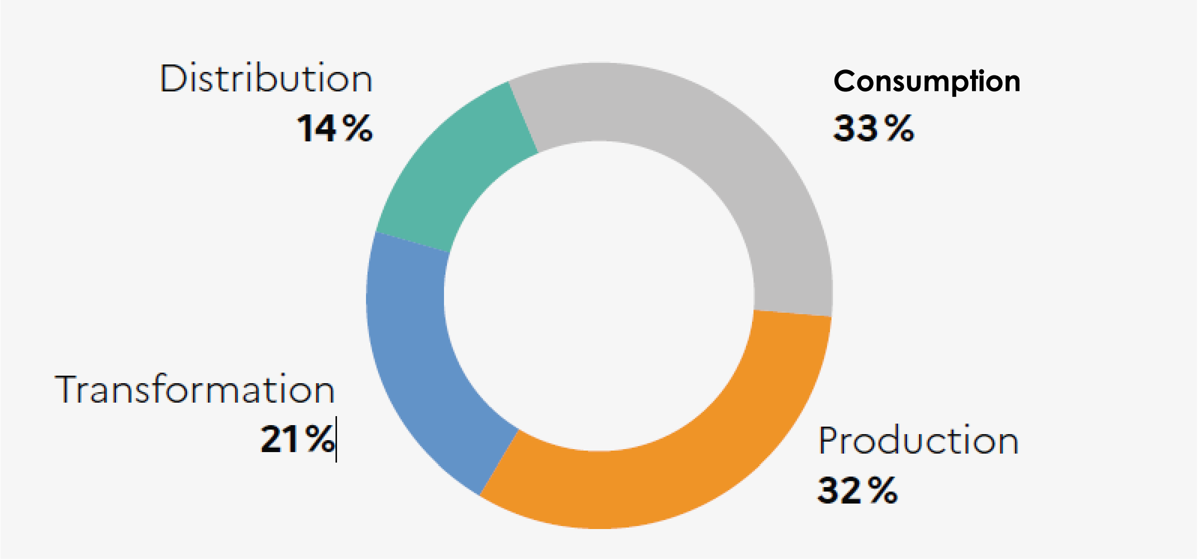
Diets of the French population



Source: Transition(s) 2050, ADEME

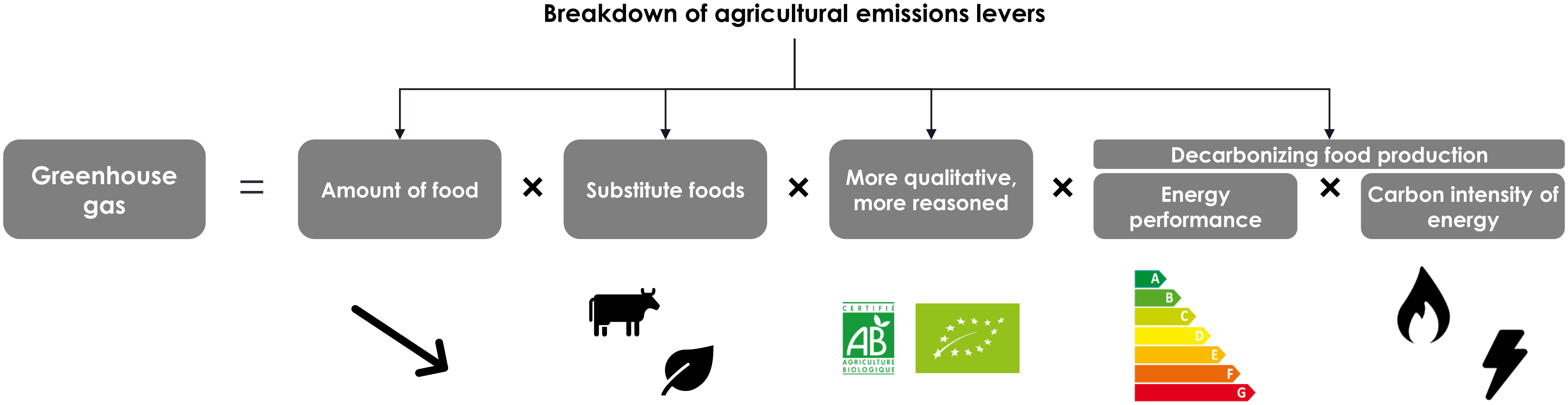
A third of food production lost

Distribution of food losses and waste in France in 2016
(% of tonnage)



Source: Transition(s) 2050, ADEME

So what to do?



Breakdown of agricultural emissions levers

Greenhouse gas = **Amount of food** × **Substitute foods** × **More qualitative, more reasoned** × **Decarbonizing food production**: **Energy performance** × **Carbon intensity of energy**

Amount of food
- *To eat less*
- *Less waste*

Substitute foods
- *Products of animal versus plant origin*

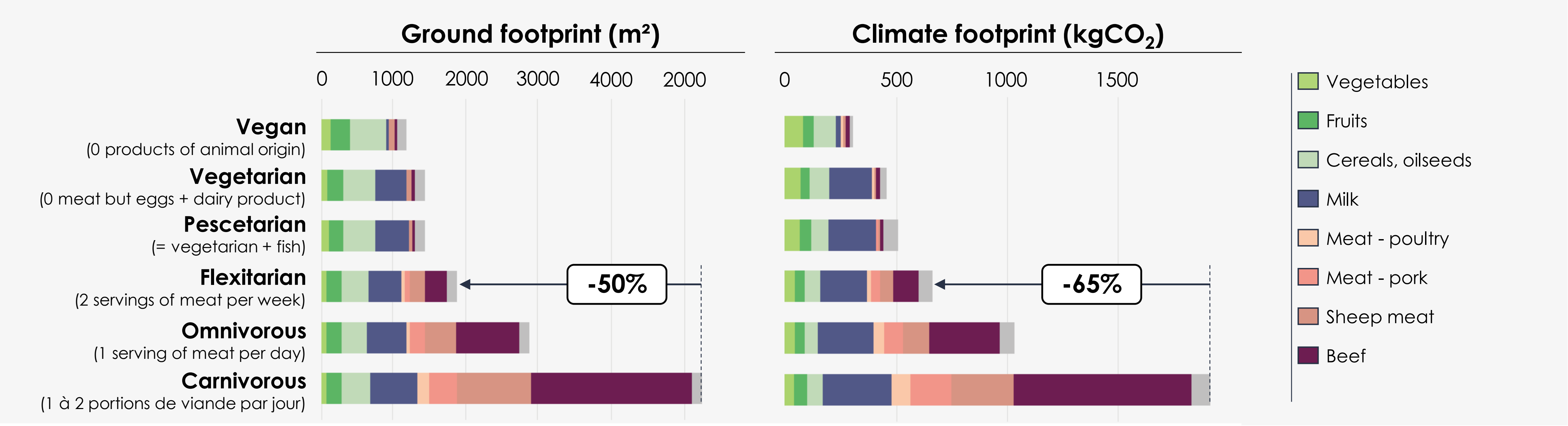
More qualitative, more reasoned
- *Biological*
- *Of the season*
- *Local*
- *Less transformed*
- *In bulk*

Energy performance
- *Efficiency of transformation processes*
- *Energy efficiency on the farm*

Carbon intensity of energy
- *Use of low-carbon energy in factories, transport and on the farm*

Flexitarian diet VS carnivore:
-65% climate impact, and -50% soil footprint

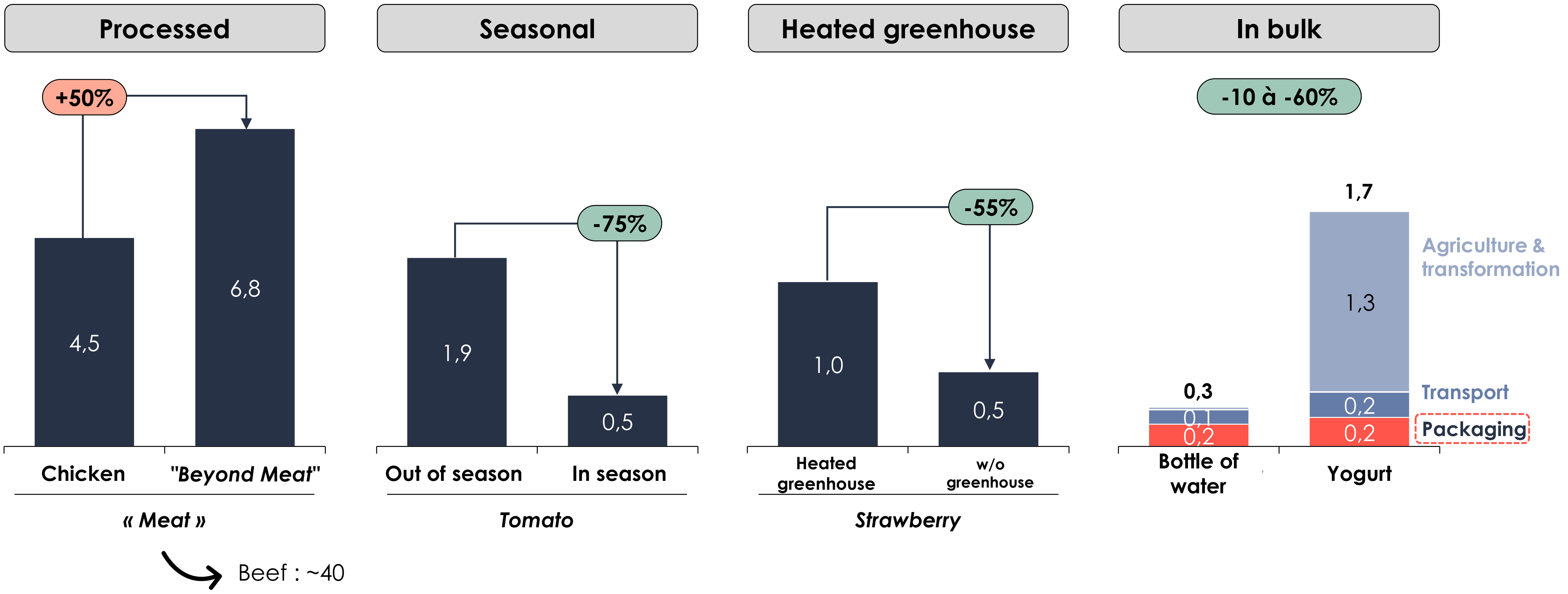
Footprint of different current diets of the French



Source: Transition(s) 2050, ADEME ; INRAE, https://www.inrae.fr/actualites/infographie-regime-moyen-dun-francais

Eating less processed, less seasonal, and in bulk significantly reduces greenhouse gas emissions

Climate impact of some food-related actions (kgCO$_2$e/kg product)



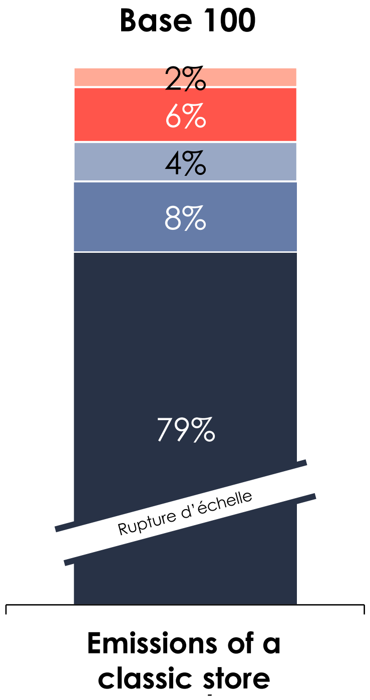
Sources: Agribalyse, ADEME, analyses Alexandre Joly

A small 40 m² “organic, plant-based, local, bulk” store emits 45% fewer emissions than a traditional store

From a classic store…

…to small 40 m² “organic, plant-based, local, bulk, local” stores

Equivalent in number of customers



Main emission sources[1]

- 🟧 **Manufacturing and energy consumption of store equipment**
- 🟥 **Travel of customers and employees from home to work**
- ▨ **Product packaging**
- ▨ **Transportation of products to the store**
- ⬛ **Production of products**

	Impact
Less surface area to heat/cool **Fewer refrigerated cabinets because the offer focuses on essential products**	-65%
Nearby store, accessible on foot or by bike	-40%
95% bulk products: fruits, vegetables, dry products, mustard, olives, household products, etc. Dairy products stored in glass jars	-90%
85% products from France, including half from the department	-65%
100% organic, few animal products	-45%
	Total: -45%

Notes: (1) Cooking and refrigeration of products at home, upstream logistics packaging, business travel, water consumption, expenses excluding store products, store construction, waste generated by unsold items represent 6% of the footprint and are not not displayed for easier reading
Sources: Agribalyse, ADEME, LSA, MTES, analyses Alexandre Joly

On the menu for agriculture 2050: plant the plate, review production methods, and produce renewable energy

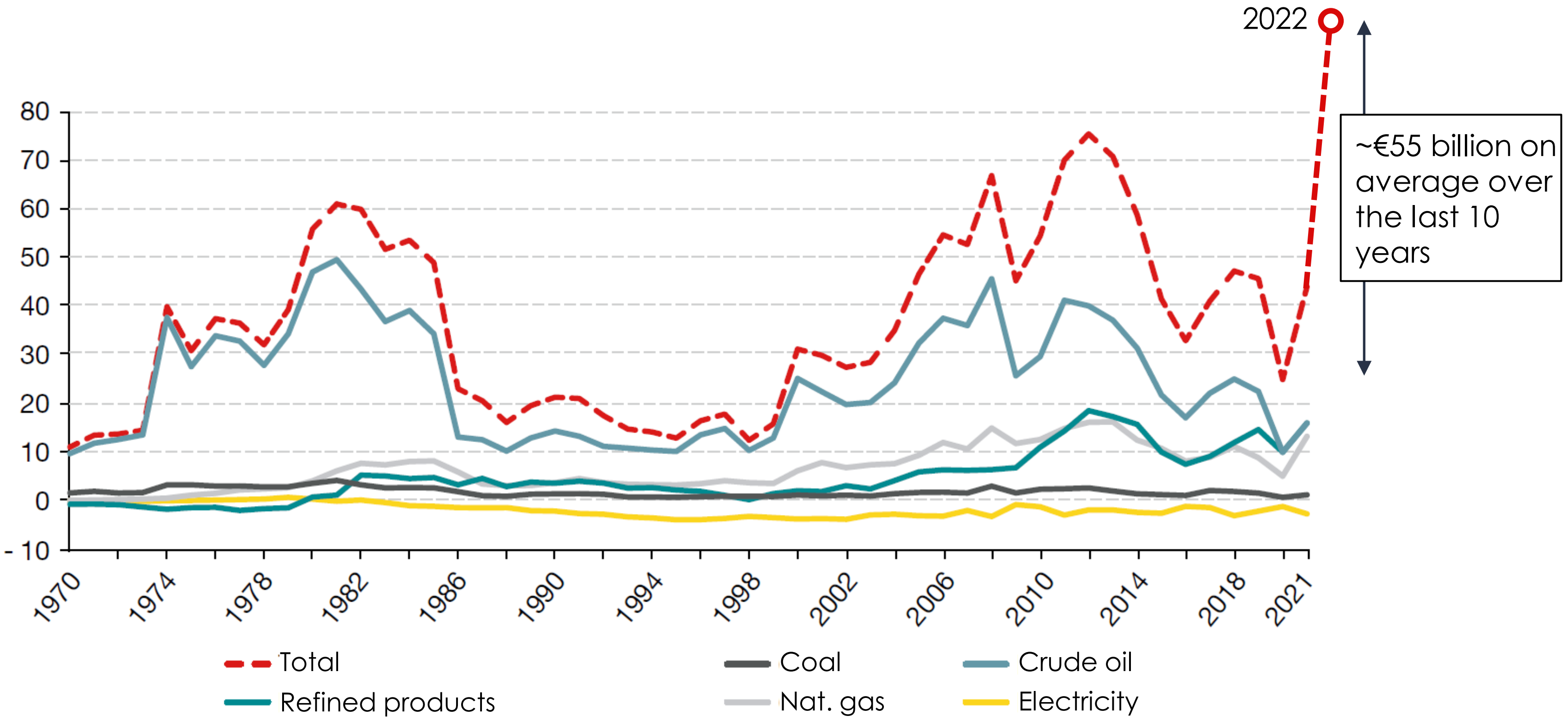
Scenarios ADEME	**Today**	**S1**	**S2**	**S3**	**S4**
Meat consumption (g/day)	123	-70%	-50%	-30%	-10%
Climate footprint of agricultural production (kgCO2e/year)	1500	-45%	-30%	-20%	-5%
Land footprint of agricultural production (m²)	4300	-40%	-30%	-15%	-5%

Source: Transition(s) 2050, ADEME

What if the energy transition made us more resilient?

Fossil fuels, a dependence that increases our trade deficit

France's energy bill (1970-2022, Mds € 2021/year)



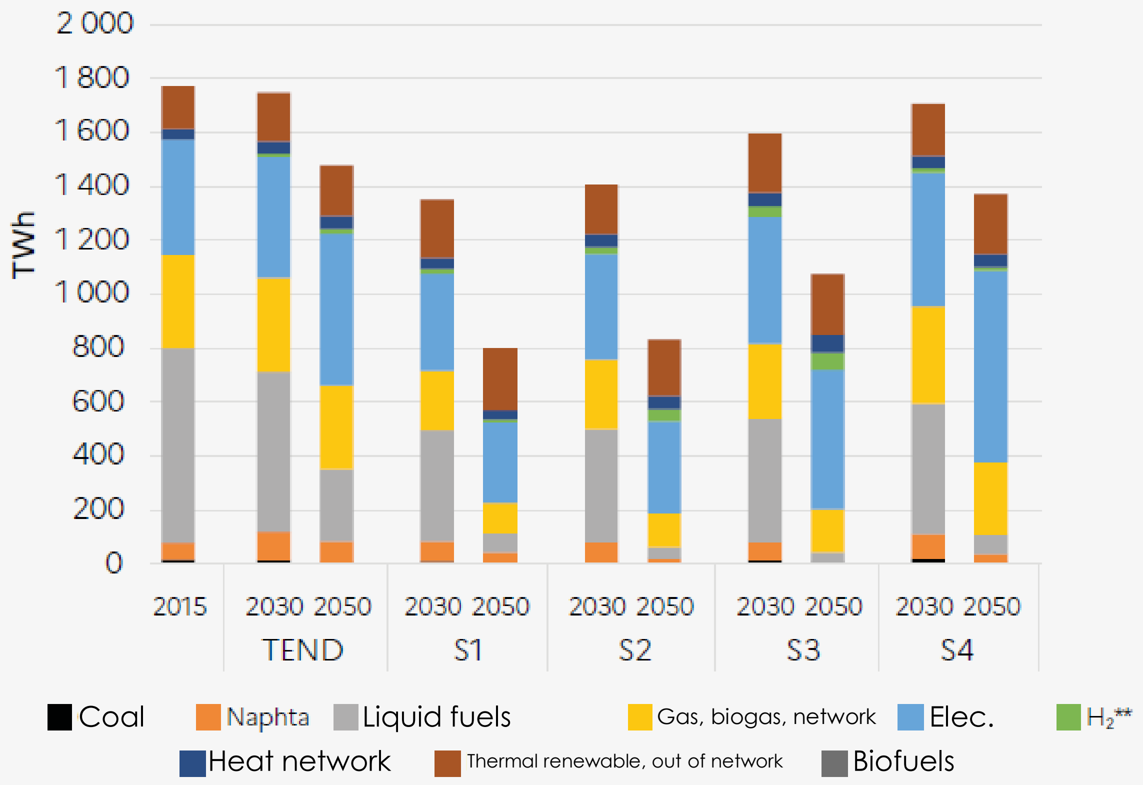
~€55 billion on average over the last 10 years

Sources: https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-energie-2022/ ; https://www.euractiv.fr/section/energie/news/la-facture-energetique-francaise-depassera-les-100-milliards-deuros-en-2022/ ; https://www.insee.fr/fr/statistiques/2381430

The energy transition increases our independence and our financial room for maneuver by reducing our energy bill

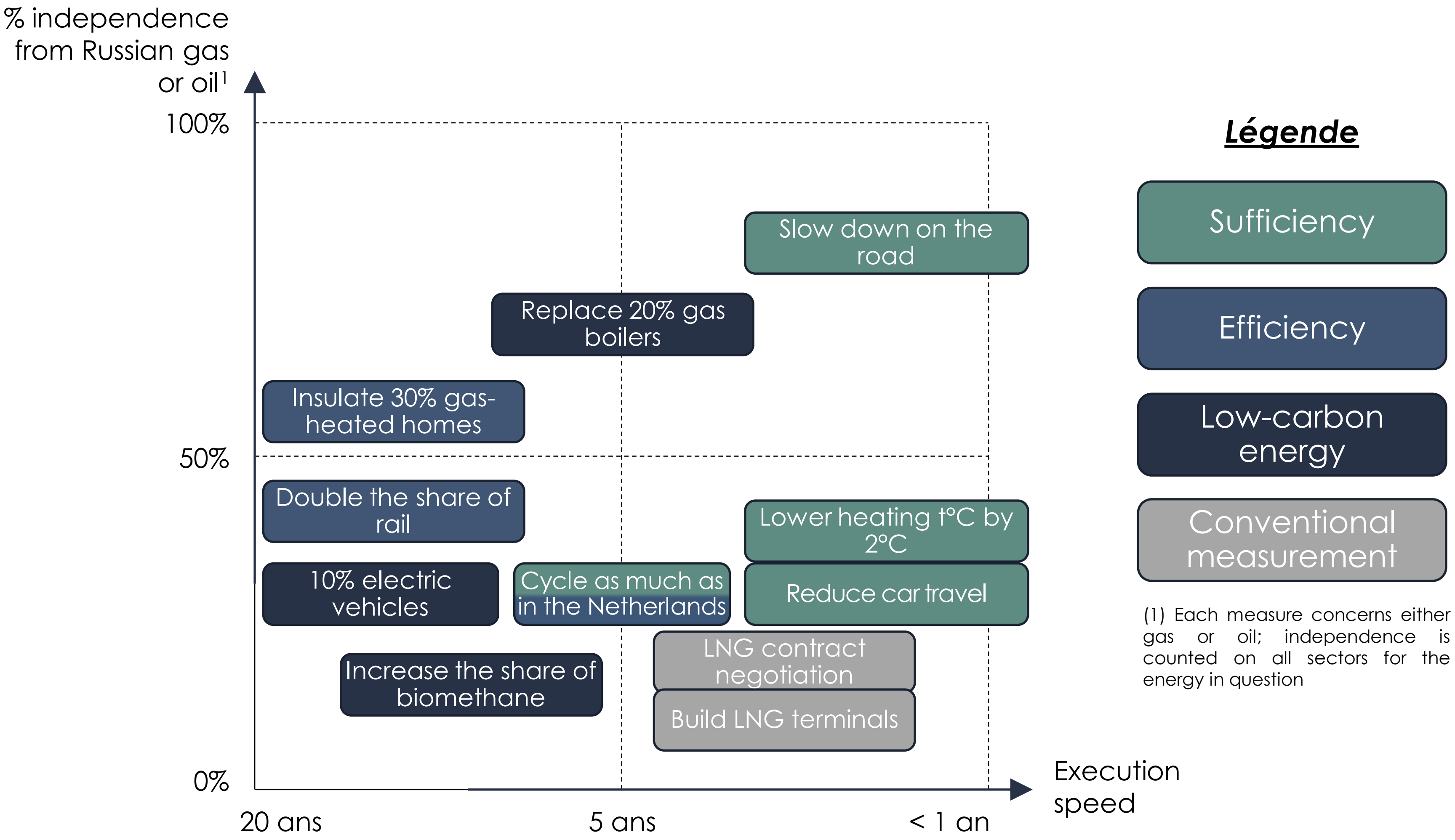
Total final energy consumption (TWh, scenarios ADEME)

⚠ *Excluding maritime and international air, non-energy uses included*



Source: ADEME, scénarios « Transition(s) 2050 »

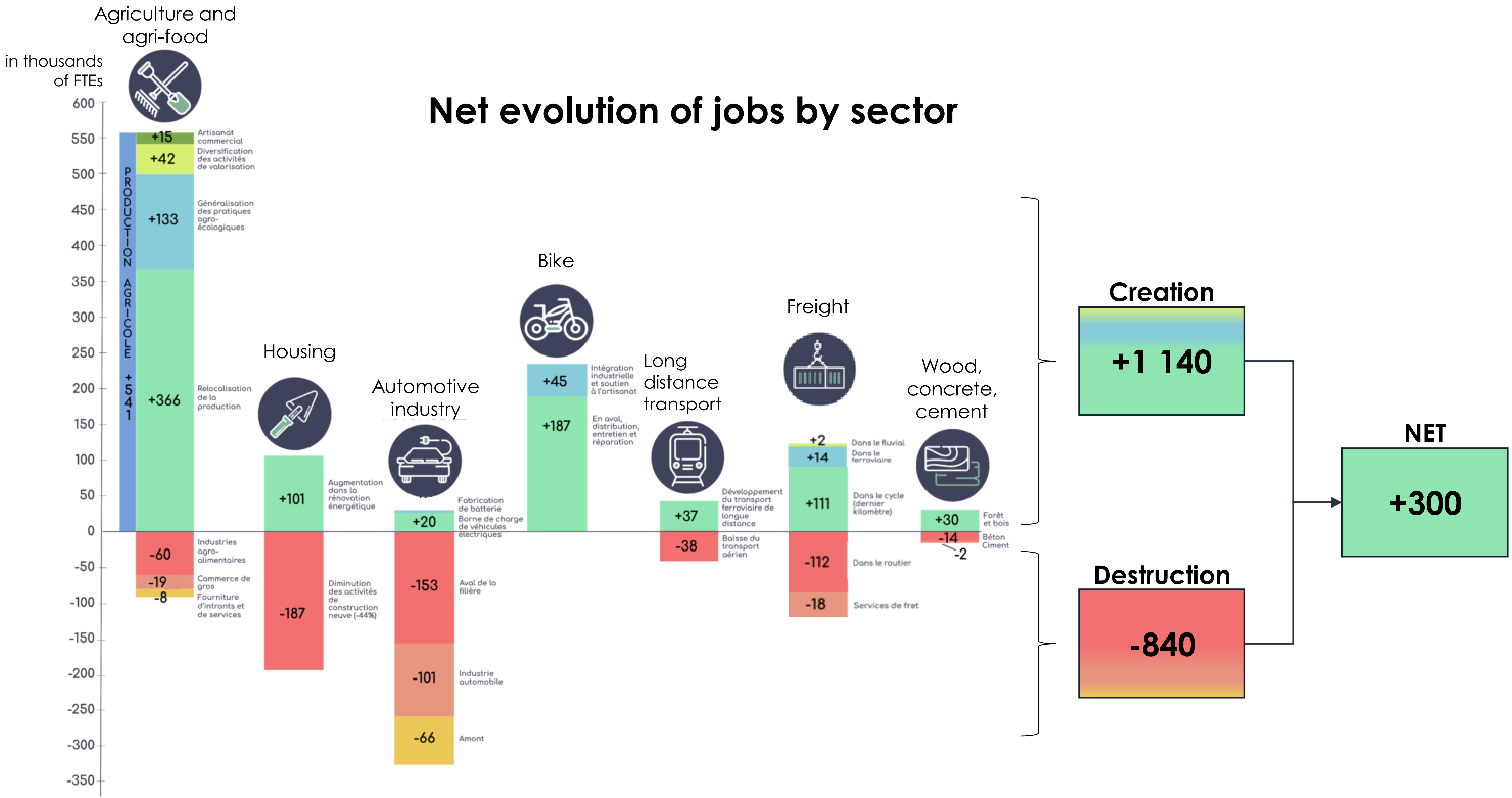
Sufficiency is a lever that can be activated quickly to regain independence: illustration on direct energy and the war in Ukraine



(1) Each measure concerns either gas or oil; independence is counted on all sectors for the energy in question

Source: https://www.carbone4.com/article-russie-sobriete#footnote-3

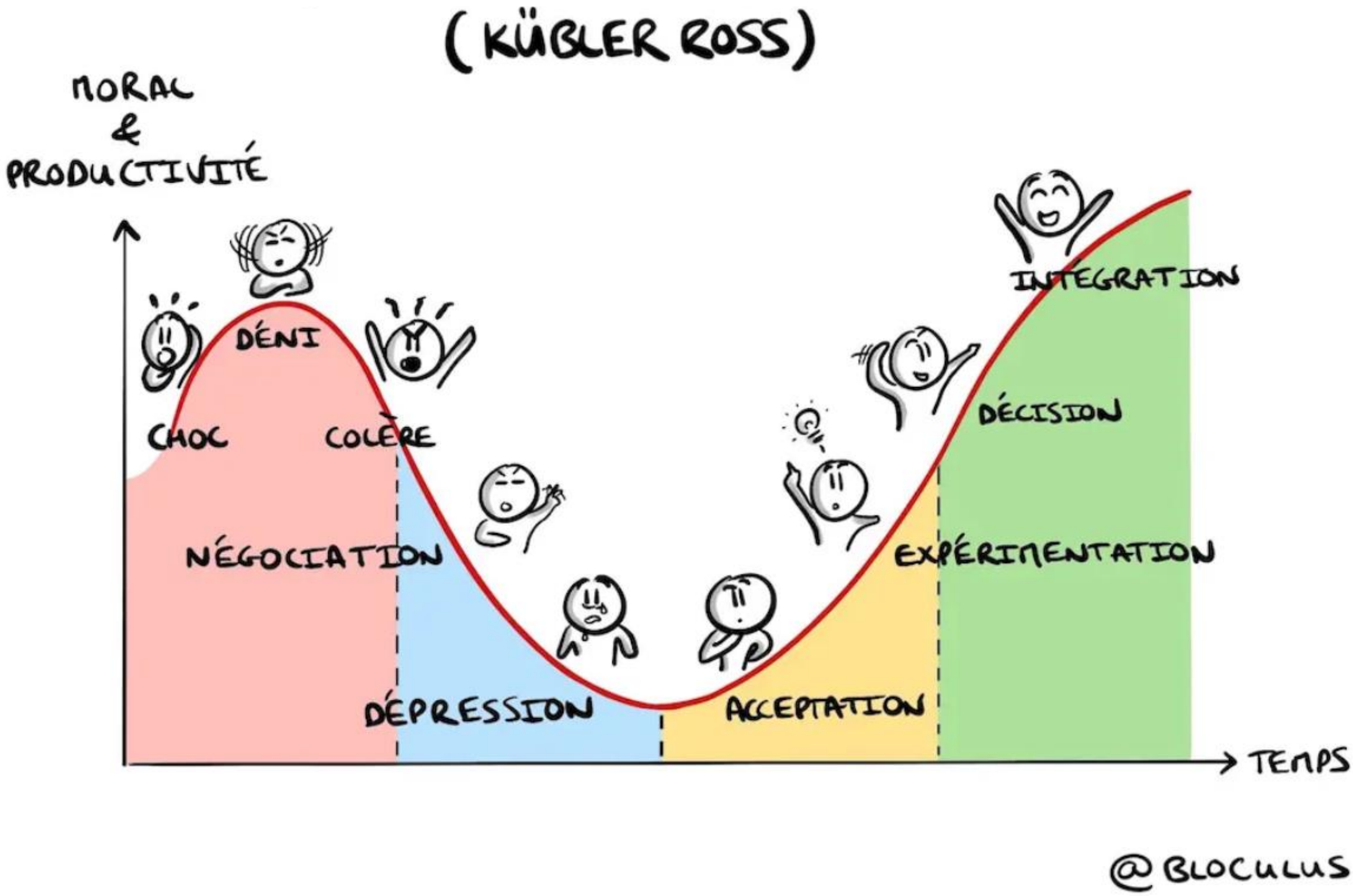
Net evolution of jobs by sector



Source: https://theshiftproject.org/wp-content/uploads/2021/12/TSP_RF-Emploi_Synthese.pdf ; https://waystoshift.com/emploi-moteur-transformation-bas-carbone-ptef/

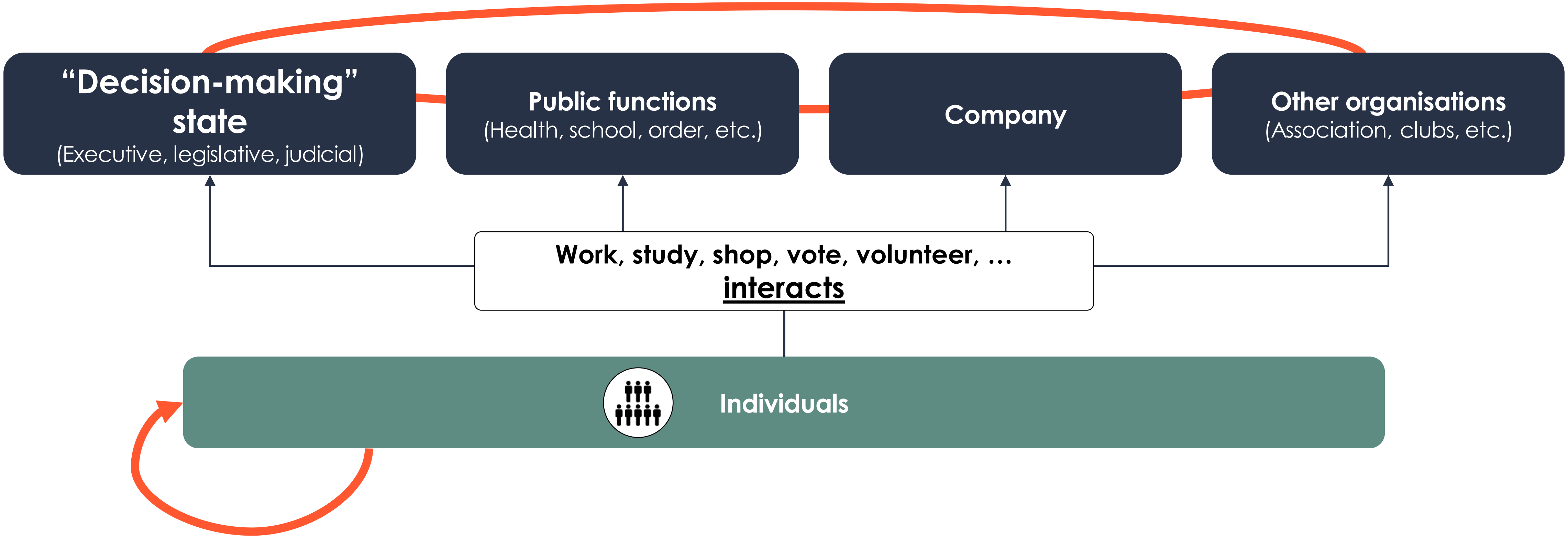
Becoming aware does not make you take action right away

Stages of change



Source: https://bloculus.com/tag/courbe-deuil/

There is no single person responsible because, quite simply, society is a complex system where all parts interact with each other.



“Decision-making” state
(Executive, legislative, judicial)

Public functions
(Health, school, order, etc.)

Company

Other organisations
(Association, clubs, etc.)

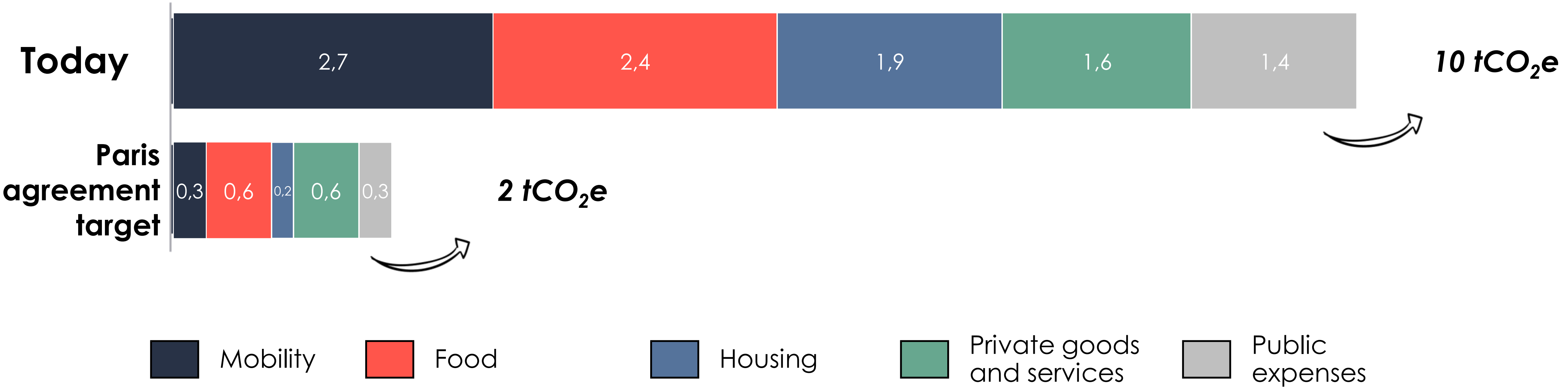
Work, study, shop, vote, volunteer, …
interacts

Individuals

On average, a French person must divide their emissions by 5 to “do their part” in order to keep global warming below 2°C

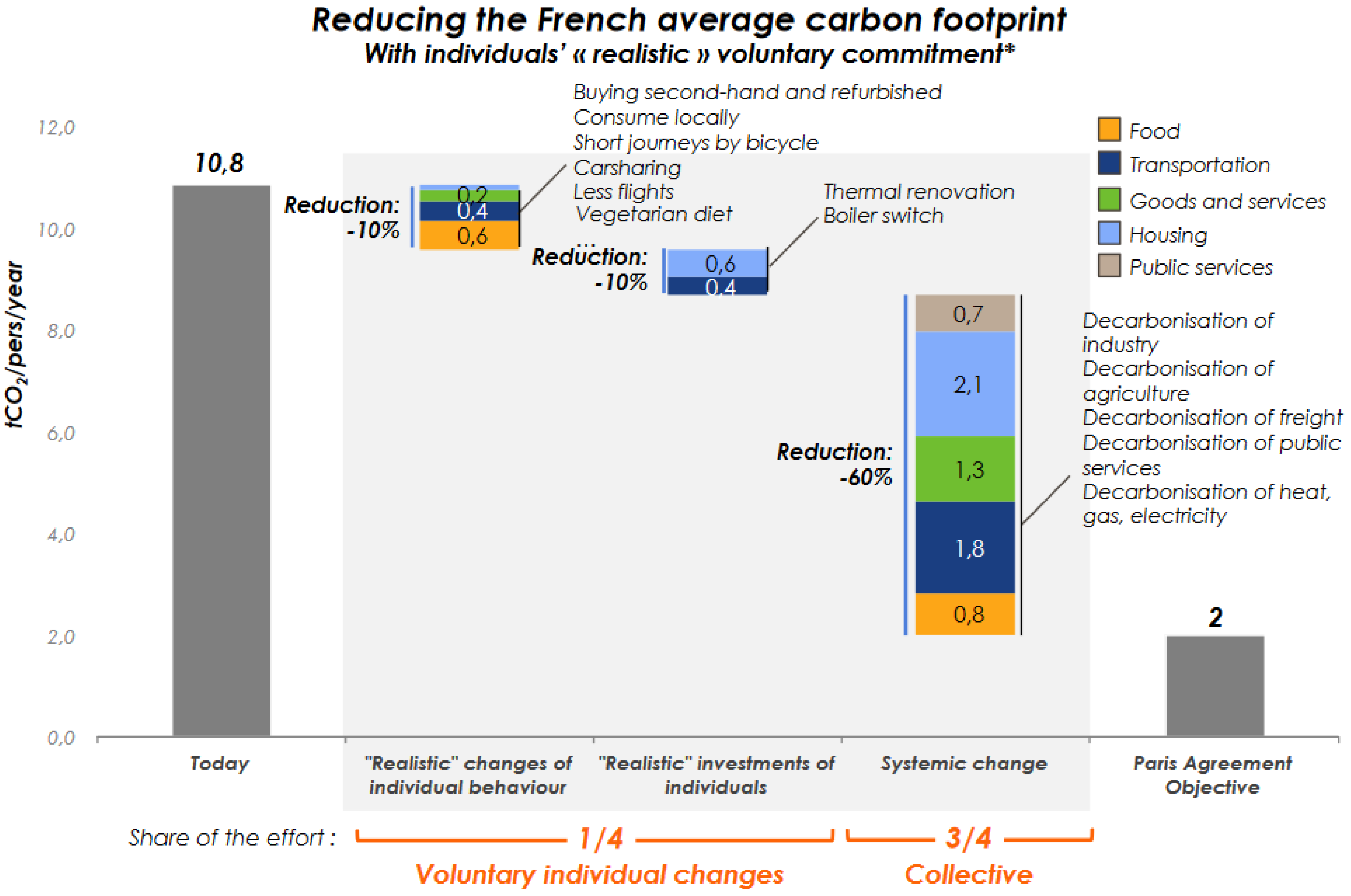
French average carbon footprint

tCO_2e, 2019-2050



https://www.carbone4.com/publication-faire-sa-part

The bulk of the effort goes through collective reorganization => State



Reducing the French average carbon footprint
With individuals' « realistic » voluntary commitment*

https://www.carbone4.com/files/wp-content/uploads/2019/11/Doing-your-fair-share-for-the-climate-Carbone-4.pdf