CAETS ENERGY REPORT 2022

ANNEXES

CAETS
International Council of Academies of Engineering & Technological Sciences

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The annexe of CAETS Energy Report 2022 contain two types of questionnaire responses.

The first type addresses mainly various aspects of electricity production and greenhouse gas emissions in the countries having responded. If available, these data are then commented on by the respondents. This is followed by answers to a set of questions aimed at better defining the legal measures taken by the respective governments to achieve the 2030-2050 goals. Countries submitted their annexes. Below are their submissions as they were given by each academy's representative.

This first type of questionnaire responses is complemented by responses from Working-Group Members that focus on their countries' efforts made in the sectors as defined in the report.

In total, these questionnaire replies allow us to obtain a more detailed view of both the responding countries and the selected sectors.

Note for the reader

Much of the data in the questionnaire responses is taken from the IEA [https://www.iea.org/countries and https://www.iea.org/data-and-statistics/data-product/emissions-factors-2021#emissions-factors], which has granted permission to reproduce information based on this data.

Due to having received responses from many countries we have tried to homogenise the representation of numbers. Nevertheless, some inconsistencies will have remained. The reader may thus find 20 000 or 20,000 for twenty thousand for example. For decimal, he may find 1.23 but also 1,23 for example.

COUNTRY ANALYSIS QUESTIONNAIRES

ARGENTINA

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1. National energy profile 2019

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Electricity/ Total Energy (%)
1990	348	42.8	11.2
1995	445	58.6	13.1
2000	495	77.6	15.7
2005	551	92.9	18.0
2010	622	114.7	18.4
2015	675	136.5	20.2
2019	642	129.4	20.1

Table 1. Total yearly consumption: final energy, electricity (TWh)
Source: Based on and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** Emission Factors (2021)

The period from 1990 to 2019 is divided into three distinct stages. From a very low baseline (GDP 1990=GDP 1980 x 0.89), the first decade showed a remarkable economic growth rate. Then the 2001 crisis ensued, but the country recovered quickly, and GDP resumed increasing at high rates (except for 2008-9) until 2011. In the following years, the economy stagnated until the end of the third decade considered in the above table, with years of recovery followed by years of recession. All told, the population increased by 37.3%, to 44.8 million, and GDP increased by 116%. The industrial sector grew by 76%. Energy consumption increased by 84.5% and electricity consumption reached a staggering increase of 202.3%. In the latter case, the ratio of electricity consumption / total energy consumption has almost doubled in the three-decade period. Energy efficiency gains were, however, not impressive mainly because of very low domestic energy prices, disconnected for many years from international prices due to price controls, massive state subsidies, and export levies.

Total yearly consumption per person: final energy, electricity (MWh per person per year)

Year	Inhabitants (million)	Energy Consumption (TWh)	Energy Consumption per person and per year (MWh)	Electricity Consumption (TWh)	Electricity Consumption per person and per year (MWh)
1990	32.6	348	10.7	42.8	1.3
1995	34.8	445	12.8	58.6	1.7
2000	36.8	495	13.5	77.6	2.1
2005	38.9	551	14.2	92.9	2.4
2010	40.9	622	15.2	114.7	2.8
2015	43.1	675	15.7	136.5	3.2
2019	44.8	642	14.3	129.4	2.9

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year)
Source: Based on and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** Emission Factors (2021)
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=AR

GDP per capita in constant currency grew 57% over the whole period, while energy consumption per person increased by 34.2%. Electricity consumption per capita grew 120%

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	93.5	18.925	2.91
1995	107.4	21.229	3.10
2000	128.0	24.424	3.50
2005	141.8	37.156	3.70
2010	162.4	42.971	4.00
2015	179.8	52.360	4.20
2019	162.2	40.052	3.60

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based on and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** Emission Factors (2021)
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=AR

A 73.5% increase in total emissions compares to the above quoted 84.5% increase in energy consumption. In turn, a 111,6% increase in emissions from electricity generation relates to a 202.3% growth in electricity consumption. This is a strong signal of the higher efficiency of mostly natural gas-powered CCPPs (Combined Cycle Power Plants) built over the 3 decades together with smaller additions in hydropower and nuclear power plants.

CO_2 emissions by fossil energy source ($MtCO_2$)

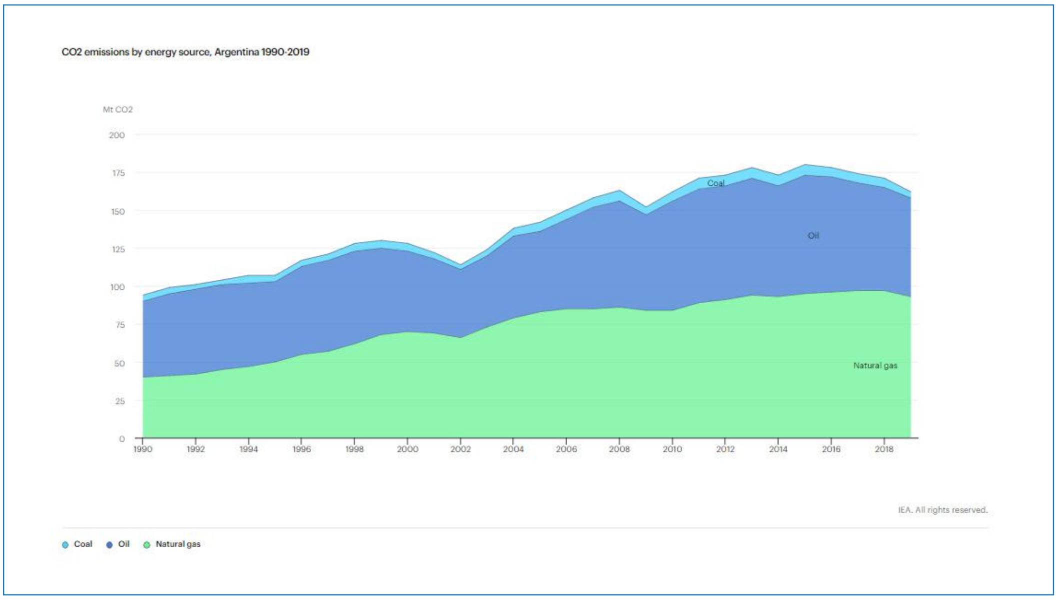

Fig. 1. CO_2 emissions by fossil energy source ($MtCO_2$)
https://www.iea.org/countries/argentina

Natural gas share in the energy mix has consistently remained over (and increasingly higher than) 50% for the last two decades. It displaced liquid fossil fuels for power generation and also for heating and industrial uses, having also a small share in transport (via compressed natural gas, or CNG). CO_2 emissions from natural gas reflect both its participation in the energy mix but also the lower level of such emissions compared to other fossil fuels.

CO_2 emissions by sector ($MtCO_2$)

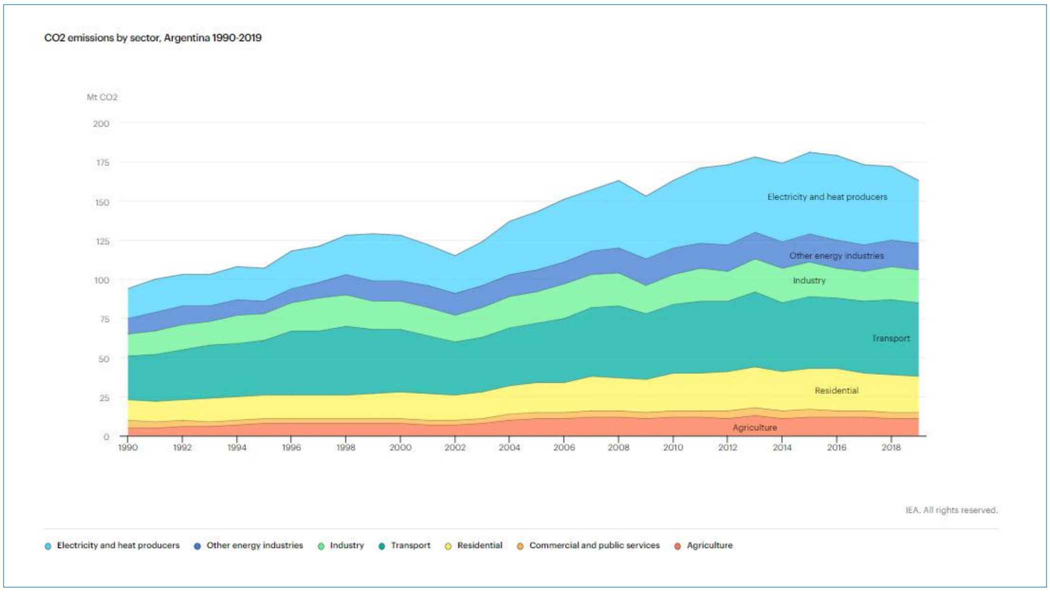

Fig. 2. CO_2 emissions by sector ($MtCO_2$)
https://www.iea.org/countries/argentina

In 2019, close to 49% of power generation was emissions-free (mostly hydropower, followed by nuclear and renewables). This is also reflected in the declining trend of CO_2 emissions, which was already observable in previous years. Transport still has an important share in emissions.

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

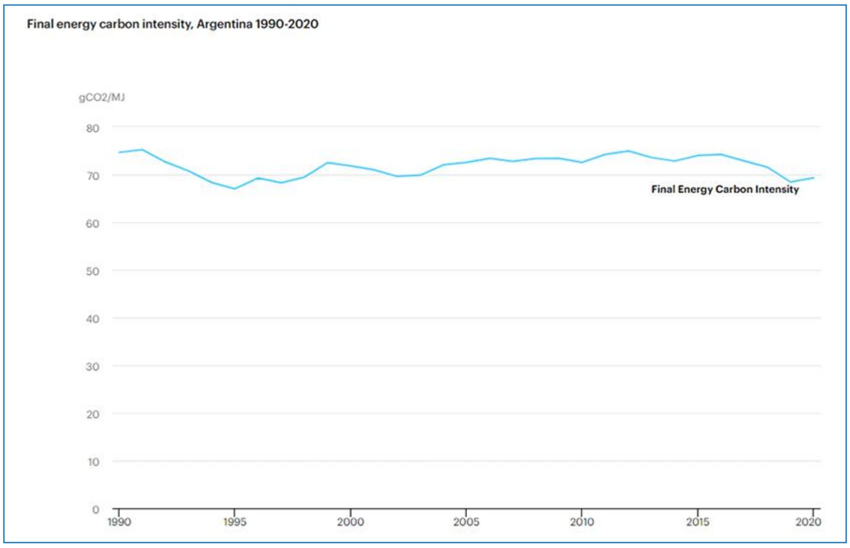

Fig. 3. Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours), **IEA**
https://www.iea.org/countries/argentina

The almost flat trend over more than two decades falls off in the last years of the third decade represented in the diagram above, and somewhat more steeply in 2019, but goes up again in 2020.

2. Energy perspectives 2030 - 2050

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

The Argentine Government established the actions to develop in order to mitigate GHG emissions in all sectors of the industry. This is stated in resolution 447-19 of the former Secretary of Government for the Environment and Sustainable Development of the Nation[1], in its Annex V and in law 27520 of 2019[2]. These actions are recommended individual initiatives, which do not constitute a true 'road map'.

Roadmap for the energy mix

None

Roadmap for the GHG emissions (country, per capita)

In December 2020, Argentina submitted a second Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC). In this NDC, it undertakes to continue the reduction of emissions. By 2030, these will be reduced by 25.7% compared to the first NCD. Argentina's net emission will not exceed 359 $MtCO_2$ in 2030, applicable to all sectors of the economy. Interest in developing a strategy to achieve CO_{2e} neutrality by 2050 was also announced.

Roadmap for the electricity mix

There is a 2025 target for new Renewable Energies, supplying at least 20% of the electricity demand. It was established by Law 27.191 enacted in 2015[3].

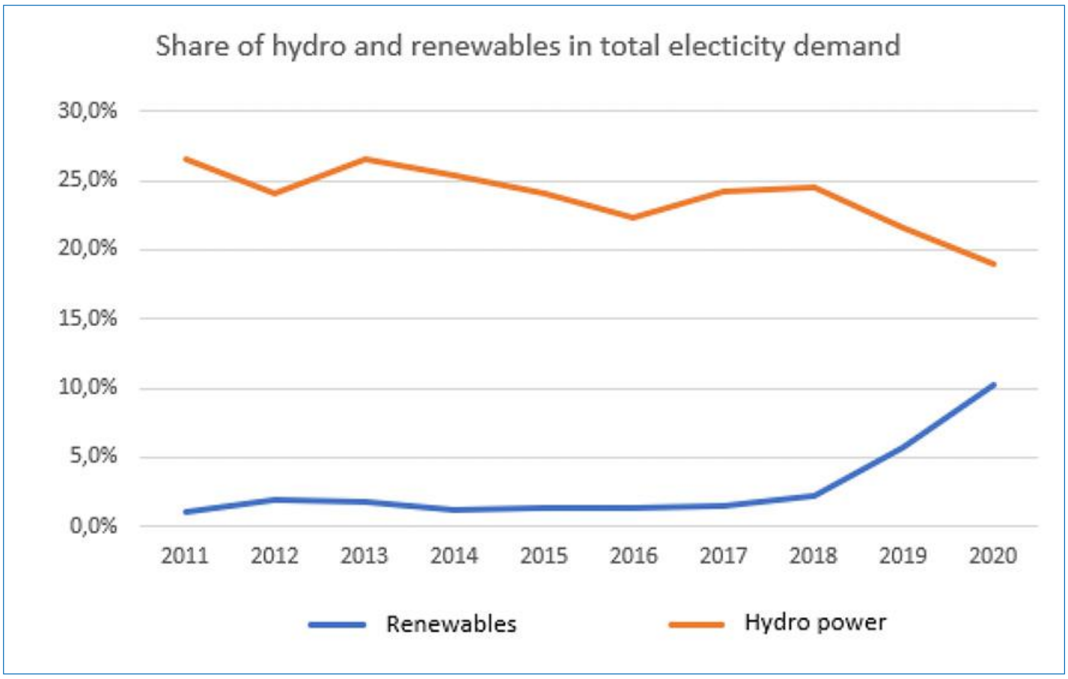

Fig. 4. Past performance
Compiled from IEA data: https://www.iea.org/countries/argentina

1 https://www.argentina.gob.ar/normativa/nacional/resoluci%C3%B3n-447-2019-332234

2 https://www.argentina.gob.ar/normativa/nacional/ley-27520-333515

3 https://www.energia.gob.ar/contenidos/archivos/Reorganizacion/renovables/legislacion/ARGENTINA_-_Renewable_Energy_Law_Act_27191_(English_version).pdf

CO_2 emissions from electricity production 2019

In 2019, total CO_2 emissions from electricity production were about 36 Mt, while CO_2 emissions from overall electricity production were about 0.27 Mt/MWh, and those from electricity production using fossil fuels were about 0.45 Mt/MWh.

Energy balance (energy sources to end-uses)

SUPPLY AND CONSUMPTION	Mineral Coal	Crude Oil	Oil products	Natural gas	Nuclear	Hydro	Biofuels & Waste	Others	Total
Production	2.59	1,099.84		1,814.88		126.90	205.28	26.25	3,275.75
Imports	22.86		118.11	238.56	92.11	39.40			511.04
Exports	-1.51	-141.89	-200.21	-9.67		-0.92	-37.81		-392.01
Stock changes	6.70	15.62	9.38	-15.20					16.50
TES	**30.65**	**973.57**	**-72.72**	**2,028.58**	**92.11**	**165.38**	**167.47**	**26.25**	**3,411.28**
Transfers									
Statistical diff	-1.38	19.18	11.22						29.01
Electricity plants	-5.74		-41.28	-626.18	-92.11	-164.12	-32.41	519.96	-441.87
CHP plants									
Heat plants									
Blast furnaces	-16.83								-16.83
Gas works			113.76	-113.76					0.00
Coke ovens									
Oil refineries		-988.59	988.59						0.00
Petchem plants									
Liquefaction plants									
Other transf							-5.74		-5.74
Energy ind own use	-2.76	-4.14	-75.66	-214.82				-13.44	-310.83
Losses	-1.51		-73.86	-177.77		-1.26	-4.14	-75.11	-333.65
TFC	**2.43**	**0.01**	**850.05**	**896.05**	**0.00**	**0.00**	**125.19**	**457.66**	**2,331.38**
Industry	1.76		18.13	323.81			42.41	179.61	565.72
Transport			568.48	85.54			64.94	1.88	720.84
Other			209.09	405.37			17.84	276.16	908.45
Non-energy use	0.67		54.34	81.35					136.36
	2.43	**0.00**	**850.05**	**896.06**	**0.00**	**0.00**	**125.19**	**457.66**	**2,331.38**

Table 4. Argentina energy balance 2019 (expressed in PJ)
Source: National Energy Balance 2019 and own calculations (1 PJ = 0,27778 TWh)

3. Building sector

3.1. Existing buildings

Energy balance 2019 (energy sources to end-uses)

Electricity distribution to buildings and industry is ensured via a high-voltage (mainly 500 kV) grid of about 15 000 km and a national grid (mainly 132 kV) of about 20 000 km. On the electricity supply side, we have 130 TWh/year, of which approximately 2% are imports, 6% renewables, 6.5% nuclear, 22% hydro, and 63.50% thermal, while generating capacity is 7% for renewables, 4% nuclear, 27% hydro, 62% thermal. On the demand side, we have 129 TWh/year, of which 43% comes from the residential sector (buildings), 29% from commercial and industrial customers, and 28% from other large customers such as Government and Private Office Buildings and utilities.

Energy partition between single houses, apartment buildings and office buildings

	%
Single houses	14%
Apartment buildings	29%
Office buildings	18%
Rest of the activities	39%

Table 5. Energy partition between single houses, apartment buildings and office buildings

Which systems are mostly used for heating?

- Local systems (Furnaces, electric heating, heat pumps, solar thermal panels, geothermal systems, etc.)?

First, if available, natural gas stoves. Second, electric heating. Third, but on a much smaller scale, other sources like firewood, coal, etc.

- Heat networks (hot water, steam). In this case, which energy sources are used? What is the CO_2 content per MWh th?

In residential buildings of several stories, central heating is based on natural gas with radiant / heating slabs (≈0,42 metric tonnes CO_2 per MWh). In office buildings or where natural gas is not available, central heating is based on electrical air conditioning (≈0,28 metric tonnes CO_2 per MWh based on the generation mix in Argentina).

Which systems are mostly used for cooling? (local systems, cooling networks)

If possible central cooling is based on electricity. Otherwise, independent electrical air conditioning will be used.

What are the main choices of the national policy – if there is one – to reduce the emissions from the existing stock of buildings? To make this reduction affordable.

- From a technological point of view? (Insulation, heat pumps, low CO_2 district network, geothermal systems, local PV production, etc.).
- From a regulatory point of view? Through land ownership regulations?
- Through subsidies, different financial mechanisms? Which are the priorities: reducing CO_2 or energy; Better inclusivity.
- Replacing parts of the existing stock of buildings?
- Is there a specific roadmap for this subject?

No national policy right now.

Is there some roadmap for making existing cities more sustainable?
No national policy right now.

Are there some case studies or best practices you would like to share?
No.

3.2. New buildings

Does your country have a national policy regarding new buildings?
If yes, what are the priorities? (For housing and for office buildings)
Is under study by the government. Not yet.

Are some technologies prioritised, in particular for heating and cooling? At the building level? At the infrastructure level? (Development of district networks, prohibiting connection to the gas network…)
No.

How are they supported? Through regulations? Subsidies?

Are there some recommendations and regulations for sustainable districts and cities?
No

4. Industry

4.1. Cement Industry

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

The first table in this presentation presents the sustainability indicators issued for 2019 by the Argentina Portland Cement Manufacturers Association (AFCP). The indicators were calculated according to GCCA-GNR.

CEMENT INDUSTRIE - SUSTAINABILITY INDICATORS

GENERAL	unit	Year 2019
Total production volumes of clinker	Mt	8,15
Total production volumes of cement for estructural use	Mt	11,08
Total production volumes of cement for masonry use	Mt	0,84
Installed capacity	Mt	15,35
Number of plants		17
Number of cements certifies		70
Dispatch of cement in bags with respect total production (cement for structural use)	%	58,3
USED MATERIALS		
Traditional raw materials for clinker production	Mt / year	12,06
Alternative raw materials for clinker production	Mt / year	0,15
Traditional raw materials that added to clinker for cement production	Mt / year	2,55
Alternative raw materials that added to clinker for cement production	Mt / year	0,80
Materials used for packaging	kg/t cement	4,1
Clinker/Cement equiv. (GNR protocol, ref 092a)	%	70,2
ENERGY CONSUMPTION		
Direct energy consumption for clinker production (GNR protocol, ref 093)	GJ/t clinker	3,55
Direct energy consumption for clinker production (GNR protocol, ref 062)	GJ/t cement	2,49
% Consumption based on alternative fuels (without biomass)	%	3,1
% Consumption based on biomass	%	3,5
CO2 emission factor for kiln fuel mix (GNR protocol, ref 096) *	kg CO2/GJ	62,7
CO2 emission factor for kiln fuel mix (GNR protocol, ref 096). Decrease compared to 2015	kg CO2/GJ	3,40
Indirect energy consumption	GJ/t cement	0,35
% Consumption based on renewable sources	%	36,60
Total energy consumption	GJ/t cement	2,84
EMISSIONS TO THE ATMOSPHERE		
CO_2 Emission		
Specific Gross CO_2 of cementitious product (GNR protocol, ref 062)	kg CO2/t cement	519
Specific Indirect CO_2 from external power generation (GNR protocol, ref 082a)	kg CO2/t cement	28
Total gross CO2 emissions, excluding CO2 from on-site power generation **.	kg CO2/t cement	547
Total gross CO2 emissions, excluding CO2 from on-site power generation. Decrease	%	5,40
Other Emissions		
NO3	kg/t cement	2,22
SO3	g/t cement	22
Particulate matter ***	g/t cement	72
WASTE		
Hazardous waste generated	kg/t cement	0,06
% Reused, recycled or recovered	%	69,3
Non-hazardous waste generated	kg/t cement	0,49
% Reused, recycled or recovered	%	50,4
REFERENCE INDICATORS		
In 2015 the reference indicators were,		
* CO2 intensity factor of the fuel mix: 66.1 kg CO2 / GJ		
** Total gross CO2 emissions, excluding CO2 from on-site power generation: 578 kg CO2/t cement		
*** Particulate matter: 128 g/t cement		

Table 6. Cement industry – Sustainable indicators
Source: Provided by the Argentina Portland Cement Manufacturers Association (AFCP)
Reproduced with permission.

Table 7 shows the energy balance (energy sources used) according to the above-mentioned restricted information delivered to the ANI by AFCP.

Description	% of thermal energy demand		
Reference year	**2019**	**2030**	**2050**
Coal	0.2	0.0	0.0
Petcoke	22.4	25.0	0.0
Natural gas	70.5	60.0	65.0
Waste of fossil origin (including fossil fuel from mixed fuels)	3.1	8.0	20.0
Biomass (including biomass from mixed fuels)	3.5	7.0	15.0
Other remaining fuels	0.0	0.0	0.0
Sum of fuels composition shares	100.0	100.0	100.0

Table 7. Energy Balance
Source: Provided by the Argentina Portland Cement Manufacturers Association (AFCP)
Reproduced with permission.

Are the best available low carbon technologies used / considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

The AFCP conducted a study of 21 measures selected from the 52 technologies developed in WBCSD[4] -CSI[5] / ECRA[6] Technology Papers 2017.

Regarding its implementation, the following issues were investigated: a) the current degree of progress; b) if there is potential in the 2018-2030 period; and c) the limitations for local applications. The investigation was strictly technical and did not include financial-economic feasibility.

The technologies for the reduction of the clinker content (strategies # 31, 34, 35, 36 and 37 of CSI/ECRA) and of the carbon footprint in the fuel matrix (strategies # 13 and 14 of CSI/ECRA) were evaluated.

The technologies for capturing, storing and reusing CO_2 (# 43 to 52 inclusive) were not taken into account, considering that there is no certainty of their viability at the 2030 horizon.

The other CSI/ECRA technologies were discarded as locally unviable or still in the development stage.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

Table 8 shows the vision of the Argentine cement industry regarding GHG emissions towards the years 2030 and 2050. To date, there are no estimates for intermediate stages.

4 World Business Council for Sustainable Development
5 Cement Sustainability Initiative
6 European Cement Research Academy

GHG EMISSIONS - VISION CEMENT INDUSTRY ARGENTINA

Description	Note	Unit	2019	2030	2050
Clinker process emissions					
Calcination process emisions factor	(i)	kg CO_2/kg clinker	0,536	0,536	0,536
CO2 from organic carbon in limestone (TOC)	(ii)	kg CO_2/kg clinker	0,011	0,011	0,011
Alternative de-carbonated raw-materials for clinker production. Posible application	(iii)			x	
Total clinker CO2 emission factor (direct emissions)	(iv)	kg CO_2/kg clinker	0,77	0,76	0,72
New binders					
Share of new binders in concrete production	(v)	%	0,00	0,00	3,00
New binders average CO2 emissions factor	(vi)	kg CO_2/kg binder	0,00	0,00	0,30
Cement					
Cement production (excluding SCM for use in concrete plants)	(vii)	Mt cement	11,9	13,6	15,1
Clinker factor	(viii)	kg CO_2/kg clinker	0,70	0,68	0,60
Specific CO2 emissions in Cement & Binder, including change in SCMs for use in concrete	(ix)	kg CO_2/ kg cementitious	0,547	0,537	Net carbon neutrality in concrete stage

Table 8. GHG Emissions – Vision cement industry Argentina
Source: Provided by the Argentina Portland Cement Manufacturers Association (AFCP). Reproduced with permission.

(i) Indicates the CO_2 emission in clinker production associated only with calcination.

(iii) It is expected to apply this technology by 2030.

(iv) It is the total emission to produce clinker. Includes calcination (i) and use of fuel. It excludes that associated with the production of electrical energy and the use of biomass.

(v) The new binders to implement are not specified. The category includes cements manufactured based on belite clinker, aluminous cements, alkaline activated binders, magnesian cements, among the most renowned.

(vi) The emission factor indicated is an international average reference value.

(ix) It is the CO_2 emission per tonne of cementitious material, which in Argentina today is equivalent to cement. It includes the partial neutralisation of the carbon footprint by re-carbonation of concrete, mortar and cement-based pastes. A CO_2 capture factor equivalent to 20% of the emission due to calcination in clinker production (average reference value of the GCCA) was estimated.

Is the implementation of low-carbon technologies helped by the government?

For refurbishing or replacing equipment?

It is not foreseen.

How are public authorities pushing the transformation?

Through benchmarking?

In 2014, Argentina emitted a total of GHG equal to 368 $MtCO_{2e}$. Of these, 11.1% (40.9 Mt) corresponded to the industrial sector.

In Argentina, the cement industry produces 1.5-2.0% of total GHG emissions. As a reference, on the worldwide level, it is 7-8%.

To mitigate these emissions in the cement industry, two measures were established:

a) Reduction of the clinker factor in cement. Unconditional goal by 2030: to 70%. In Argentina, it implies a reduction of 0.368 $MtCO_2$. This goal (70% clinker factor) was already obtained in 2019.

b) Co-processing - Thermal substitution in clinker furnaces (use of alternative fuels):

- Unconditional goal to 2030: 5%
- Conditional goal to 2030: 15% (Its fulfilment is subject to legal, technical and economic / financial conditions).

Audits?
No audits are foreseen. Only its possible instrumentation is considered.

Other incentives. Fuel taxes
At the moment, there is only one regulation regarding CO_2 taxation on fuels in the country, which applies to some fuels used by the industry (petroleum coke and other liquid fossil fuels). The CO_2 tax on fuels today amounts to about USD 5 per tonne of coke.

Are there incentives for carbon capture, utilisation, and storage? How?
There are no incentives.

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?
Tables 1 and *2* include indicators on the use of alternative fuels, raw materials and waste recycling.

Currently there is only one regulation regarding CO_2 taxation on fuels in the country, which affects some fuels used by the industry (petroleum coke and other liquid fossil fuels). The CO_2 tax on fuels today amounts to about USD 5 per tonne of coke.

Nowadays, recycling is not relevant in the concrete industry. However, there are some actions in that direction.

Are there some case studies or best practices you would like to share?
We can highlight the following cases and / or practices.

a) Low CO_2 intensity in the fuel mix in the clinker furnace, even despite a thermal substitution rate lower than the world average. This is a consequence of the high rate of natural gas use.

b) Low intensity of CO_2 per tonne of cement, due to the previous point a) and the low clinker factor.

c) Use of calcined clays as artificial pozzolana. This an industrial-commercial practice since 2018 (Cementos Avellaneda). The conditions for implementing this process were studied for factories located far from supply sources of other Supplementary Cementing Materials (SCM). The use of calcined clays as artificial pozzolana made it possible to reduce the Clinker factor.

4.2. Chemical Industry

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?
There is no published energy or emissions data for industry –- only a government estimate (2016) of total chemical industry emissions of 2,5 $MtCO_{2e}$, or 6,1% from the total industry sector. The National petrochemical Institute, IPA, will work with local industries to develop data on energy use / decarbonisation plans and GHG intensity. This will start in October.

The Chemical and Petrochemical Manufacturing Association does not have any information on GHG. Some data obtained directly from industry are shown below (Emissions units: metric tonnes of CO_{2e}):

Process emissions	
Ethylene	0.4 tonnes/tonne ethylene
Polyethylene	0.16/tonnes pe
Polypropylene	0.3 tonnes/tonne pp
Total emissions, process plus fuel value	
PET	1.35/tonne PET
Polypropylene	1.343/ tonne PP
PVC	1.65 tonnes/tonne PVC

Table 9. Process emissions
Public data.

Are the best available low carbon technologies used / considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

There are local initiatives, such as using heat pumps for reboilers in distillation. There are no regulations or incentives. By 2025, 20% of electricity consumption in all industries will be covered by renewable energy.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

No roadmap established for 2030 / 2050.

Is the implementation of low-carbon technologies helped by the government? For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

No government support or audits.

Are there incentives for carbon capture, utilisation, and storage? How?

No government support or audits.

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

Recycling of plastics is around 15%. A law being is prepared to incentivise recycling.

Are there some case studies or best practices you would like to share?

A private energy efficiency audit recommended the installation of gas turbines for power generation and heat recovery to petrochemical installations. The chemical / petrochemical production of Argentina for 2020 is shown below.

Argentina chemical / petrochemical Production 2020-IPA statistics- (tonnes/yr)	
Ammonia	778 003
Urea	1 283 575
Ethylene	736 784
Polyethylene	644 277
Polypropylene	201 800
PVC	162 628
Polystyrene	63 597
Methanol	223 521
PET	160 000
Caustic soda	269 937
Chlorine	232 816
Benzene	89 664
Toluene	78 014

Table 10. Argentina Chemical / Petrochemical Production 2020-IPA statistics- (tonnes/yr) Reproduced with permission

CANADA

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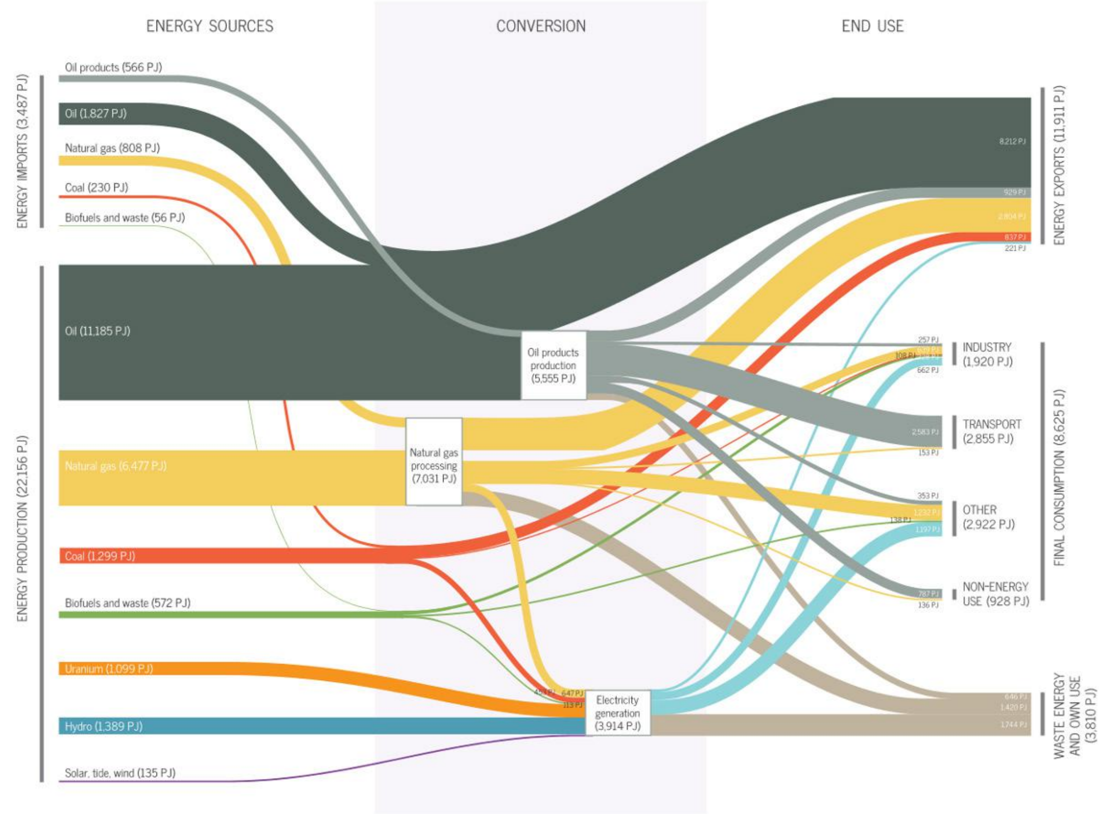
Canada

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

The diagram below shows the energy flows in the Canadian economy.



Note: Energy flows of less than 50 PJ are not displayed. Totals may not add up due to rounding. Final consumption captured under "Other" includes residential, commercial and public services, agriculture and forestry, fishing and non-specified. Source: IEA 2021

Fig. 1. Sankey diagram of the energy flows in the Canadian economy, **IEA**

As highlighted in the 2021 edition of the Canadian Energy Outlook, the Canadian energy system displays several characteristics that make it stand out from other countries. The abundance of domestic resources allowing Canada to be a major energy exporter explains not only the size and composition of its energy sector but also how and where energy is used across the country. However, presenting the energy system at the national scale hides the fact that the production and use of energy vary greatly across provinces. If similarities across provinces can be observed mainly on the consumption side in sectors like transport or commercial and residential buildings, it is the opposite for the industrial sector, whose importance in energy consumption varies greatly on a provincial basis, a difference attributable mostly to energy production activities.

Canada Total Primary Energy Supply

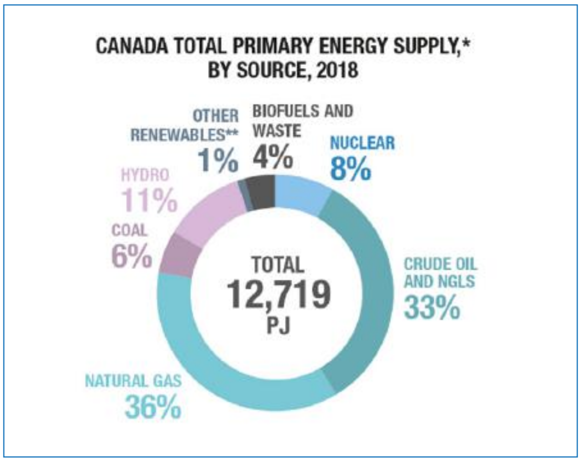


Fig. 2. Canada's Total Primary Energy supply
Source: Canada Energy Factbook 2021. Page 36. CC BY-NC
M136-1-2020-eng.pdf (publications.gc.ca)

Canada's total primary energy **supply** for the domestic market in 2018 was 12 719 petajoules (3 533 TWh). Natural gas accounted for 36% of the total primary energy supply, followed by crude oil and NGLs at 33%, hydro at 11%, nuclear at 8%, coal at 6%, and other renewables at 1%.

According to Statistics Canada (2021), the primary energy **production** in Canada was 21 414 petajoules (5 948 TWh) in 2019. Crude oil accounted for the largest proportion of primary energy production in Canada at 50.1%, followed by natural gas (31.8%), primary electricity (8.5%), coal (5.3%) and gas plant natural gas liquids (4.3%). Crude oil accounted for the largest share of primary energy production for the tenth consecutive year.

Exports of Canadian energy and energy products were 13 904 petajoules (3 862 TWh). In 2019, Canada exported 80.6% of its crude oil production and 42.9% of its marketable natural gas. Imports of energy were 4 097 petajoules (1 138 TWh). Crude oil accounted for 43.8% of imports, followed by natural gas (30.2%).

Domestic energy consumption was 8 882 petajoules (2 467 TWh).

The oil and gas sector is responsible for a significant amount of GHG emissions as shown in the figure below.

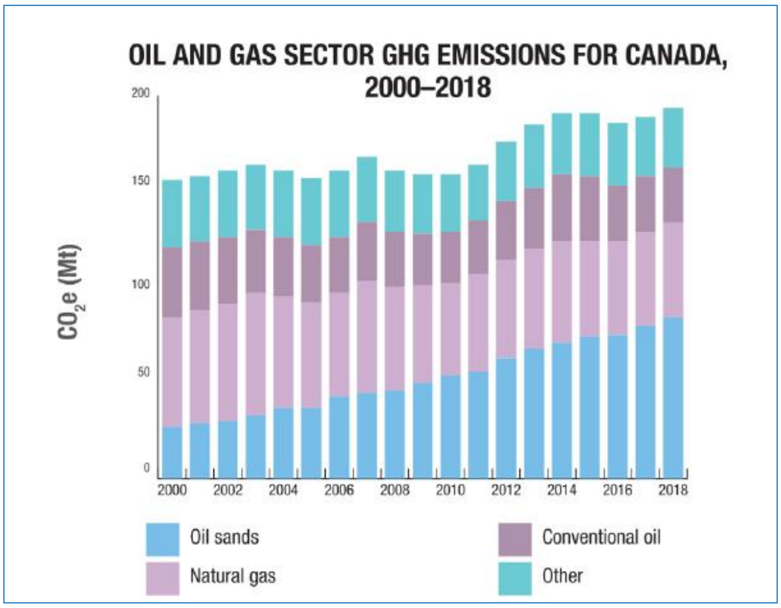


Fig. 3. GHG emissions from the Oil & Gas sector.
Source: Canada Energy Factbook 2021. CC BY-NC
NRCan, M136-1-2020-eng.pdf (publications.gc.ca) Page 31

GHG emissions from oil and gas production have gone up 23% between 2000 and 2018, largely from increased oil sands production, particularly in situ extraction which requires a lot of steam. During this period, oil sands production emissions more than tripled while conventional oil and natural gas emissions decreased by 14%. If nothing is done, the overall emissions should increase to 194 Mt by 2030.

Is the implementation of low-carbon technologies helped by the government? What legal status do the related documents have? What is their timeline?

Canada's various levels of government (federal, provincial and territorial, and municipal) have plans to cut GHG emissions and accelerate the energy transition in order to fulfil Canada's commitment to the 2015 Paris Agreement. Objectives have been set for 2030 and 2050 but there is no official roadmap to achieve the objectives. Several projections and scenarios have been studied to establish decarbonisation pathways, which are used below to address the topics raised in the questionnaire.

To facilitate the reading, here is the conversion factor:

1 PJ = 0.277 TWh = 163 450 boe

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

The Canadian strategy to decrease the country's carbon footprint is not focusing only on oil and gas as shown below.

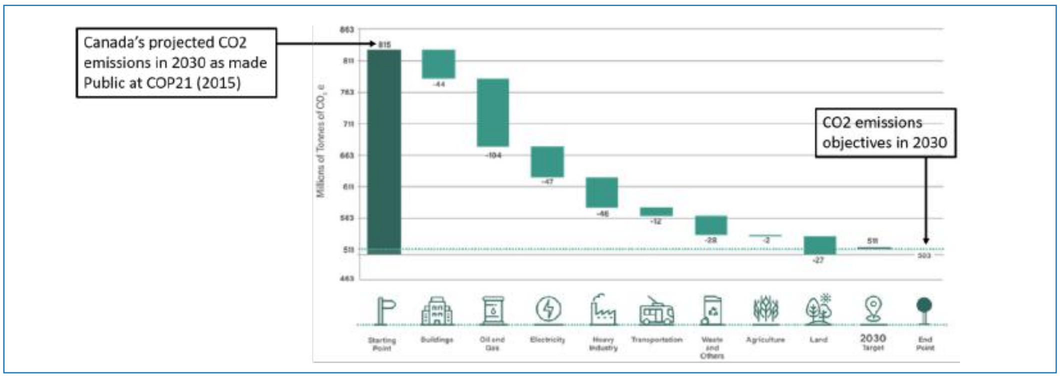


Fig. 4. Projected reduction in CO_2 emissions in 2030 by sector. CC BY-NC
Source: Environment and Climate Change Canada [Progress towards Canada's greenhouse gas emissions reduction target], Page 7

In order to achieve the objectives, several measures are envisaged.

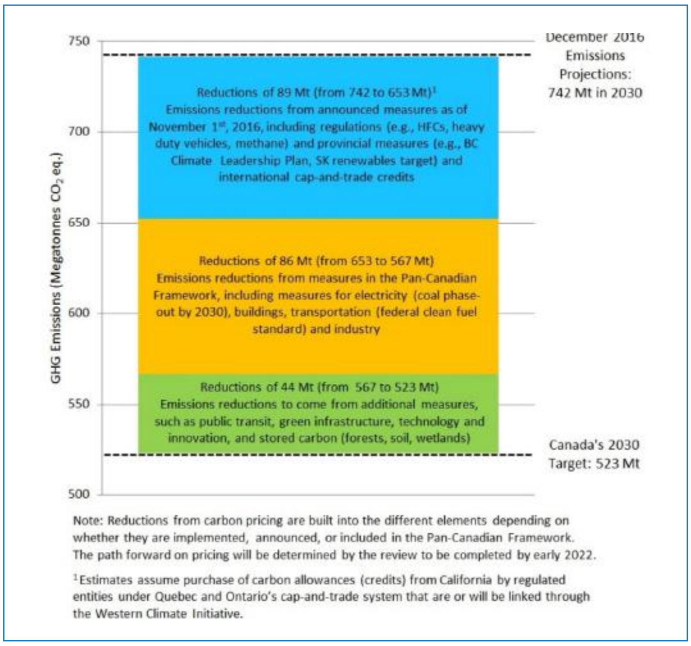


Fig. 5. Pathway to meeting the GHG reduction target by 2030. Not copyrighted.
Source: PAN-CANADIAN FRAMEWORK on Clean Growth and Climate Change, [En4-294-2016-eng.pdf (publications.gc.ca)]. Page 53

This bar graph shows the pathway to meeting Canada's target for greenhouse gas emission reductions by the year 2030. The top of the bar reflects Canada's December 2016 greenhouse gas emissions projections for the year 2030 which is estimated to be 742 Mt of carbon dioxide equivalent greenhouse gases, while the bottom of the bar shows Canada's 2030 target of 30% below 2005 levels, which is equal to 523 Mt. Note that reductions from carbon pricing are built into the following sections of the bar graph depending whether they are implemented, announced, or included in the Pan-Canadian Framework.

The top section of the bar reflects emissions reductions from measures announced as of November 1, 2016, including regulations for heavy-duty vehicles, hydrofluorocarbons, and methane for the oil and gas sector. Provincial climate change measures are also reflected in this section, including British Columbia's Climate Leadership Plan, and Saskatchewan's plans to increase renewables for electricity generation. This is projected to bring Canada's 2030 greenhouse gas emissions to 653 Mt of carbon dioxide equivalent greenhouse gases, down 89 Mt from the December 2016 emissions projections. This bar also assumes purchases of carbon credits from California by regulated entities under Quebec's cap-and-trade system that is or will be linked through the Western Climate Initiative.

The middle section of the bar reflects measures presented in the Pan-Canadian Framework on Clean Growth and Climate Change including for: electricity, including phasing out coal-traditional coal-fired electricity by 2030; buildings; transportation, including the clean fuel standard; and industry. This is projected to bring Canada's 2030 greenhouse gas emissions to 567 Mt of carbon dioxide equivalent greenhouse gases, down an additional 86 Mt from the measures announced as of November 1, 2016.

The bottom section of the bar reflects reductions to come from additional measures, such as public transit, green infrastructure, innovation, and stored carbon in forests, soil, and wetlands. This is projected to bring Canada's 2030 greenhouse gas emissions to 523 Mt of carbon dioxide equivalent greenhouse gases, down an additional 44 Mt from the measures announced as of November 1, 2016, and as found in the Pan-Canadian Framework on Clean Growth and Climate Change. This bottom section meets Canada's target of 30% below 2005 levels by 2030.

Late June 2021, Bill C-12 have been voted in Parliament. While imperfect, it will require the Canadian government to set and regularly report on progress meeting national targets for reducing greenhouse gas emissions. In setting targets, the government must take into account the best available science and Indigenous knowledge, as well as input from an already established independent expert advisory body. The bill also requires the federal environment commissioner to report on the government's progress at least once every five years.

Several trajectory scenarios have also been proposed to achieve a net-zero economy

(Canadian Energy Outlook 2021) – specifically:

- CP30: policies in place in 2020 + carbon tax @170 CAD/t in 2030
- NZ60: -30% by 2030, -80-% by 2050, net-zero in 2060
- NZ50: -40% by 2030, net-zero in 2050 (current federal government ambitions)

	2016	2030			2050		
	$MtCO_2e$	CP30	NZ60	NZ50	CP30	NZ60	NZ50
Reductions wrt 2005 (730 $MtCO_2e$)		-9%	-28%	-38%	-15%	-79%	-100%
Total emissions ($MtCO_2e$)	705	642	511	438	598	146	0
Main contributing sectors							
Electricity	82	-60%	-70%	-89%	-94%	-155%	-167%
Waste	17	-52%	-63%	-63%	-58%	-64%	-68%
Oil and gas (including fugitive emissions)	161	+7%	-54%	-60.0%	+14%	-88%	-94%

Table 1. Reduction of CO_2 emissions according to scenarios for 2030 and 2050
Source: Canadian Energy Outlook 2021. Page 193, CC BY-NC, CEO2021_20211112.pdf (polymtl.ca)

Roadmap for the energy mix

The evolution of the Canadian energy mix (primary energy use) is shown below along with two scenarios for the future: 'Reference' (-●-●-●-) corresponds to the policies announced as of Sept. 2020 and 'Evolving' (coloured areas) to enhanced policies with stronger federal government ambitions.

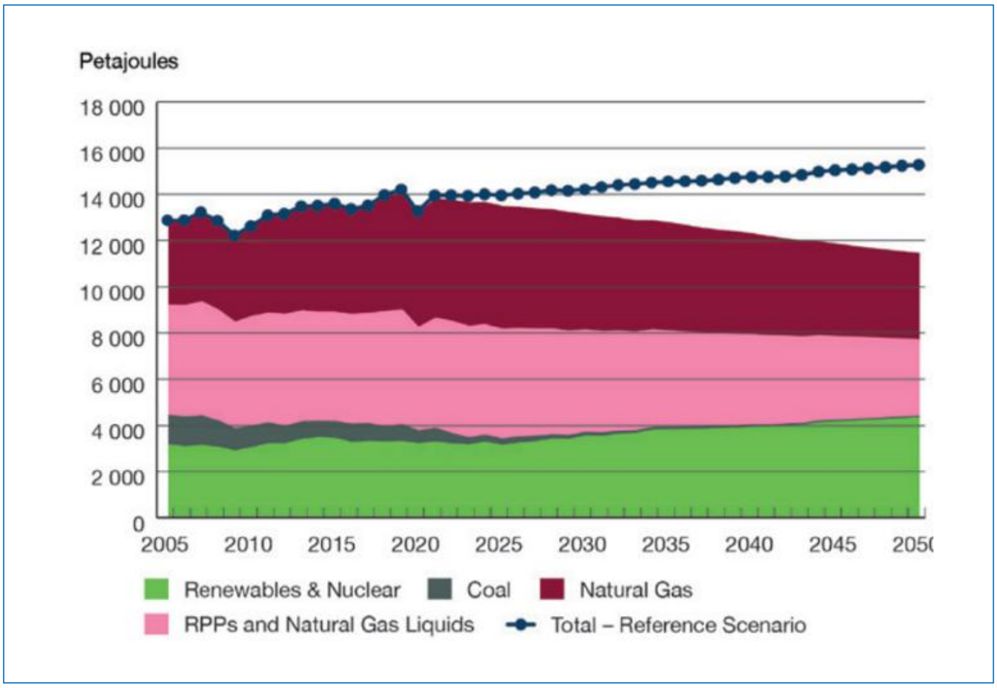


Fig. 6. Roadmap for the energy mix 2005 to 2050 by fuel type.
Source: Canada Energy Future (2020). CC BY-NC. Canada Energy Regulator (cer-rec.gc.ca). Page 39

In the Evolving Scenario, the consumption of fossil fuels in Canada remains below its 2019 peak. By 2030 it is 12% lower, and 35% lower by 2050. Coal declines in the 2020s as it is phased out of electric generation. Refined petroleum product (RPP) use gradually declines due to energy efficiency improvements and increased use of renewable fuels and electricity. Natural gas use increases in the early part of the projection, driven by increasing demands in electricity generation, and upstream crude oil and natural gas production. Natural gas use falls in the latter parts of the projection, as renewables play a bigger role in electricity generation, leading to decreasing needs of fossil fuels in this sector. In contrast, fossil fuel consumption is relatively unchanged throughout the projection period in the Reference Scenario. This is due to steady improvements in energy efficiency offsetting population growth and increasing industrial output, particularly in the oil sands, as well as a shift to the service economy. At the same time, demand for renewable energy sources such as hydroelectricity, wind, solar, and biofuels increases by 45% from 2019 to 2050 in the Evolving Scenario. Nuclear demand increases by 2%. Combined with declining fossil fuel use, the share of these low and non-emitting sources increases from 23% of the energy mix in 2019, to 38% by 2050. To meet these rising demands, Canada relies more on renewable generation. Wind, solar, and hydro electricity generation grow in the projections. In the Evolving Scenario, 90% of electricity generation comes from renewable and nuclear generation in 2050. This compares to 81% today.

Roadmap for the GHG emissions

Sectoral and economy-wide measures are expected to reduce Canada's emissions by 144 Mt by 2030, relative to 674 Mt of greenhouse gas emissions in 2030 under the 2020 Reference Case. The LULUCF accounting contribution, plus the expected impact of the proposed nature-based solutions and the measures in the plan to reduce emissions from fertilizer use in agriculture combined are expected to reduce emissions by a further 27 Mt. Combined, these reductions arrive at approximately 503 Mt in 2030, or about 8 Mt below Canada's 2030 target. This represents about a 31% reduction below Canada's 2005 emissions.

The Table below illustrates the expected emission reductions of the measures included in the plan in 2030.

	Projected emissions in 2030 (MT)
2020 Reference Case	**674**
Sectoral Measures, post-2022 carbon price and CFS (liquid only)	**144**
LULUCF accounting contribution	**17**
Nature-based solutions & agriculture measures	**10**
Total projected emissions from the Plan	**503**
Canada's 2030 Target	**511**

Table 2. Expected emission reductions from the measures included in the Evolving Scenario in 2030
Compiled from public information.

The following Table shows emission reductions by sector from 2005 levels.

	Historical				Projected		Change 2005 to 2030
	2005	2010	2015	2018	2020	2030	
Oil and Gas	158	159	191	193	177	138	-20
Electricity	119	96	81	64	38	11	-108
Transportation	161	168	172	186	155	151	-10
Heavy Industry	87	75	79	78	65	61	-26
Buildings	86	82	86	92	90	65	-21
Agriculture	72	68	71	73	73	74	2
Waste & Others	46	42	41	42	39	31	-15
LULUCF, NBS and agriculture measures	n.a.	11	-8	-13	-25	-27	-27
Total (incl. LULUCF)	**730**	**702**	**712**	**716**	**612**	**503**	**-227**

Table 3. Emission reductions by sector from 2005 levels
Compiled from public information.

The Figure below shows the evolution of Canada's targets in the last 3 year. The 2018 data comes from the National Inventory Report (NIR).

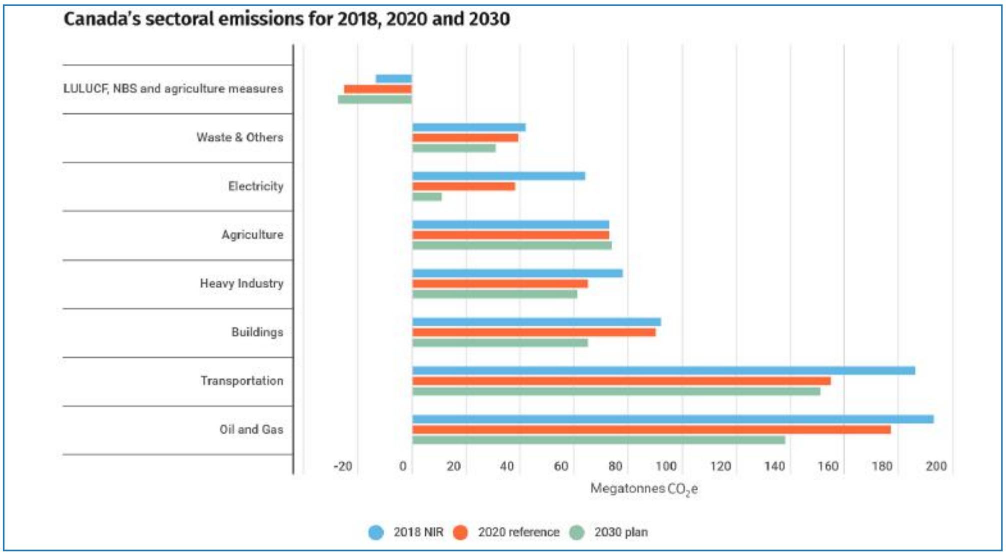


Fig. 7. Emission targets in 2018 and 2020 and projected target for 2030 (according to the plan). CC BY-NC
Source: https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/healthy_environment_healthy_economy_plan.pdf and https://www.canada.ca/content/dam/eccc/documents/pdf/climate-change/climate-plan/annex_modelling_analysis_healthy_environment_healthy_economy.pdf
See also: 2030 Emissions Reduction Plan: Clean Air, StrongEconomy, Pathway to 2030:
https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030.html

In order to achieve the above targets, some milestones have been proposed as shown below.

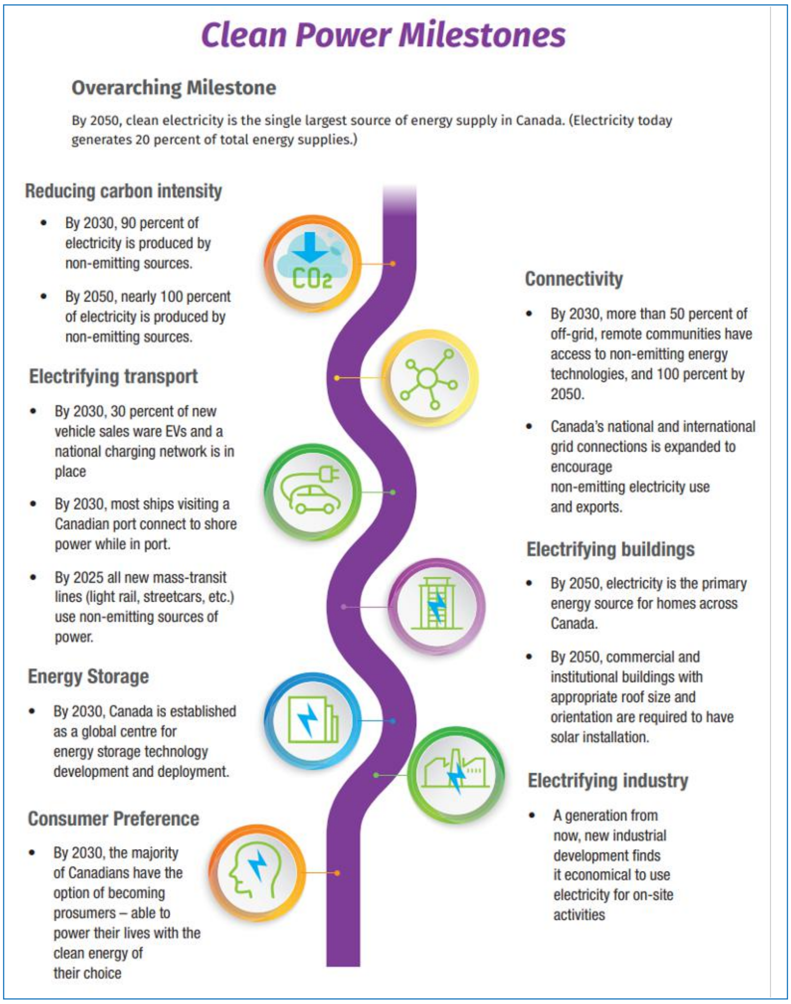


Fig. 8. Canada's Energy Transition (2018)
Source: Canada's Energy Transition: Getting to Our Future, Together, June 2018, CC BY-NC
https://natural-resources.canada.ca/sites/nrcan/files/energy/CoucilReport_june27_English_Web.pdf

Canada has one of the highest GHG intensities per capita as evidenced in the bar chart below. Several factors can explain such a high emission level namely the size of the country (transport of goods and people over large distances), the climate conditions (hot summer and cold winter), and the industrial structure where the extraction of raw materials plays an important role.

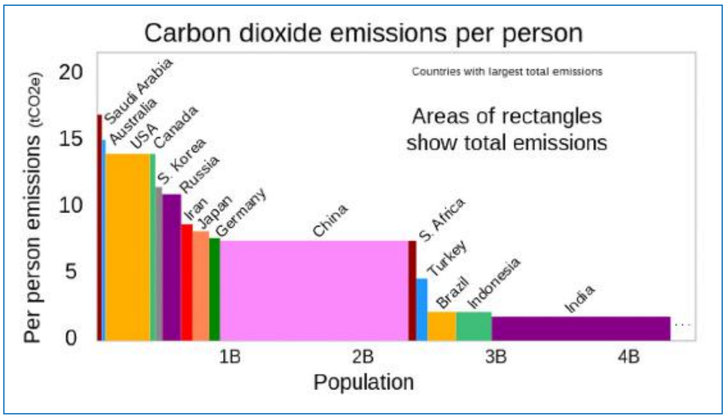


Fig. 9. Greenhouse gas emissions per capita for the largest emitting countries
Source: https://en.wikipedia.org/wiki/List_of_countries_by_greenhouse_gas_emissions_per_capita RCraig09, CC BY-SA 4.0
https://creativecommons.org/licenses/by-sa/4.0,
via Wikimedia Commons https://commons.wikimedia.org/wiki/File:20210626_Variwide_chart_of_greenhouse_gas_emissions_per_capita_by_country.svg
https://upload.wikimedia.org/wikipedia/commons/f/f3/20210626_Variwide_chart_of_greenhouse_gas_emissions_per_capita_by_country.svg

Roadmap for the electricity mix and CO_2 emissions

The electricity mix in Canada is already significantly decarbonized as shown below.

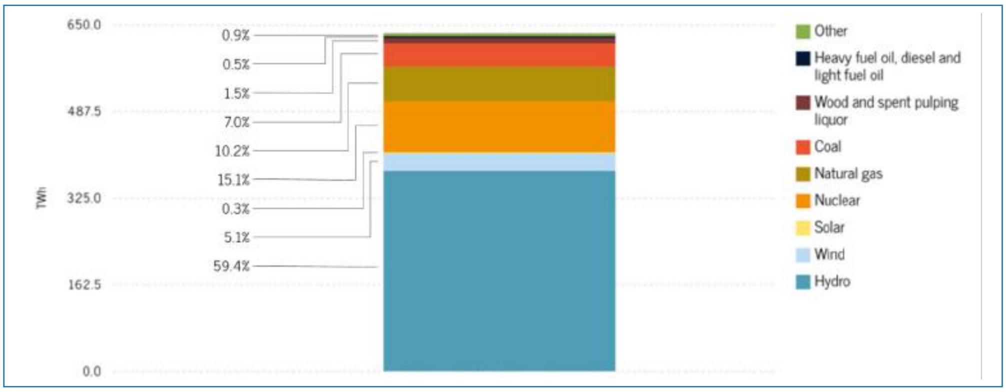


Fig. 10. Canadian electricity mix
Source: Statistics Canada 2021. CC BY-NC

The evolution of the electricity sector's GHG emissions until 2018 is shown below.

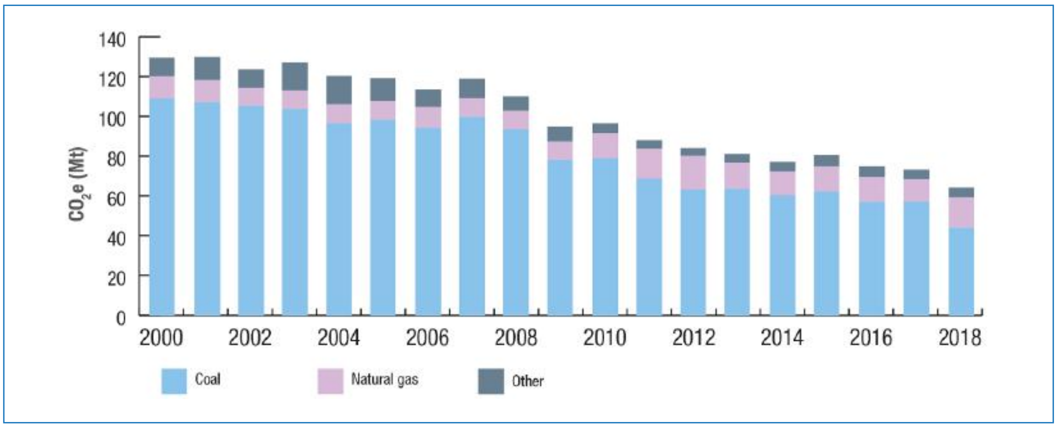


Fig. 11. Historic reduction of GHG emissions from electricity generation from 2000 to 2018
Source: Natural Resources Canada 2021. CC BY-NC

Greenhouse gas emissions (GHG) from electricity generation were stable at almost 130 MT in 2001. Since then, GHG emissions have declined to less than 70 MT in 2018. Renewable electricity generation has increased by 16% between 2010 and 2018, with solar and wind having the largest growth. In 2018, almost 82% of electricity in Canada came from non-GHG-emitting sources. Hydro made up 60%, nuclear 15%, and other renewables the remaining 7%.

With the projected shutdown of coal extraction in the coming years and the repowering of power plants, the carbon footprint of the electricity mix will further improve. Power generation is expected to continue to grow due to the further electrification of the economy (transportation and buildings) as well as for demographic reasons. The projected evolution of the electricity mix until 2050 is shown below. It should be noted that wind energy will play a major role. Indeed, many regions have favourable wind conditions (onshore and offshore) and the deployment of wind parks is relatively quick as compared to the construction of new hydro-dams or nuclear plants.

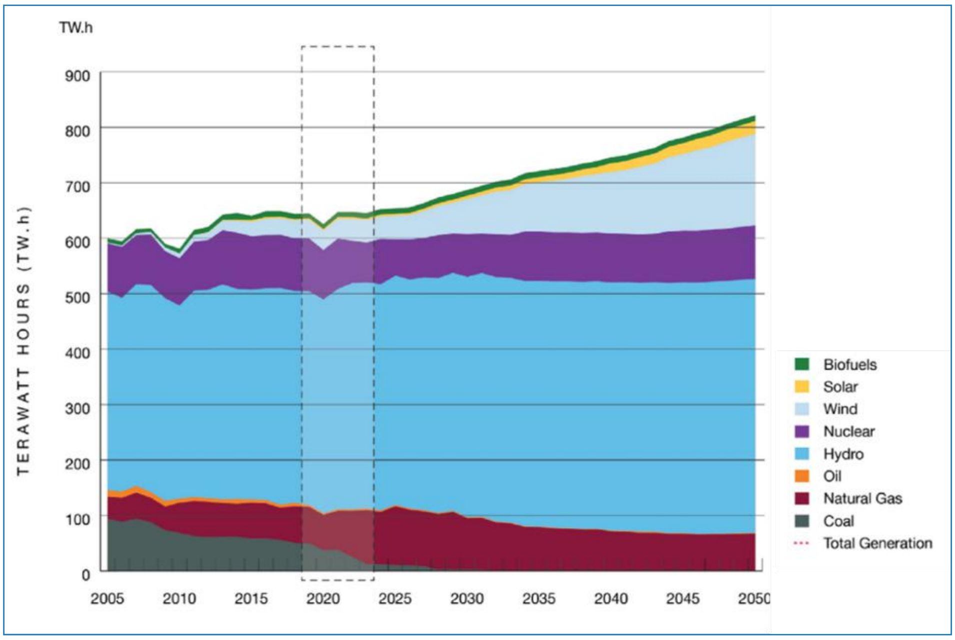


Fig. 12. Historic and projected electricity generation by type of energy source.
Source: Canada's Energy Future 2020. CC BY-NC
Canada Energy Regulator (cer-rec.gc.ca). Page 56

Carbon capture, utilisation, and storage in Canada

Canada is a leader in carbon capture and storage (CCS) and carbon capture, utilization, and storage (CCUS) with a number of operating projects and decades of experience in the technology (about 17 per cent of global CCUS projects in operation or under construction). CCS separates (or "captures") CO_2 from industrial exhaust, for example, at coal power plants, before injecting it into deep underground rock formations. CCUS "utilises" CO_2 for other things, including enhanced oil recovery (EOR), which is a process of injecting CO_2 into declining oil fields to help to recover additional oil from reservoirs.

Western Canadian CCS projects are possible because of a combination of technical expertise, geological suitability for CO_2 storage, and legal, regulatory, and policy frameworks. The number of operating projects continues to grow. In 2014, the SaskPower Boundary Dam power station became the world's first power plant with CCS. In 2015, the largest CCS project in Canada, Shell's Quest CSS project began capturing CO_2 from a bitumen upgrader near Edmonton and injecting it into an underground reservoir for storage. The Alberta Carbon Truck Line (ACTL) is on-stream since the first half of 2020. ACTL takes CO_2 from the new Sturgeon refinery and a nearby fertiliser plant and transports it by pipe 240 kilometres to an EOR project in central Alberta. The Quest and ACTL projects, at 1.0 and 1.7 million tonnes of CO_2 per year respectively, store the equivalent emissions of 600 000 cars annually. The CO_2 is pumped into the oil-bearing rock formation to recover more oil. The additional recovery potential is 15-20% of the original oil

The table below summarizes the present projects.

Facility name (click on link to view)	CO2 capture capacity (Mtpa)	Primary storage type
Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2	1.2-1.4	Enhanced oil recovery
Alberta Carbon Trunk Line ("ACTL") with Nutrien CO2 Stream	0.3-0.6	Enhanced oil recovery
Boundary Dam Carbon Capture and Storage	1.0	Enhanced oil recovery
Great Plains Synfuel Plant and Weyburn-Midale	3.0	Enhanced oil recovery
Husky Energy Lashburn and Tangleflags CO2 Injection in Heavy Oil Reservoirs	0.2	Enhanced oil recovery
Inventys and Husky Energy VeloxoTherm Capture Process Test	0.1	Enhanced oil recovery
Quest	1.0	Dedicated geological storage - onshore deep saline

Table 4. Current CCS projects. Source: Canada Energy Regulator 2021
Source: Canada Energy Regulator Market snapshot 2019. CC BY-NC
https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2019/market-snapshot-carbon-capture-utilization-storage-market-developments.html

As highlighted by the Oxford Institute for Energy Studies (2021), future growth of CCUS in Canada is expected to be spurred by increased deployment of capture technologies in mature industries such as oilsands extraction, refining, and fertilizer and cement manufacturing. For instance, the ACTL is fed by both the oilsands-based NWR Sturgeon refinery and the Nutrien fertilizer plant. Growth is also expected from DACCS and BECCS, with Canadian firm Carbon Engineering considered a pioneer of the former. Until recently, the deep decarbonization of these industries in the near to medium term was viewed as a longshot.

Several projects have recently been announced for the production of hydrogen from decarbonized natural gas, and the transport of CO_2 for sequestration, alongside promises of future green hydrogen projects.

Blue Hydrogen

Project	Partners	Location	Carbon capture	Start date
Blue hydrogen plant	Air Products, Alberta and Canadian governments	Edmonton, AB	3Mt/year	2024
Polaris 1 (blue hydrogen)	Shell Canada	Fort Saskatchewan, AB	0.75 Mt/year	2025
Blue hydrogen plant	Suncor and ATCO	Edmonton, AB	2 Mt/year	2028

Table 5. Blue hydrogen project. Compiled from public information

CO_2 Pipelines

Project	Partners	Hub	Capacity	Start date
Alberta Carbon Grid	TC Energy and Pembina Pipeline	Fort Saskatchewan, AB	20 Mt/year	2025
CO2 Trunkline	Cenovus, CNRL, Imperial, MEG and Suncor	Cold Lake, AB	40 Mt/year	TBA

Table 6. Proposed CO_2 pipelines. Compiled from public information

The most important of these announcements was the alliance of the five largest oilsands-based energy firms to form the Oilsands Pathways to Net Zero Initiative 30. Together, these firms – Cenovus, CNRL, Imperial, MEG Energy, and Suncor – control over 90 per cent of Canada's oilsands production. While they have previously demonstrated a willingness to collaborate, as seen in the technology-driven Canada's Oilsands Innovation Alliance (COSIA), this would mark the first time that they all partner to deliver major projects of this size and scale. If all the announced blue hydrogen projects are sanctioned, Canada's CO_2 capture capacity would increase from 7 $MtCO_2$/year to nearly 13 $MtCO_2$/year by 2028.

Financing issues

Although the role to be played by CCUS in significantly reducing emissions in industries that are hard to decarbonize is acknowledged, there has been a hesitancy – particularly from oil and gas firms – to invest heavily in the technology. This is due to the belief that CCUS alone is not profitable, since it does not add reserves or increase the netback on a barrel of oil, two key balance sheet metrics for oil and gas firms. The Quest project cost CAD 1.35 billion, with up to CAD 865 million financed by the government for an estimated all-in cost of around CAD 80/tCO_{2e}.

Beyond Quest, most carbon capture and storage (CCS) and CCUS projects in the oil and gas sector are small-scale and primarily targeted at EOR, where the CCUS pays for itself by delivering near-zero-cost oil that would not otherwise be extracted. EOR is largely restricted to facilities that can be connected to depleted wells, making it unattractive to oilsands miners as well as to most refineries.

Integrated projects like the ACTL, which delivers waste CO_2 streams from a fertilizer plant and upgrader/refinery to ageing reservoirs in central and southern Alberta, are an option. However, the likely exclusion of EOR as a designated use of captured CO_2 under the government's investment scheme means that most new projects will be based on sequestration or carbon utilization.

This will be enabled by the significant cost reduction through learning that has occurred since Quest, which it is estimated would cost 30 per cent less if built today. The figure below illustrates the evolution of the capital cost for several key CCUS projects, in CAD/t CO_2 (Oxford Institute for Energy Studies 2021). The cost reduction is significant as compared to the Boundary Dam and Quest pioneering projects.

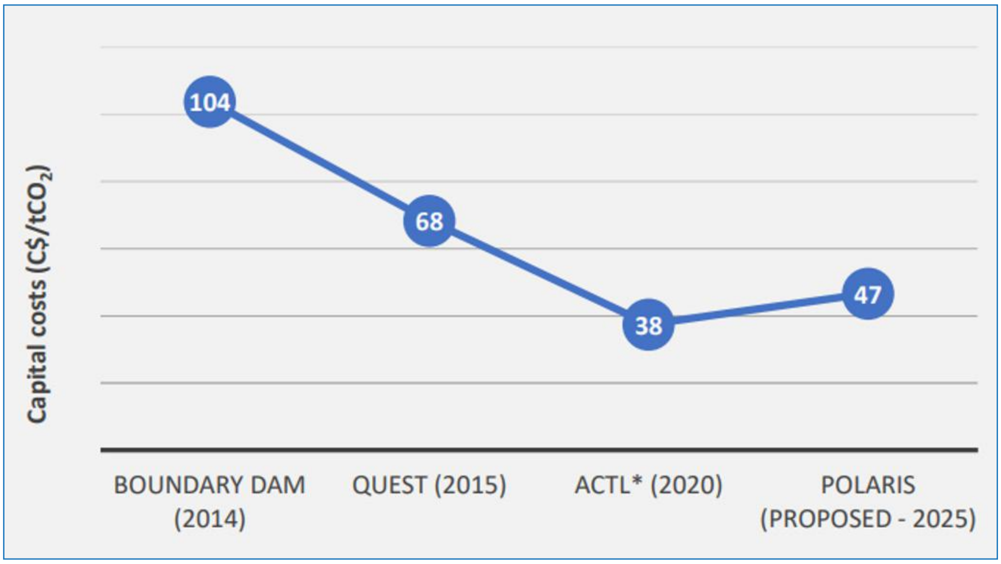


Fig. 13. Capital cost for CC(U)S facilities by project. CC BY-NC
Source: The-Role-of-CCUS-in-Accelerating-Canadas-Transition-to-Net-Zero.pdf (oxfordenergy.org)

CROATIA

Table of Contents

1. National energy profile 2019

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	82.0	14.2	17.3
1995	70.0	10.7	24.2
2000	76.5	12.6	16.5
2005	91.0	15.4	16.9
2010	89.6	16.9	18.9
2015	81.3	16.4	20.2
2019	84.5	17.2	20.3

Table 1. Total yearly consumption: final energy, electricity (TWh)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

Electricity consumption has been increasing constantly since 1990 from 14.2 TWh all the way to 17.2 TWh in 2019. At the same time, total energy consumption declined from the 1990 level of 82 TWh to 1995 level of 70 TWh after which it again started increasing to reach a maximum value of 91 TWh in 2005. The share of electricity in final energy peaked in 1995 when it reached 24.2%. In 2000, the share of electricity was at an all-time low of 16.5%. Since then, it has been constantly increasing and reached 20.3% in 2019.

Per capita yearly final energy and electricity consumptions (MWh)

Year	Inhabitants (per million)	Energy Consumption (TWh)	Energy Consumption per person and per year (MWh)	Electricity Consumption (TWh)	Electricity Consumption per person and per year (MWh)
1990	4.8	82.0	17.1	14.2	2.9
1995	4.6	70.0	15.2	10.7	2.3
2000	4.4	76.5	17.4	12.6	2.9
2005	4.4	91.0	20.7	15.4	3.5
2010	4.3	89.6	20.1	16.9	3.9
2015	4.2	81.3	19.4	16.4	3.9
2019	4.1	84.5	20.6	17.2	4.2

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=HR

The population of Croatia has been decreasing steadily since 1990 from 4.8 million to 4,1 million in 2019. The negative population trend is a result of negative natural growth and emigration to the rest of Europe. Total energy consumption declined from 82 TWh in 1990 to 70 TWh in 1995. It started rising again after the year 2000 and reached a peak of 91 TWh in 2005. Since then, it has been diminishing and reached 84.5 TWh in 2019. The decrease after 2005 was the result of an economic slowdown, a decline in population and the introduction of renewable energy and energy efficiency measures. Per capita energy consumption increased paradoxically alongside a decrease in population, which can be explained by the adoption of more electrical devices, which consequently also explains the similar trend in electricity demand.

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	20.3	3.4	4.3
1995	14.8	2.4	3.2
2000	16.8	3.4	3.8
2005	19.9	4.2	4.6
2010	18.3	4.1	4.3
2015	15.4	3.3	3.7
2019	15.3	2.3	3.5

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=HR

Croatia reduced emissions from 20,3 Mt in 1990 all the way to 15,3 Mt in 2019. The decrease in emissions in the first part of the observed timespan is due to subdued economic activity. The drop in the last 10 years is due to the transition of the economy to a service-based economy. In addition, the decline in the Croatian population is also partially responsible for the decline in emissions. The decrease of emissions from electricity generation is a result of the continued transition from fossil fuel power plants to the application of new renewable generating technologies.

CO_2 emissions by fossil energy source ($MtCO_2$)

Fig. 1. CO_2 emissions by energy source Croatia 1990-2019, **IEA**
https://www.iea.org/countries/croatia

The emissions from coal burning decreased right after 1990, from 3 Mt to 1 Mt of CO_2, but they increased again in the period between 2003 and 2016 to 3 Mt. In the later years, the emissions from coal have not exceeded 2 Mt. Emissions originating from oil followed a similar path as they decreased from 13 Mt in 1990 to 9 Mt between 1992 and 1994. These emissions reached 2 peaks of 13 Mt each thereafter: one from 1998 to 1999, while the other was between 2003 and 2007. After 2008, the emissions from oil utilisation also decreased to a mostly stable level of 9 Mt since 2013. The natural gas-related emissions on the other hand have remained at a fairly stable level since 1990 at around 4 Mt with the exception of the period between 2002 and 2011, where they reached about 5 Mt/year.

CO_2 emissions by sector ($MtCO_2$)

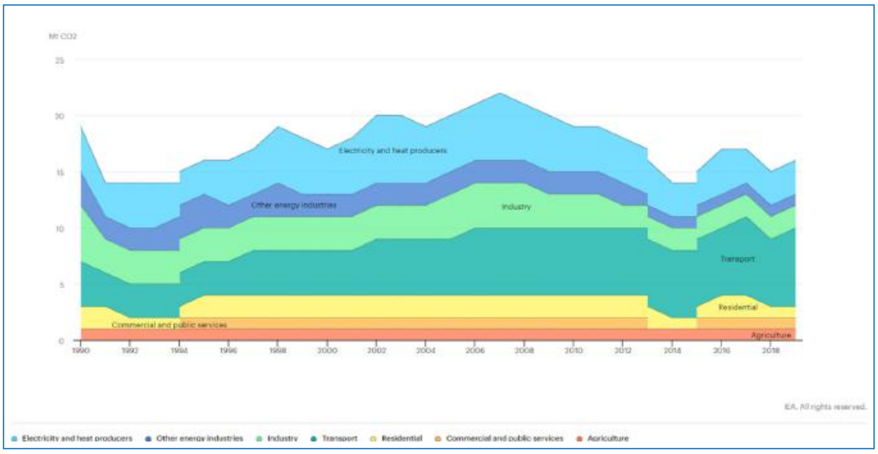


Fig. 2. CO_2 emissions by sector Croatia 1990-20199, **IEA**
https://www.iea.org/countries/croatia

In the transport sector emissions increased from the levels of 4 Mt in 1990 to 7 Mt in 2019. The emissions from electricity and heat generation followed a different path: they have been increasing from 4 Mt in 1990 to 7 Mt in 2007 with a decrease thereafter to 3 Mt in 2019, partly due to the economic recession in 2008. As a consequence of the transition toward a service-based economy, there was also a noticeable reduction in emissions from the industry sector.

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

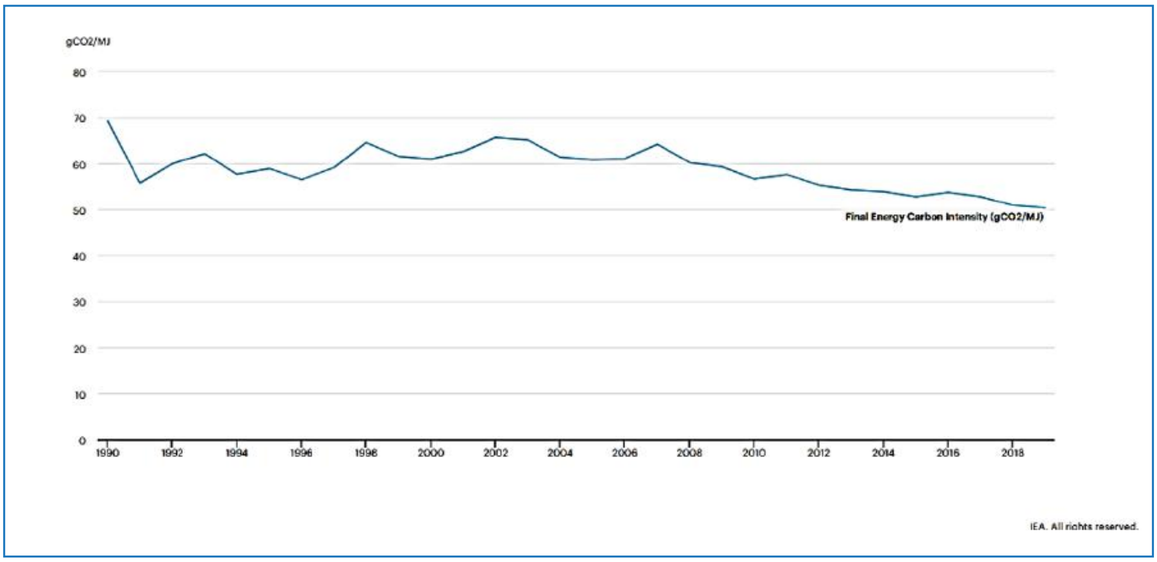


Fig. 3. Final energy carbon intensity Croatia 1990 - 20199, **IEA**
https://www.iea.org/countries/croatia

Croatian final energy carbon intensity dropped from a value of 69.2 gCO_2/MJ in 1990 to a value of 50.4 in 2019. Most of the decrease happened during the period after 2008.

2. Energy perspectives 2030 - 2050

If possible, give the national perspectives for 2030 and 2050 or the roadmap to 2030 and 2050 if they exist.

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

Croatia's strategies and programmes related to the energy sector are under the authority of the Ministry of Economy and Sustainable development. The pertinent texts are available here: https://mingor.gov.hr/o-ministarstvu-1065/djelokrug-4925/energetika/energetska-politika-i-planiranje/strategije-planovi-i-programi-2009/2009. The most important documents are:

Croatian energy strategy until 2030, with 2050 outlook, period 2020-2050, accepted by the Government (see https://mingor.gov.hr/UserDocsImages/UPRAVA ZA ENERGETIKU/Strategije, planovi i programi/Strategija energetskog razvoja RH 2030 s pogledom na 2050.pdf) [in croatian]

Integrated National Energy and Climate Plan for the Republic of Croatia, period 2021-2030 (see https://mingor.gov.hr/UserDocsImages/UPRAVA%20ZA%20ENERGETIKU/Strategije,%20planovi%20i%20programi/hr%20necp/Integrated%20Nacional%20Energy%20and%20Climate%20Plan%20for%20the%20Republic%20of_Croatia.pdf) [in english]

Energy efficiency programme for the decarbonisation of the energy sector, period 2019-2050 (see https://mingor.gov.hr/UserDocsImages/UPRAVA%20ZA%20ENERGETIKU/Dekarbonizacija%20energetske%20u%C4%8Dinkovitosti.pdf) [in croatian]

Croatian net-zero CO_2 energy strategy, period 2020-2050 (see https://mingor.gov.hr/o-ministarstvu-1065/djelokrug-4925/energetika/energetska-politika-i-planiranje/strategije-planovi-i-programi-2009/2009) – Government acceptance pending. [in croatian]

Roadmap for the energy mix

The Croatian energy strategy until 2030 with 2050 outlook proposes an energy mix by 2050 considering two scenarios: S1 – rapid energy transition, and S2 – moderate energy transition.

S1	2000	2010	2017	2030	2040	2050
H2	0.0	0.0	0.0	0.0	0.3	30.2
El energy	294.2	341.2	597.9	292.7	157.9	2.2
Non-renewable waste	1.3	7.6	11.5	10.6	10	8.1
RES	1 557.2	2 064.3	1 894.3	2 642.3	3 039.1	3 663.9
Natural gas	2 209.4	2 632.4	2 493.3	2 167.6	1 774.2	1 455.4
Oil	3 950.2	3 729.1	3 476.9	3 075.7	2 498.8	1 340.2
Coal	431.5	682.7	392.3	208.2	35.7	19.3
Total	8 443.8	9 457.3	8 866.2	8 397.1	7 516.0	6 519.3

Table 4. Consumption of primary energy allocated to fuel sources in scenario S1 (in ktoe)
Compiled from the sources listed under 2. Energy perspectives 2030 – 2050, see above

S2	2000	2010	2017	2030	2040	2050
H2	0.0	0.0	0.0	0.004	0.2	15.9
El energy	294.2	341.2	597.9	335.4	160.2	2.1
Non renewable waste	1.3	7.6	11.5	10.6	10.0	8.1
RES	1 557.2	2 064.3	1 894.3	2 759.9	3 270.2	3 426.0
Natural gas	2 209.4	2 632.4	2 493.3	2 312.6	2 229.2	2 124.0
Oil	3 950.2	3 729.1	3 476.9	3 140.3	2 608.6	1 788.0
Coal	431.5	682.7	392.3	214.5	42.2	27.7
Total	8 443.8	9 457.3	8 866.2	8 773.304	8 320.6	7 391.8

Table 5. Consumption of primary energy allocated to fuel sources in scenario S2 (in ktoe)
Compiled from the sources listed under 2. Energy perspectives 2030 – 2050, see above

Roadmap for the GHG emissions (country, per capita)

GHG emissions projections are available in *Croatian NECP*, as shown below, with S1 and S2 scenarios previously explained.

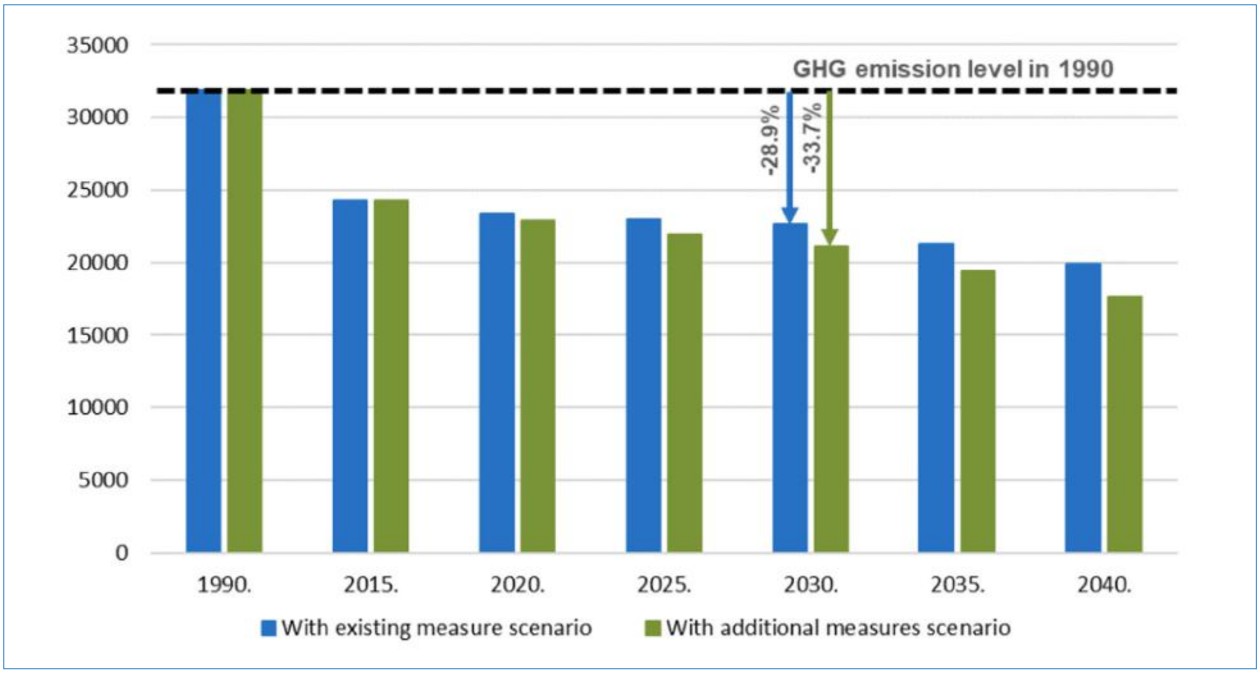


Fig. 4. GHG emissions according to the Croatian NECP (in kt CO_2e)
Source and Permission see figure 6

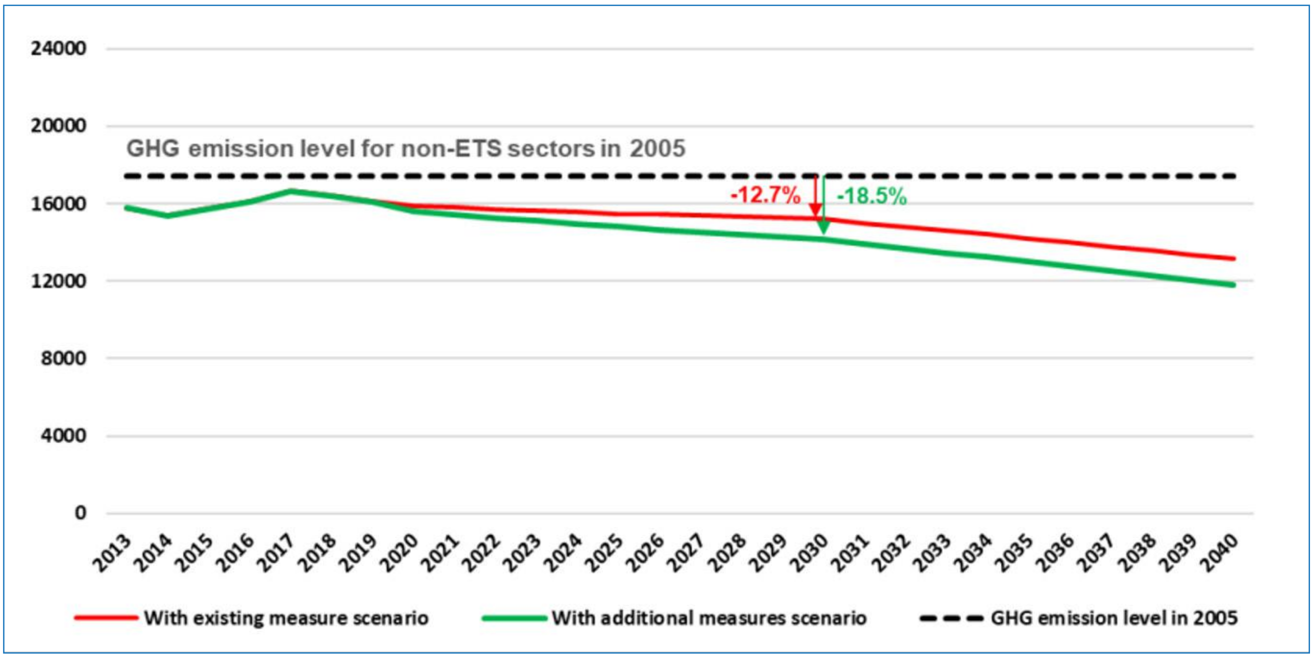


Fig. 5. Projection of greenhouse gas emissions from sectors outside of ETS, for the scenario with existing measures and the scenario with additional measures
Source and Permission see figure 6

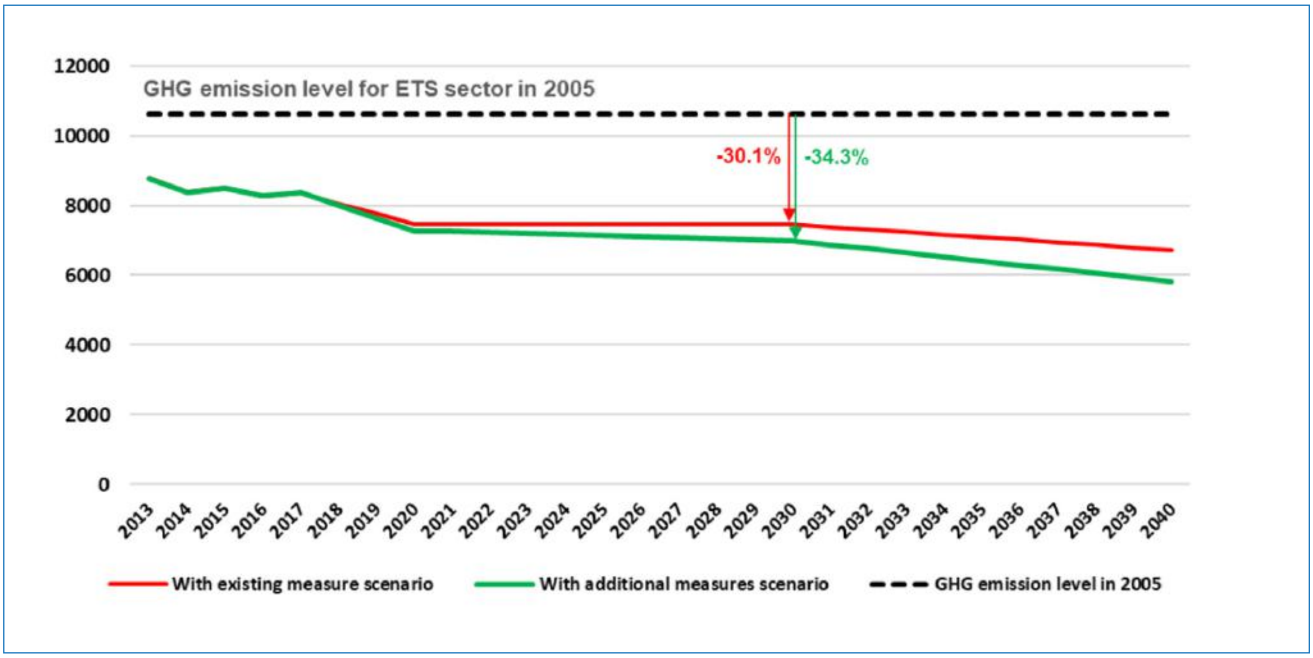


Fig: 6. Projection of greenhouse gas emissions from the ETS sector, for the scenario with existing measures and the scenario with additional measures Fig 4, 5, and 6: provided by Energy Institute Hrvoje Požar; ***Source:*** "Integrated National Energy and Climate Plan for the Republic of Croatia for the period 2021-2030, December 2019", Pages 225 and 226. Reproduced with Permission https://mingor.gov.hr/UserDocsImages/UPRAVA%20ZA%20ENERGETIKU/Strategije,%20planovi%20i%20programi/hr%20necp/Integrated%20Nacional%20Energy%20and%20Climate%20Plan%20for%20the%20Republic%20of_Croatia.pdf

Roadmap for the electricity mix

The *Croatian energy strategy until 2030 with 2050 outlook* presents the 3 scenarios of development of energy system. It sets the objective of reducing the emissions by 2030 in comparison to 1990 in the scenario S0 by 32.8%, in S1 by 37.5% and in S2 by 35.4%. By the year 2050, the planned reduction in S0 scenario is 49.3% in comparison to 1990 levels, in S1 by 74.4% and in S2 by 64.3%. Electricity generation from renewable energy is planned to increase to 60% in 2030 for the scenario S0, to 66% in S1 and to 61% in S2 scenario. For the case of 2050, the share of RES in electricity generation is planned to reach 82% in S0, 88% in S1 and 83% in S2 scenario.

The tables below present the electricity mix according to the *Croatian energy strategy until 2030 with 2050 outlook*.

S1	2000	2010	2017	2030	2040	2050
industrial CHP	559.8	446.8	414.2	320.3	280.4	239.8
public CHP	797.6	2 589.0	3 383.0	3 316.4	2 394.0	1 636.8
PP	3 270.1	2 494.8	1 395.9	719.8	0.0	1 764.3
Geothermal	0.0	0.0	0.0	128.8	365.8	427.8
Solar	0.0	0.1	78.7	1 371.0	3 316.0	5 133.1
Wind	0.0	139.1	1 204.0	4 331.6	7 183.7	10 563.2
Hydro	6 471.3	9 232.3	5 507.7	7 307.2	7 637.7	9 772.7
Total	11 098.8	14 902.1	11 983.5	17 495.1	21 177.6	29 537.7

Table 6. Electricity mix in S1 scenario (in GWh)
Compiled from the sources listed under 2. Energy perspectives 2030 - 2050

S2	2000	2010	2017	2030	2040	2050
industrial CHP	559.8	446.8	414.2	320.3	280.4	239.8
public CHP	979.6	2 589.0	3 383.0	3 508.0	3 971.5	1 399.7
PP	3 270.1	2 494.8	1 395.9	799.5	160.3	1 951.9
Geothermal	0.0	0.0	0.0	128.8	365.8	427.8
Solar	0.0	0.1	78.7	1 013.3	2 374.6	3 624.4
Wind	0.0	139.1	1 204.0	3 548.8	5 544.6	7 858.9
Hydro	6 471.3	9 232.3	5 507.7	7 319.2	7 702.5	8 244.3
Total	11 280.8	14 902.1	11 983.5	16 637.9	20 399.7	23 746.8

Table 7. Electricity mix in S2 scenario (in GWh)
Compiled from the sources listed under 2. Energy perspectives 2030 - 2050

CO_2 emissions from electricity production

The specific CO_2 emissions of the Croatian power system are displayed in *Table 8.* The table displays 2 columns. One is dedicated to the carbon intensity of the energy consumed in Croatia, while the other is dedicated to the energy that is generated in Croatia. The values are sourced from the Croatian annual energy report – Energy in Croatia [2].

Year	For energy consumed in Croatia	For energy generated in Croatia
2015	148	236
2016	163	233
2017	131	207
2018	106	148
2019	121	179
2020	124	166

Table 8. Data on specific electricity sector emissions (gCO_2/kWh)
Compiled from the sources listed under 2. Energy perspectives 2030 - 2050

Energy balance (energy sources to end-uses)

Croatia's energy balances as Sankey diagram are shown below. The diagram is available via IEA here: https://www.iea.org/sankey/#?c=Croatia&s=Balance

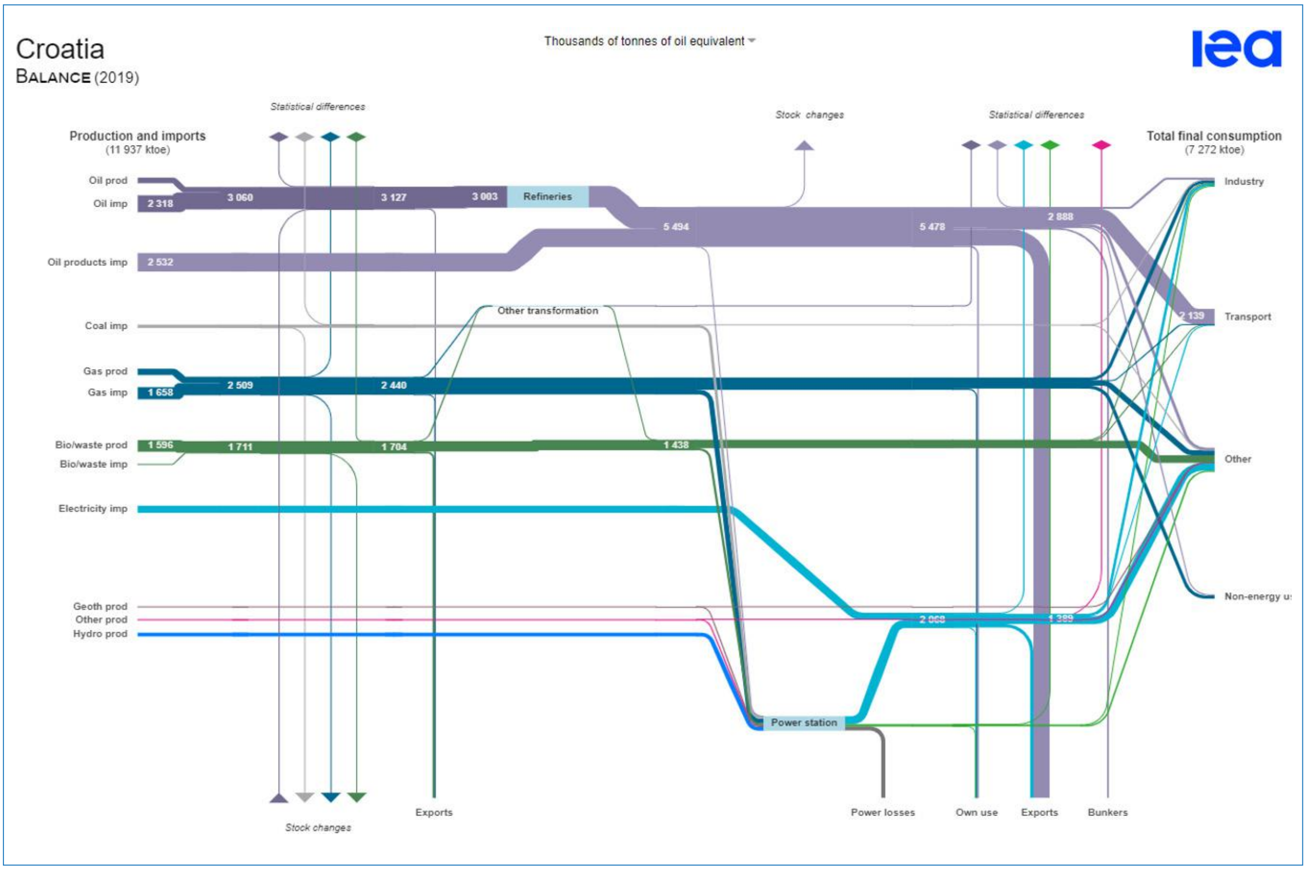


Fig. 7. Sankey diagram on Croatia's energy balance , **IEA**

FRANCE

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1. National energy profile 2019

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	1 647	348	21.1
1995	1 758	394	22.4
2000	1 878	440	23.4
2005	1 949	484	24.8
2010	1 858	503	27.1
2015	1 791	479	26.8
2019	1 745	475	27.2

Table 1. Total final energy and electricity consumption by year
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

During this period three main factors of the evolutions have been: (a) a slow increase of the population from 58.2 million to 67.2 million (+ 15.5%), (b) a decrease of the industry, (c) some effort on energy efficiency. The result is a 6% increase of final energy consumption over the period 1990-2019.

Concerning the electricity, after an increase of around 40% between 1990 and 2010, the consumption has been stabilised and slightly decreasing from 2010 to 2019.

As in the other countries, the major trend is an increase of the ratio electricity consumption/final energy consumption. France has a bit higher ratio than many other European country, partially since electric heating has been more developed to reduce oil imports in the 70's.

Per capita yearly final energy and electricity consumptions (MWh)

Year	Final energy consumption/capita MWhyear	Electricity consumption per capita MWh
1990	28.3	6.0
1995	29.6	6.6
2000	30.8	7.2
2005	30.8	7.7
2010	28.6	7.7
2015	26.9	7.2
2019	25.9	7.0

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=FR

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	345	-	5.93
1995	344	36 572	5.77
2000	365	41 576	5.99
2005	372	46 084	5.89
2010	340	44 973	5.23
2015	305	32 456	4.50
2019	294	30 254	4.36

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=FR

The important emissions reduction this last 10 years is the consequence of a decrease of industry on one side, and the shutdown of coal plants on the other side. The emissions level per capita is low compared to many other industrialized countries since the electric mix is largely decarbonated with nuclear and hydraulic generation.

CO_2 emissions by fossil energy source ($MtCO_2$)

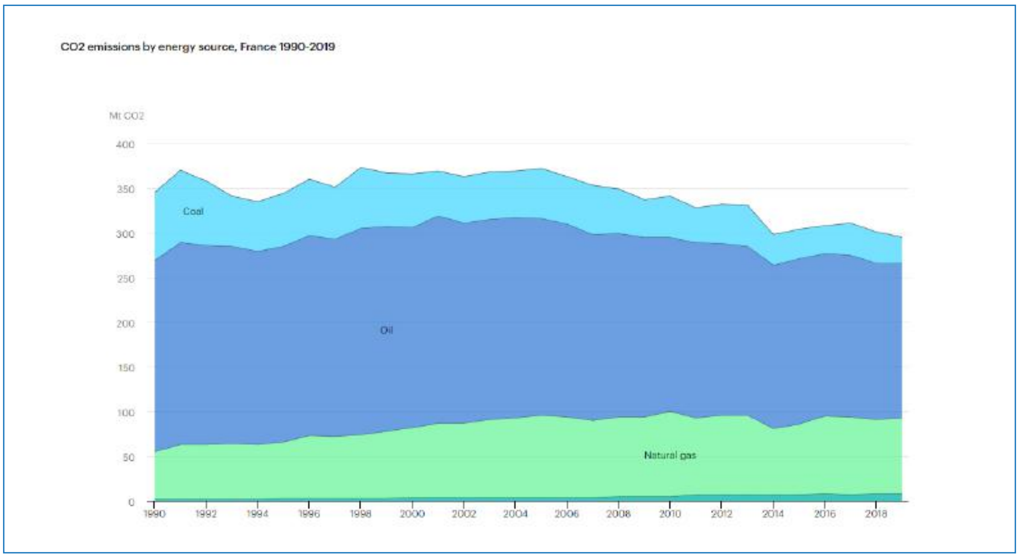

Fig. 1. CO_2 emissions by fossil energy source, **IEA**
https://www.iea.org/countries/france

As in many other OECD countries, the use of coal has been significantly reduced, the use of oil slightly decreasing but the use of natural gas has been increasing.

CO_2 emissions by sector ($MtCO_2$)

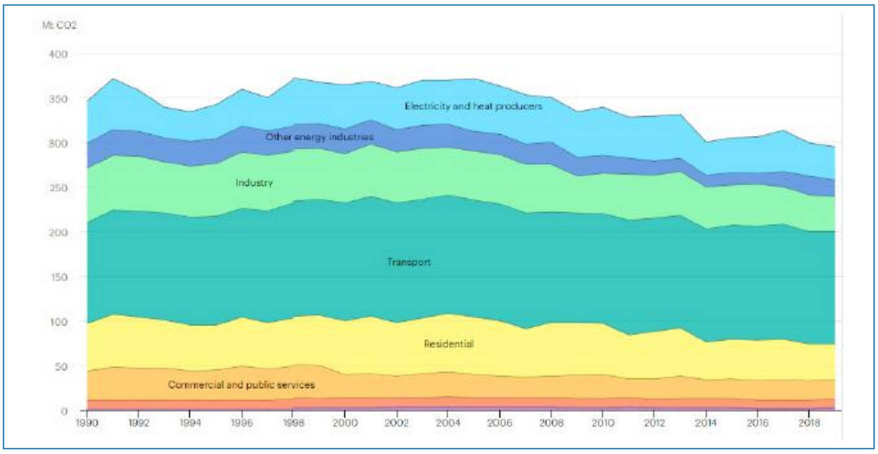

Fig. 2. CO_2 emissions by sector, **IEA**
https://www.iea.org/countries/france

The increase of the emissions due to transport are visible on this diagram. The "Electricity+heat" sector doesn't decrease, but the emissions from electricity are decreasing (see *Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2),* page 38) and the emissions from heat are increasing.

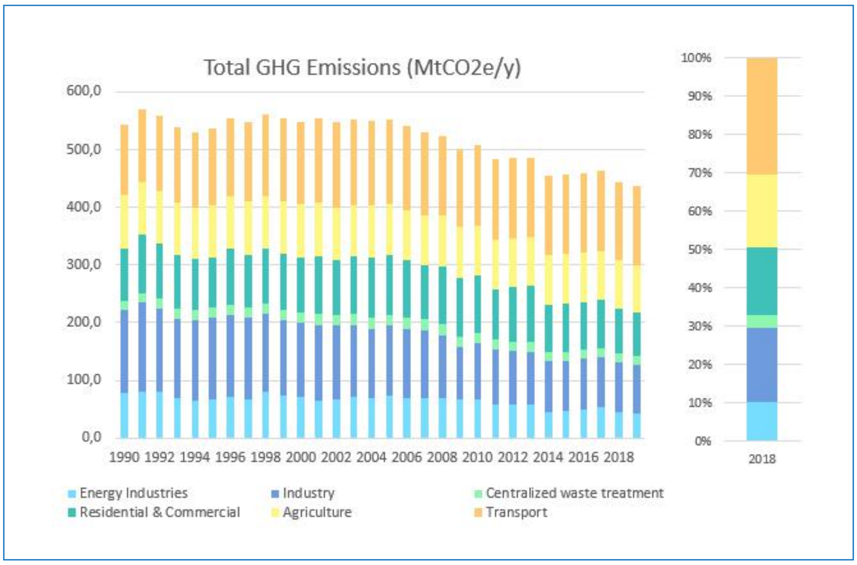

Fig. 3. Total CO_2 emissions by sector including agriculture
Source of data: CITEPA https://www.citepa.org/fr/2022-co2e/
Open Source

The following detailed text refers to *Fig.3.*, which includes emissions from agriculture.

In 2018, France's territorial emissions were 445 $MtCO_{2e}q$ compared to 546 $MtCO_{2e}q$ in 1990 (excluding the land sector); they have therefore decreased by 18.5% over this period, i.e. a decrease of around 0.7% per year, and their per capita level is now one of the lowest among developed countries (6.4 tCO_{2e}/cap). In particular, 2018 saw a 4.2% decrease in emissions compared to 2017.

In France, national GHG emissions (excluding LULUCF carbon sinks) were at an average level of 554 Mt CO_{2e} between 1990 and 2005. After a period of decline between 2005 and 2014 (-2.2%/year on average), emissions had undergone a slight increase (+0.7%/year on average) between 2014 and 2017, due especially to transport and heating.

Since 2018, emissions are again decreasing (-4% in 2018, -1% in 2019), a trend that should continue in 2020 given the Covid-19 crisis. Emissions in 2018 (445 Mt CO_{2e}) and 2019 (436 Mt CO_{2e}) are at the lowest levels recorded since 1990.

In 2018, 31% of GHG emissions were related to the transport sector, 19% to agriculture, 19% to the residential-tertiary sector, 18% to manufacturing and construction, 10% to the energy industry, and 3% to waste. However, only six sub-sectors are responsible for half of the GHG emissions: diesel passenger vehicles (11.7%), residential (heating..., 10.9%), tertiary (heating, refrigeration..., 7.8%); cattle breeding (7.7%); diesel heavy-duty vehicles (6.4%) and diesel light-duty vehicles (5.4%). The notable decreases between 2017 and 2019 correspond to the energy (-29% from electricity production), residential-tertiary (-9%), agriculture (-2%) and waste (-5%) sectors.

France's National Low-Carbon Strategy (SNBC) sets France's climate objectives. For each four-year period, emissions must not exceed a given carbon budget on average over the period.

The first carbon budget (2015-2018) was not respected. The average annual carbon budget for the period 2019-2023, set in 2020 by the revised SNBC, is 422 MtCO_{2e}/year. The indicative annual budget for 2019 was 443 Mt CO_{2e}, while the provisional estimate of 2019 emissions was 436 Mt CO_{2e}. If this pre-estimate is confirmed by the 2019 consolidated inventory, the year 2019 would therefore meet the target.

Emissions will still have to decrease in the following years by nearly -10 Mt CO_{2e} on average per year (i.e. -2.3%/year) for the 2nd carbon budget to be respected on average over the period. Even if the emissions for the year 2020 are not yet estimated, the effects of the measures to fight against Covid-19 could lead to a -5% to -15% decrease in GHG emissions in 2020, even if these are very provisional approximations at this stage.

Refineries-related emissions

Between 1990 and 2017, emissions directly related to oil refining in France decreased by 37.3%. However, this decrease is largely due to the closure of four refineries and the decrease in the net production of finished products in France, compensated by higher imports, given the strong demand for diesel fuel, which cannot be met without costly adaptation of the production tool. It is therefore not necessarily significant from the point of view of climate change mitigation.

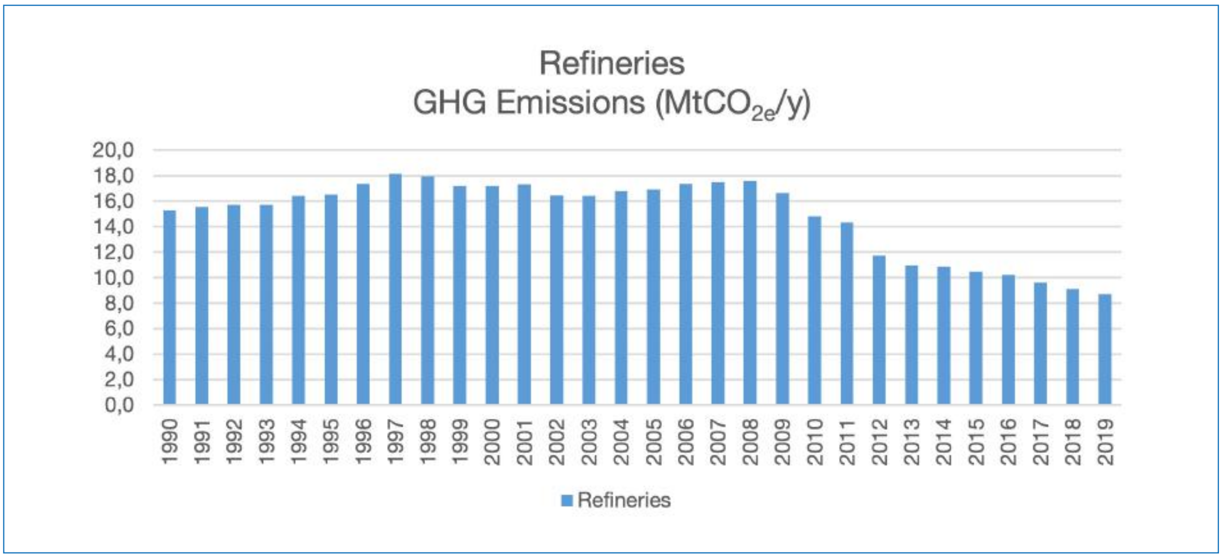

Fig. 4. Refineries GHG emissions
Source of data: CITEPA, April 2022 https://www.citepa.org/fr/2022-co2e/
Open Source

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

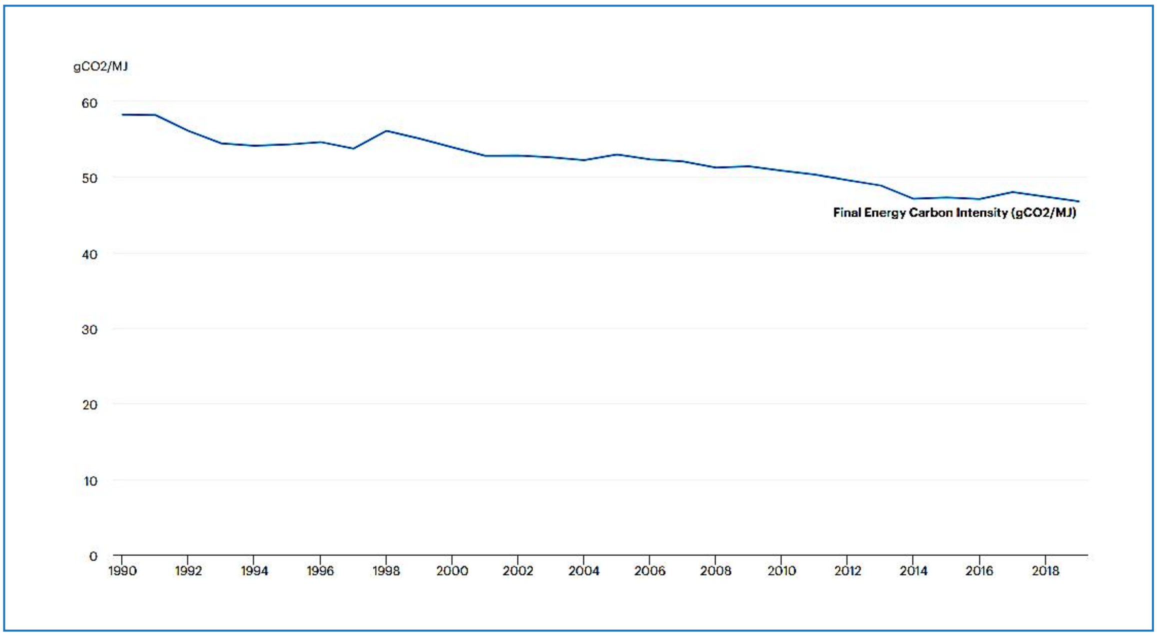

Fig. 5. Final energy carbon intensity, France 1990-2019, **IEA**
https://www.iea.org/countries/francel

Electricity Carbon intensity: gCO_2/kWh

The CO_2 intensity of electricity has always been low due to the important share of nuclear electricity generation capacity, and also the contribution of hydroelectricity. The values were: 108 g in 1990, 77 g in 2000, 50 g in 2020. This decrease was largely consequence of the phasing out of most of the coal plants and also to the increase of wind and solar electricity these last years.

2. Energy perspectives 2030 - 2050

2.1. Perspectives

France's national outlook for 2030 and 2050 is presently governed by the Energy and Climate Law of November 8, 2019.

This law has been translated into operational rules by means of the *Multiannual Energy Programming* (long-term energy planning) and the *National Low Carbon Strategy*, both issued by government orders of April 21, 2020.

They are integrated in an "Energy code".

It sets a long-term trajectory for the energy mix, as well as the priorities for action regarding the role of the various forms of energy on the continental metropolitan territory, in order to achieve the national objectives, set by the law (specific evolving programmes exist for France's overseas territories).

The *National Low Carbon Strategy* is France's roadmap for achieving its greenhouse gas emission reduction targets (-40% by 2030 [1990 base] and carbon neutrality by 2050, in accordance with article 1 of the Energy and Climate Law). It defines the guidelines and concrete measures to be implemented in public, sectoral and territorial policies. It sets short- and medium-term carbon budgets (GHG emission ceilings not to be exceeded at national level over five-year periods) to define the emission reduction trajectory to be followed.

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

As mentioned above, law-specific objectives are to reduce greenhouse gas emissions by 40% between 1990 and 2030 and achieve carbon neutrality by 2050 by dividing greenhouse gas emissions by a factor of more than six.

Multiannual Energy Programming and *National Low Carbon Strategy* timelines are 5 years. The updated French Energy-Climate Strategy will be the roadmap to reduce GHG emissions and adapt French society to the impacts of climate change. It brings together:

- The *Energy-Climate Programming Law*;
- The *National Low Carbon Strategy*;
- The *Multiannual Energy Programming*;
- The *National Plan for Adaptation to Climate Change*.

The *Energy-Climate Programming Law* is due to be issued by July 2023 and the corresponding *Multiannual Energy Programming and National Low Carbon Strategy* 12 months thereafter.

As the new *French Energy-Climate Strategy* is due to be issued by the end of 2023, it has to be presented to parliament by end of 2022.

Roadmap for the energy mix

Targets for final energy consumption and its reduction, see “National Low Carbon Strategy Project : The ecological and inclusive transition towards carbon neutrality” project report 2018 https://www.ecologie.gouv.fr/sites/default/files/Projet%20SNBC%20EN.pdf and IEA: “France 2021 : Energy Policy Review » https://iea.blob.core.windows.net/assets/7b3b4b9d-6db3-4dcf-a0a5-a9993d7dd1d6/France2021.pdf”.

	2017	2023	2028
Final energy consumption (TWh)	1 634	1 525	1 378
% reduction vs.2012	0.9%	7.6%	16.5%

Table 4. Past and projected final energy consumption 2017 - 2028
Data Compiled from various sources of French National Energy Planning (examples see above)

The Energy code set the following for 2030 for energy: 33% renewables, 38% for heat consumption, 15% for fuels, 10% for gas and 40% for electricity. Fit for 55 impose 40% of renewable for 2030. Therefore, the *Multiannual Energy Programming* shall be revised to take Fit for 55 into account.

Roadmap for the GHG emissions (country, per capita)

The present roadmap for the GHG emissions in the present National Low Carbon Strategy defines the next three carbon budgets as follows

Mean yearly emission (Mt CO_{2e})	Reference 1990	Reference 2005	Reference 2015	2019-2023	2024-2028	2029-2033
Total excluding LULUCF[1]	546	553	458	422	359	300
Total with LULUCF	521	505	417	383	320	258

Table 5. Past and projected GHG emissions for France from 1990 to 2033
Data Compiled from various sources of French National Energy Planning (examples see above)

Roadmap for the electricity mix

The Climate and Energy Law sets the objective of reaching a nuclear share of 50% in the electricity mix by 2035. The objective is thus included in the Energy Code.

The table below presents the electricity mix in TWh that the *Multiannual Energy Programming* will make possible in 2023 and 2028 when the measures therein defined are adopted (scenario A and B are slight differing scenarios of the *Multiannual Energy Programming*).

[1] Land Use, Land-Use Change and Forestry (LULUCF)

TWh		Realised 2019	2023	2028 Scenario A	2028 Scenario B
Nuclear		379.4	393.0	382.0	371.0
Fossil	Coal	1.6	0.0	0.0	0.0
	Fuels	41.0	34.0	32.0	32.0
	Gas				
Renewable	Hydro	60.0	62.0	62.0	62.0
	On shore wind	33.7	52.0	77.0	81.0
	PV	11.6	24.0	43.0	53.0
	Bioenergy	9.7	9.0	9.0	10.0
	Offshore wind	0.0	9.0	20.0	21.0
Total		537.0	583.0	625.0	630.0

Table 6. Present and future electricity mix up to 2028, Scenario A and B
Data Compiled from various sources of French National Energy Planning (examples see above, previous page)

Taking into account the recent announcement of the French President concerning nuclear energy, one can assume that the closure of 12 nuclear plants by 2035 as forecast in the *Multiannual Energy Programming* to bring nuclear power down to 50% of the electricity mix, might be cancelled. One might also assume, taking into account the results of the "Energetic future 2050" study of RTE (the French Transmission and System Operator (TSO)) - with 6 scenarios – that the 2050 roadmap defined by present or future French governments will include nuclear as a large part of the electrical mix in 2050.

CO_2 emissions from electricity production

The present French electricity sector is an atypical system: 93% decarbonised - 20 MtCO_2 equivalent in 2019.

Energy balance (energy sources to end-uses)

France Energy Balance (Enerdata 2019) in million tonnes of oil equivalent (mtoe). 1 mtoe = 11,63TWh.

Mtoe	Coal, Lignite	Crude oil	Oil products	Gas	Hydro, Nuclear,	Power	Heat	Bio-mass	Total
PRIMARY PRODUCTION	0.00	0.92		0.01	113.10		0.40	17.49	131.93
Imports	7.20	49.59	45.53	48.66		1.35	0.00	1.68	154.00
Exports	0.00	-0.08	-17.39	-9.68		-6.31	0.00	-0.96	-34.43
Aviation and marine bunkers	0.00	0.00	-7.69	0.00				0.00	-7.69
Stock variations	0.06	0.18	0.20	-1.55				0.09	-1.03
PRIMARY CONSUMPTION	7.25	50.61	20.65	37.44	113.10	-4.96	0.40	18.29	242.79
Refineries	0.00	-52.29	51.79	0.00		0.00	0.00	0.00	-0.50
Power plants	-1.49	0.00	-1.54	-6.55	-113.10	48.71	2.52	-4.46	-75.92
Own use, losses* * Including returns and transfers and heating plants.	-2.73	1.68	-5.21	-2.76		-6.40	1.13	-1.20	-15.48
FINAL CONSUMPTION	3.02		65.69	28.13		37.35	4.06	12.63	150.89
Industry	2.73		2.47	9.07		10.52	1.70	1.69	28.18
Transport	0.00		41.20	0.09		0.82	0.00	3.45	45.57
Other sectors, including	0.06		10.08	17.67		26.01	2.36	7.49	63.67
Residential	0.02		4.40	10.37		13.57	1.49	6.74	36.59
Tertiary	0.04		2.49	7.07		11.71	0.85	0.57	22.72
Agriculture	0.00		3.17	0.24		0.72	0.03	0.18	4.34
Non energy uses	0.23		11.94	1.29		0.00	0.00	0.00	13.47

Table 7. Present (2019) energy balance for various energy sources and by sector
Source: Enerdata www.enerdata.net Historical final energy sources for end users

Reproduced with permission.

The above table shows clearly that coal does not play a significant role in the energy balance anymore, while oil & gas on one hand and nuclear & hydropower on the other hand provide almost equal amounts of energy for consumption. Biomass has become a significant energy vector.

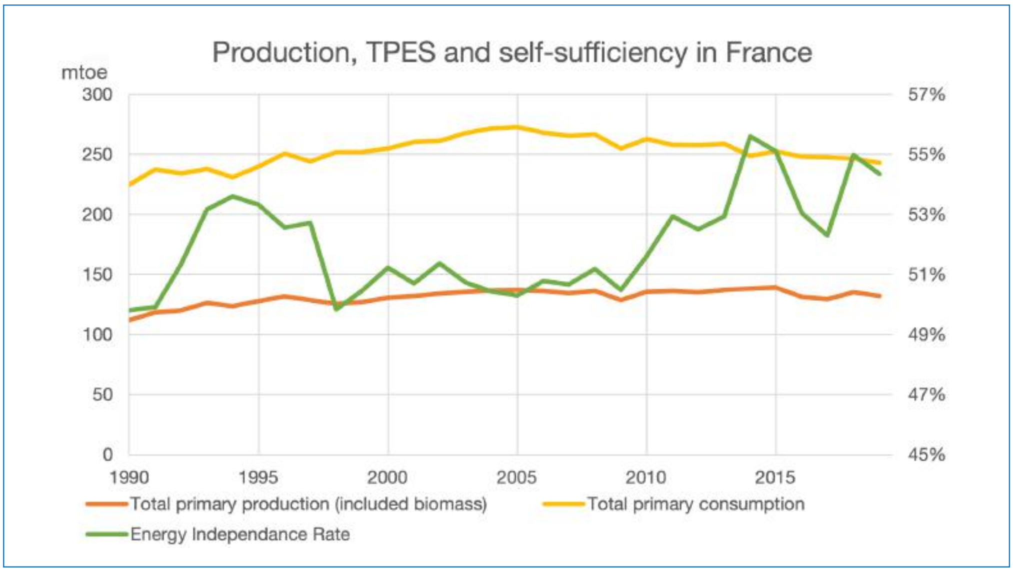

Fig. 6. Energy production and self-sufficiency
Source: Enerdata www.enerdata.net. Since the 1980s, France produces half of the energy the country consumes, due to the development of the nuclear sector. Reproduced with permissinon

The source of energy production is shown in the chart below.

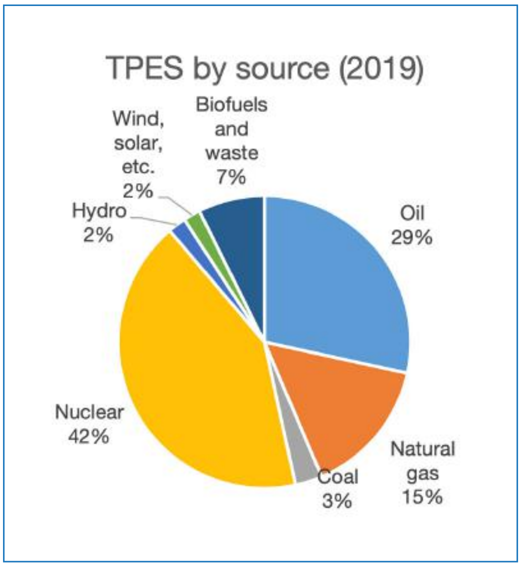

Fig. 7. Energy production by source
Source: Enerdata. Reproduced with Permission.

The chart below shows the evolution over time of the various energy sources with fossil fuels slowly declining and renewables gaining.

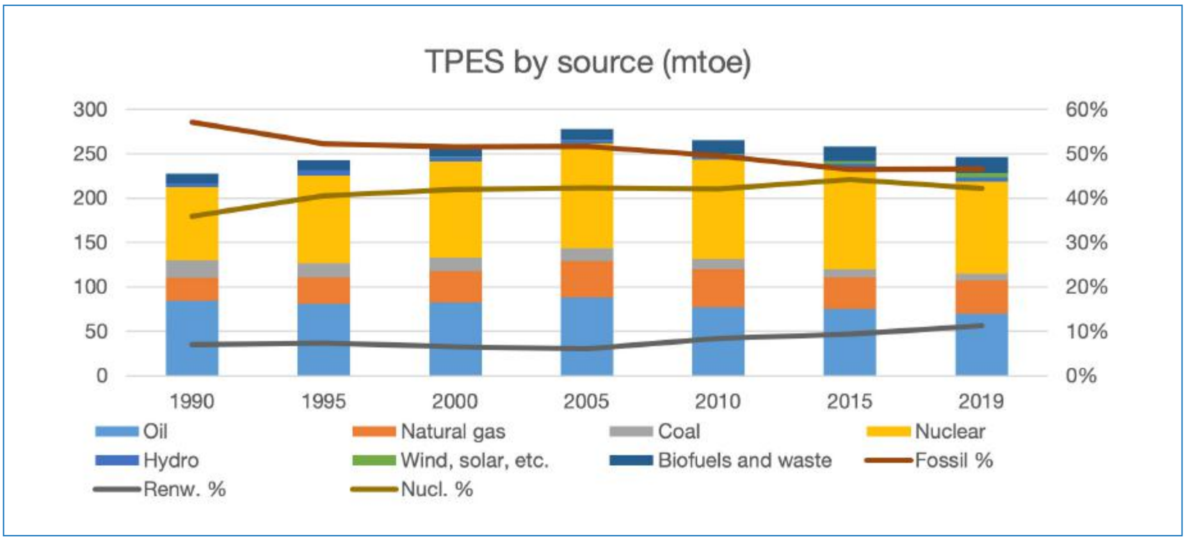

Fig. 8. Evolution of sources for energy productio
Source: Enerdata. Reproduced with Permission.

France's total primary energy supply (TPES) was 246 million tonnes of oil-equivalent (Mtoe) in 2019. Since the peak of 277.8 Mtoe in 2005, TPES contracted by 11.3%.

Nuclear accounts for 42% of TPES in 2019, the largest share of nuclear in TPES in the World.

Fossil fuels accounted for 47% of TPES, made up of oil (29%), natural gas (15%) and coal (3%). This share was 52% in 2000 (declining by 0.8% per year since).

Renewable energy sources accounted for 11% of TPES, made up of biomass and waste (7%), hydro (2%), wind and solar and others (2%). TPES from renewable energy grew by 2.7% per year over the 2010-2019 period.

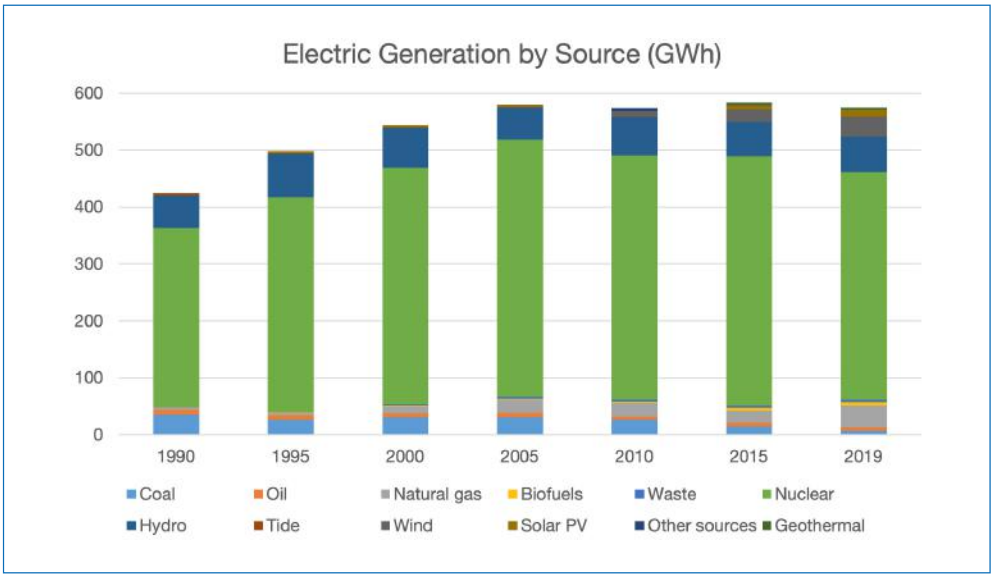

Fig. 9. Evolution of sources for electricity production
Source: Enerdata. Reproduced with Permission.

- France has a very low-carbon electricity mix owing to its large nuclear fleet, the second-largest after the United States. France is the world's largest net exporter of electricity
- France derives about 70% of its electricity from nuclear energy, due to a long-standing policy based on energy security. Government policy is to reduce this to 50% by 2035.

- There are currently 56 Operable Reactors for a total capacity of 61,370 MWe and one reactor in construction (Flamanville) with a capacity of 1,630 MWe
- In October 2014 the Energy Transition for Green Growth bill was passed by the National Assembly and so went onto the Senate. This set a target of 50% for nuclear contribution to electricity supply by 2025, and capped nuclear power capacity at 63.2 GWe, the level at the time. This meant that EDF would have to shut at least 1.650 GWe of nuclear capacity when its Flamanville 3 EPR starts commercial operation. The bill also set long-term targets to reduce greenhouse gas emissions by 40% by 2030 compared with 1990 levels, and by 75% by 2050; to halve final energy consumption by 2050 compared with 2012 levels; to reduce fossil fuel consumption by 30% by 2030 relative to 2012; and to increase the share of renewables in final energy consumption to 32% by 2030. The Senate early in 2015 amended the bill to remove the nuclear cap, but this was not accepted in the lower house. The National Assembly approved the bill including 970 amendments in July 2015, but with the 63.2 GWe nuclear cap and only 50% nuclear supply by 2025. In October 2016 the government postponed until after the 2017 presidential and National Assembly elections any decision on which, if any, reactors would close in order to reduce the nuclear share to 50%. In 2017 France postponed its 2025 target for reducing the share of nuclear to 50%. In December 2017 the French President stated that nuclear is "the most carbon-free way to produce electricity with renewables." In November 2018, a draft of the country's new energy plan confirmed that 2035 was the new target date for the reduction of nuclear's share to 50%. The plan states that 14 of the country's nuclear reactors will shut down by 2035, 4-6 of those by 2030. However, the plan also states that the option to build new nuclear reactors remains.

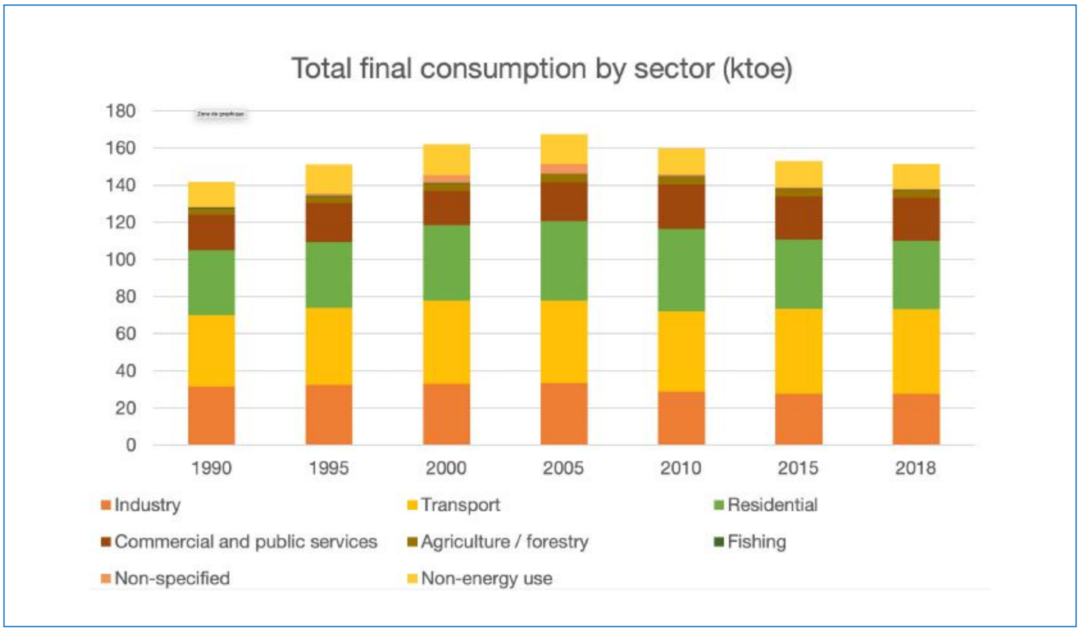

Fig. 10. Evolution of final energy consumption by sector
Source: Enerdata. Reproduced with Permission.

Transport is the largest consuming sector and accounted for 30% of TFC in 2018, or 45.3 Mtoe. The industrial and residential sectors represented 18% and 24%, respectively, while the commercial sector consumed 15%.

Since 2000, TFC has declined by 6.7% reflecting the structurally weak economic growth and energy efficiency progress in residential and commercial and services sectors.

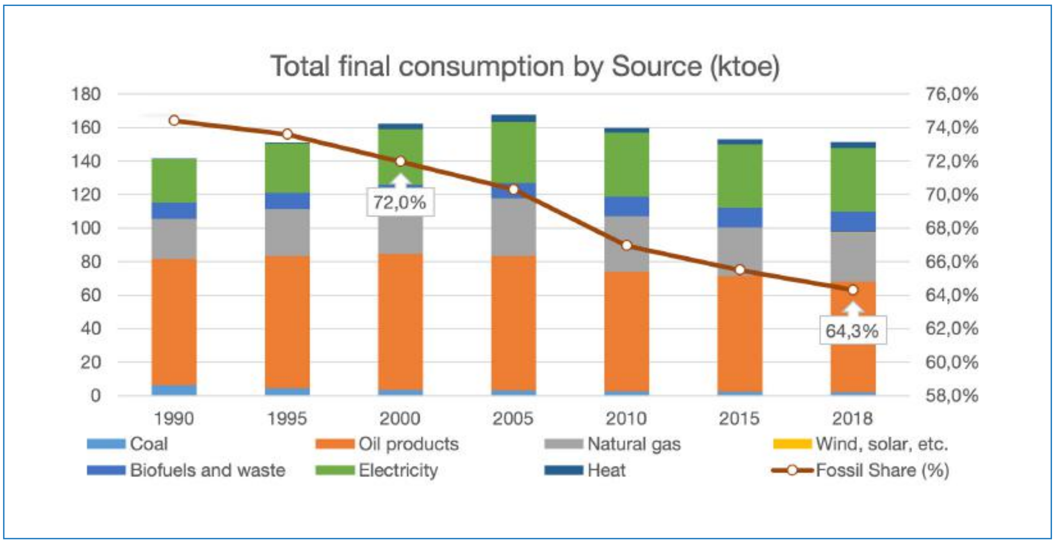

Fig. 11. Evolution of final energy consumption by source
Source: Enerdata. Reproduced with Permission.

Fossil energy represents 64% of TFC in 2018, vs. 72% in 2000 as coal consumption has been slashed by almost 40%, and oil products by 18.6%.

2.2. France Energy Legislation

From a legal point of view, France's energy law is ruled under both European Union law and national law. France energy policy and strategy is now grounded on two pillars, introduced by the 2015 energy transition for green growth Act (LTECV): **the SNBC** and **the PPE**. Both were adopted in April 2020. France also released, in April 2020, its national energy and climate plan (**NECP**) in compliance with the European Union Regulation on governance of the energy union and climate action (EU/2018/1999).

The PPE (decree n02020-456) establishes the priorities in terms of energy policy for public actors to reach the objectives set by the LTECV and the LCE and has a significant impact on the national energy strategy. It is legally binding, so that the strategies and planning documents which include energy guidance (i.e. regional climate, air quality and energy plans) must be consistent with the PPE. The PPE notably aims at reducing the final energy consumption by 7.6% in 2023 and 16.5% in 2028 (compared to 2012). The PPE also aims at shutting down the last coal plants by 2022 and 14 out of the 58 existing nuclear reactors by 2035 including those of the Fessenheim plant. As for renewable energies, the PPE sets ambitious targets for each source and an indicative timeframe for the launch of calls for tenders for renewable energy plants. For instance, by 2023, the installed power must reach 24.1 GW for onshore wind energy, 20.1 GW for photovoltaic energy (five times the current installed power), 25.7 GW for hydropower and 2.4 GW for offshore and floating wind power. For the latter, five calls for tenders will be organised in the upcoming three years.

The SBNC (decree n02020-457) defines cross-cutting and sectoral objectives to conduct Frances's policy in terms of GHG emissions in the long-medium run. This non-binding document has set "carbon budgets", i.e. national emissions thresholds on five-year terms, broken down into sectoral activities. The 2020 SNBC was subject to a public participation procedure. Ones of the main objectives of the 2020 SBNC are, by 2050, to reduce the GHG emission in the industry sector by 81% comparing to 2015.

NECP - The European Union has laid down targets for 2030 that its Member States shall reach. The latter was expected to notify to the Commission their NECP for 2021-2030, which must describe national objectives and national climate-energy contributions as well as policies and measures planned or adopted to implement them. Therefore, the French NECP outlines France priority actions in the energy sector for the next decade and mainly relies on the PPE and the SNBC mentioned hereabove.

Recent developments in legislation

The end of 2019 and, moreover, 2020 have seen major evolutions in terms of French legislation and regulation applying to the energy sector. A wide range of legal texts were adopted, notably starting with the LCE on November 2019 and followed by several ordinances issued by the government.

The LCE (Loi Energie Climat) was drafted following the law n02015-992 related to LTECV as well as the Paris Agreement in 2015, and now constitutes the pillar of France's energy policy. It aims at ensuring the implementation of the French national and international commitments as well as reaching the goals assigned by the SNBC and the PPE (cf. hereabove), in accordance with the EU Clean Energy Package adopted on November 30, 2016, by the European Commission. Among these goals, France notably targets the **"carbon neutrality" by the end of 2050** (by dividing its GHG emissions by six in comparison to 1990 (instead of four in the LTECV), but delays for 2035 regarding the goal of cutting the share of nuclear energy of the electricity production (previously set to 2025 by the LTECV). It also raised the target related to the share of energy from renewable sources in gross final consumption up to 33% by 2030. The LCE is also noticeable as it addresses the transposition of the EU Clean Energy Package and provides further mechanisms to foster the development of renewable energies.

Law on the orientation of mobilities (LOM) - The LOM n'2019-1428 was adopted in December 2019. Although less important in terms of energy policy than the LCE, it sets ambitious objectives for the energy transition in the transport sector. For instance, the law forbids the sale of cars using carbon-based fossil fuels by 2040 and aims at reducing the GHG emissions by 37.5% before 2030.

In addition, following the European Green Deal, the French government introduced **"the national strategy for decarbonised hydrogen"** on September 8, 2020. This strategy set three objectives: a) installing enough electrolysers to make a significant contribution to the decarbonation of the economy: the government aims at reaching a hydrogen production capacity of 6.5 GW by 2030; b) developing clean mobility, particularly for heavy vehicles, in order to save over 6 million tonnes of $C0_2$ by 2030: the government would like to develop territorial projects involving local authorities and industries in order to accelerate the deployment of hydrogen-powered professional mobility; and c) building an industrial sector in France that creates jobs and guarantees technological expertise. The government support will reach 7 billion euros and will focus on both supply and demand, supporting research to develop more efficient technologies.

2.3. Two Case Studies on biomasse

BioTfuel

The BioTfueL project developed by Axens, CEA, IFP Énergies Nouvelles, Avril, ThyssenKrupp Industrial Solutions and TotalEnergies aims to develop an innovative process for the gasification of biomass into high quality biodiesel and biokerosene. The gasification allows to enlarge the spectrum of biomass usable for the production of biofuels by using lignocellulose (agricultural co-products, forest residues or specific biomass). This process can also be used to treat fossil feedstocks mixed with biomass, in particular, to take into account the seasonal nature of the resource. This project aims to develop and commercialize a complete process chain for the thermochemical production of advanced biodiesel and biokerosene. These high-quality fuels will be free of sulfur and aromatic compounds and can be used, alone or in blends, in all types of diesel and jet engines.

Fig. 12. Location BioTfuel
Source: TotalEnergies, https://totalenergies.com/fr/expertise-energies/projets/bioenergies/biotfuel-convertir-residus-vegetaux-carburant
Reproduced with permission.

Futurol

Launched in 2008, the Futurol™ project has been conducted with the support of 11 partners, covering the entire process, from the plant resource to the fuel tank: ARD, IFP Energies nouvelles, INRAE, Lesaffre, Office national des forêts (French National forestry Office), Tereos, Total, Vivescia, Crédit Agricole Nord Est Participations, CGB and Unigrains. The various steps in the process were successfully validated on a continuous pilot at Pomacle-Bazancourt (Marne, northern France) and an industrial demonstrator at Tereos' Bucy-le-Long site.

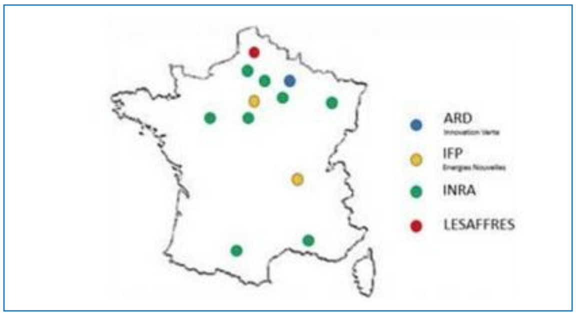

Fig. 13. Location Futurol R&D Teams, Produced from various sources.

The Futurol project will develop a process to produce bioethanol by fermenting non-food lignocellulosic biomass. Many other products can be obtained from such process for fuel/energy and chemical applications alike. The originality of Futurol™ technology lies in its four-step implementation process: steam explosion of biomass, combined hydrolysis and fermentation, ethanol separation and in-situ enzyme production. One of its great strengths is its autonomy. Technological autonomy, first of all, thanks to the in situ production of the enzymes and the propagation of yeasts adapted to the raw materials treated. And also in terms of energy, since the technology enables total autonomy of the industrial site, and even energy exports.

A first industrial plant will be built by INA which will produce 55 000 tons (equivalent to 70 million liters of ethanol) of bioethanol using lignocellulosic raw materials such as agricultural waste and energy crops such as miscanthus.

In addition to advanced biofuels, processes such as BioTfueL or Futurol (a process for converting lignocellulosic residues into ethanol) also produce molecules that can be used in subsequent transformation processes to produce biobased chemical intermediates. For example, the ATOL process converts ethanol produced from lignocellulosic derivatives into bio-olefins. This type of combination amounts to establishing biorefineries that satisfy both the biofuel and chemical intermediate markets.

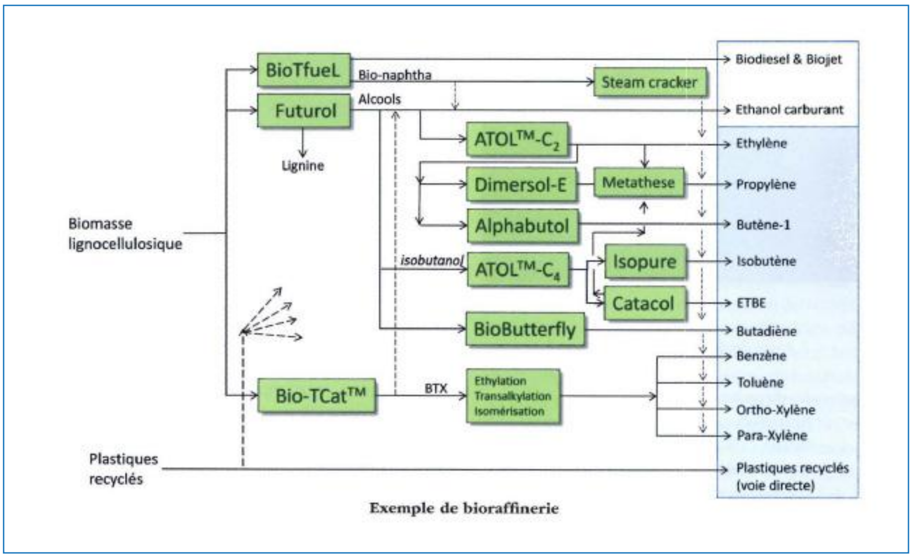

Fig. 14. Pathways for final energy consumption via biorefinery
Source: La Revue de l'Énergie n° 645 – juillet-août 2019, « L'industrie des hydrocarbures face aux enjeux de la transition énergétique », Fabrice Bertoncini, Jean-Pierre Burzynski, Pierre Marion, Jérôme Sabathier. Reproduced with Permission.
https://www.larevuedelenergie.com/lindustrie-des-hydrocarbures-face-aux-enjeux-de-la-transition-energetique/.

GERMANY

Table of Contents

1. Introduction

National energy profile 2019

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consump-tion (TWh)	Elec/Energy (%)
1990	2 800	527	18.8
1995	2 713	516	19.0
2000	2 619	545	20.1
2005	2 694	589	21.8
2010	2 697	594	22.0
2015	2 569	574	22.3
2019	2 578	549	21.3

Table 1. Total yearly consumption: final energy, electricity
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

Energy consumption in Germany decreased by 8% during the period from 1990 to 2019. This resulted from: *a)* improvements in energy efficiency; *b)* substitutions in the energy mix; and *c)* a decline in energy consumption in energy-intensive industrial sectors. The consumption-enhancing factors, such as population growth and mild weather, were significantly weaker than the consumption-reducing ones.

Concerning electricity, after an increase of around 44% between 1990 and 2010, consumption slightly decreased from 2010 to 2019. An increase in the electricity consumption / final energy consumption ratio could be observed during the period considered.

Per capita yearly final energy and electricity consumptions (MWh)

Year	Inhabitants (per million)	Energy Consump-tion (TWh)	Energy Consumption per person and per year (MWh)	Electricity Consumption (TWh)	Electricity Consump-tion per person and per year (MWh)
1990	79.0	2 800	35.5	527	6.7
1995	81.1	2 713	33.4	516	6.4
2000	81.4	2 619	32.2	545	6.7
2005	81.6	2 694	33.0	589	7.2
2010	80.8	2 697	33.4	594	7.3
2015	81.8	2 569	31.4	574	7.0
2019	83.5	2 578	30.9	549	6.6

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year)
Source: Based on and/or calculated from the following data: **International Energy Agency** - Data and statistics
https://www.iea.org/data-and-statistics Explore energy data by category, indicator, country or region, **IEA** Emission Factors (2021)
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=DE

Per capita energy consumption in Germany declined by 13%, during the period 1990–2019, while per capita electricity consumption remained static.

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	940.0	342.7	11.8
1995	856.6	322.4	10.5
2000	812.3	311.9	10.0
2005	786.9	315.3	9.7
2010	758.9	300.1	9.5
2015	729.7	290.0	8.9
2019	644.1	209.5	7.8

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based on and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics Explore energy data by category, indicator, country or region, **IEA** Emission Factors (2021)
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=DE

CO_2 emissions in Germany have fallen since 1990: from 940 million metric tonnes of CO_2 equivalents in 1990 to 644 million metric tonnes in 2019. Overall, this corresponds to a reduction of around 31.5%. CO_2 emissions per capita have also been dropping by around one third during the last 20 years. This is mainly due to increased emissions trading certificate prices and the expansion of renewable energies.

CO_2 emissions by fossil energy source ($MtCO_2$)

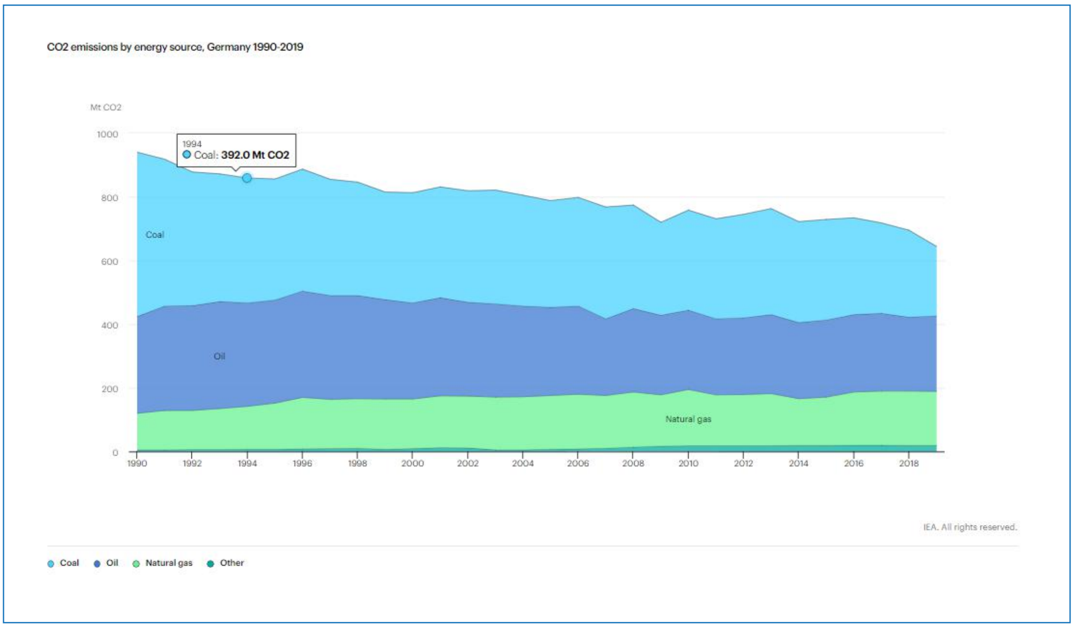

Fig. 1. CO_2 emissions by fossil energy source, **IEA**
https://www.iea.org/countries/germany

During the period 1990-2019, CO_2 emissions from coal significantly decreased (from 514 Mt in 1990 to 218 Mt in 2019), which indicates a strong reduction in coal-fired power generation in Germany.

While the use of natural gas has increased by 47.8% during the period considered (from 115 Mt in 1990 to 170 Mt in 2019), the use of oil has fallen by almost one-third (from 301 Mt in 1990 to 237 Mt in 2019).

CO_2 emissions by sector ($MtCO_2$)

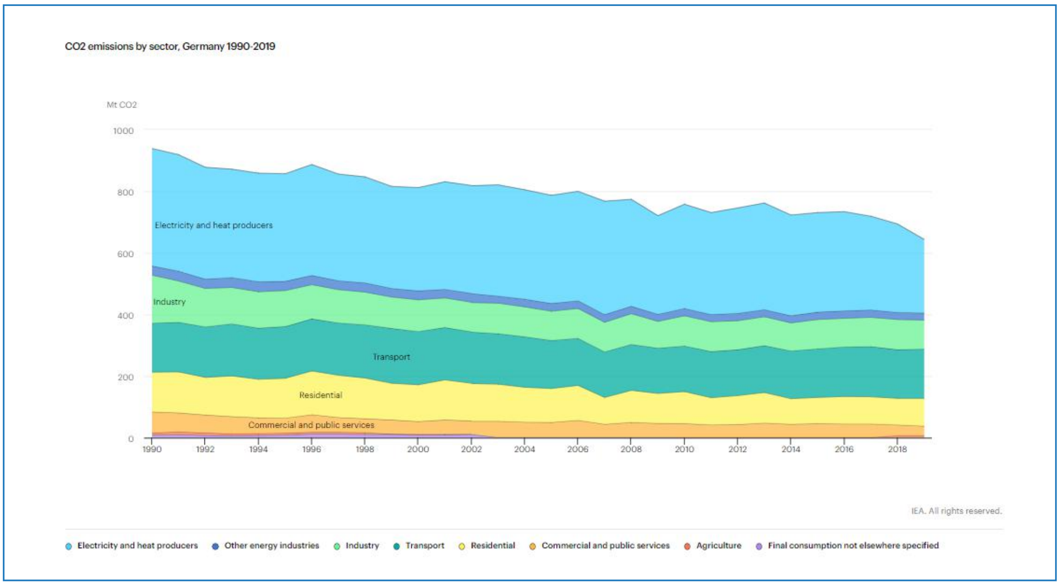

Fig. 2. CO_2 emissions by sector, **IEA**
https://www.iea.org/countries/germany

With the exception of the transport sector, in which CO_2 emissions remained unchanged, the amount of CO_2 emissions in all other sectors decreased during the period 1990–2019. The significant decline in emissions from the industrial sector is visible in this diagram.

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

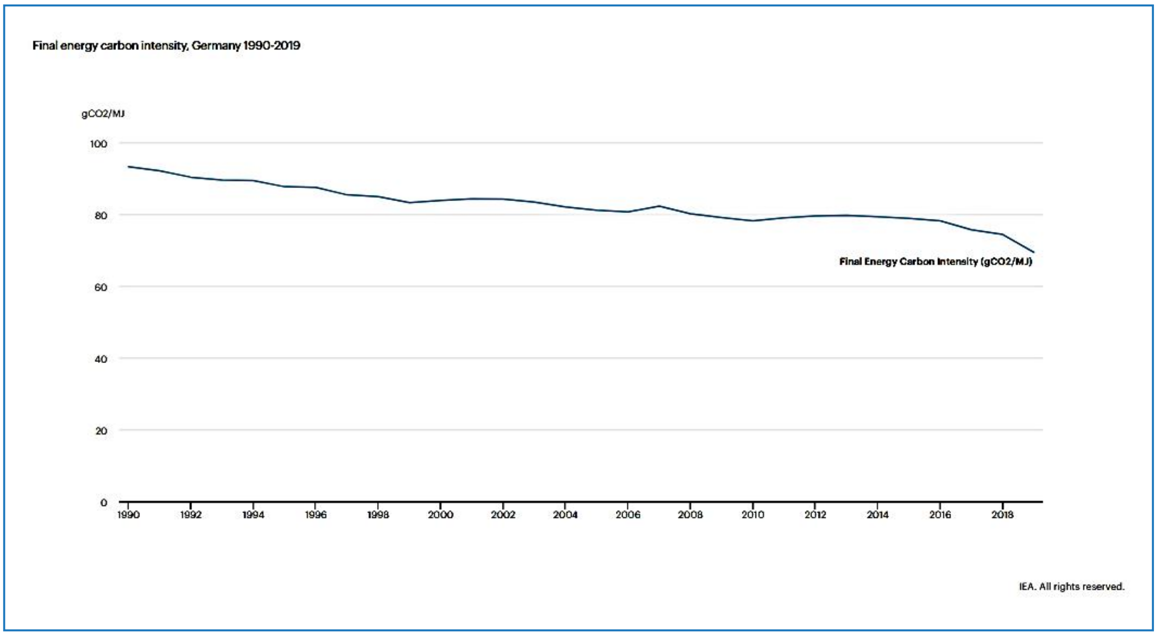

Fig. 3. Final energy carbon intensity, **IEA**
https://www.iea.org/countries/germany

Between 1990 and 2019, emission intensity in Germany decreased by a good quarter (25.5%), falling from 93.2 gCO_2/MJ to 69.4 gCO_2/MJ. This development reflects the increased use of biofuels and the reduction of the shares of gas and coal in the German electricity mix.

Electricity Carbon intensity: gCO_2/kWh

The CO_2 intensity of electricity has always been low due to the important share of nuclear electricity generation capacity, and also the contribution of hydroelectricity. The values were: 108 g in 1990, 77 g in 2000, 50 g in 2020. This decrease was largely consequence of the phasing out of most of the coal plants and also to the increase of wind and solar electricity this last years.

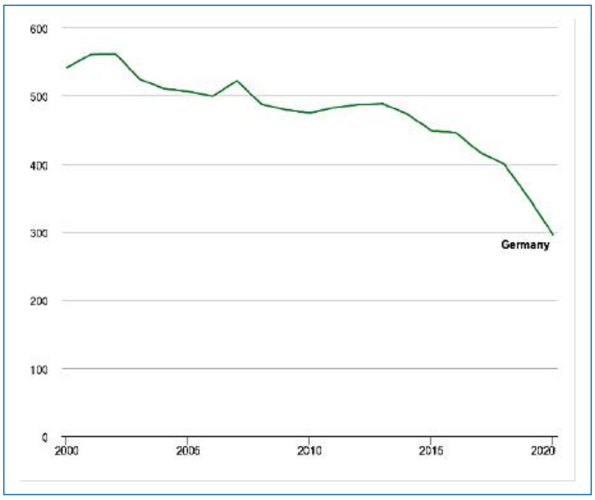

Fig. 4. Electricity Carbon intensity, **IEA**
https://www.iea.org/data-and-statistics/charts/development-of-co2-emission-intensity-of-electricity-generation-in-selected-countries-2000-2020

The CO_2 intensity of electricity generation in Germany fell from 541.6 gCO_2/kWh to 295.8 gCO_2/kWh between 2000 and 2020. The main factor that contributed to this development was the fact that more electricity was being generated from renewable energy sources and less from coal firing.

2. Energy perspectives 2030 - 2050

If possible, give the national perspectives for 2030 and 2050 or the roadmap to 2030 and 2050 if they exist.

The following list of questions should serve as a guide for providing information on this topic. Please feel free to answer in a different manner if you like.

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

EU level

EU regulations are binding and must immediately be applied by the Member States. Germany must observe and implement regulations adopted by the EU, and therefore our national climate policy is closely linked to European climate policy. Both the European Green Deal (EGD) and the newly presented ‘Fit for 55’ package under the EGD have a huge impact on our national targets and laws.

European Green Deal

The Green Deal is a comprehensive growth strategy for a climate-neutral and resource-efficient economy. Its primary objective is to achieve EU-wide net zero emissions by 2050, which would make Europe the first climate-neutral continent in the world. On 11 December 2019, the Commission presented a Communication setting out its vision for the Green Deal and a comprehensive work programme to develop EU policies along these lines. The European Green Deal shows how sustainable transformation can succeed. It contains a range of different measures spanning climate action, nature conservation, biodiversity conservation and mobility and industrial policy to energy, agricultural and consumer protection policy.

The European Green Deal is also our lifeline out of the COVID-19 pandemic. One third of the EUR 1.8 trillion investments from the ‘Next Generation EU’ Recovery Plan and the EU’s seven-year budget will finance the European Green Deal.

Fit for the 55-package under the EGD

As part of the European Green Deal, with the European Climate Law, the EU has set itself a binding target of achieving climate neutrality by 2050. This requires current greenhouse gas emission levels to substantially drop in the next decades. As an intermediate step towards climate neutrality, the EU has raised its 2030 climate ambition, committing to cutting emissions by at least 55% by 2030, compared to 1990 levels. On 14 July 2021, the European Commission adopted a package of proposals to implement the increased ambition. The package contains legislative proposals to revise the entire EU 2030 climate and energy framework, including the legislation on effort sharing, land use and forestry, renewable energy, energy efficiency, emission standards for new cars and vans, and the Energy Taxation Directive. The Commission proposes to strengthen the emissions trading system (ETS), extend it to the maritime sector, and reduce over time the free allowances allocated to airlines. A proposed new emissions trading system for road transport and buildings should start in 2025, complemented by a new social climate fund with a financial envelope of EUR 72.2 billion to address its social impacts. New legislation is proposed on clean maritime and aviation fuels. To ensure the fair pricing of GHG emissions associated with imported goods, the Commission proposes a new carbon border adjustment mechanism.

National level

Climate Action Act

Germany's Climate Change Act first entered into force in December 2019. The purpose of this Act is to provide protection from the effects of worldwide climate change by ensuring the achievement of the national climate targets and compliance with the European targets.

An amended Climate Change Act 2021 was presented by the Federal Government on 12 May 2019. The new law brings forward the deadline for achieving climate neutrality by five years to 2045 and tightens the interim target for greenhouse gas emission reduction from 55% to 65% by 2030 compared to 1990. For 2040, a new interim target of 88% reduction applies. After the year 2050, negative greenhouse gas emissions are to be achieved (For details, see *Roadmap for the GHG emissions*, page 57).

Energy Efficiency Roadmap

The Roadmap was launched on 18 December 2019, when the Federal Government adopted the cross-sectoral Energy Efficiency Strategy 2050. The stated aim of the Energy Efficiency Strategy 2050 at the time was for German primary energy consumption to fall by 30% by 2030 and by 50% by 2050 (from 2008)[1]. The target date for the completion of the dialogue process is autumn 2022.

The amendment to the Climate Change Act 2021 tightened climate regulations and enshrined in law the goal of achieving greenhouse gas neutrality by 2045. This meant a change to the timetable for the Energy Efficiency Roadmap. Even more ambitious energy efficiency targets are to be attained: by 2030, primary energy consumption is to fall by around 40% and it must be halved by 2045[2].

Roadmap for the energy mix

Germany’s National Energy and Climate Plan, adopted on 10 June 2020, considers expanding renewable energies to 30% of gross final energy consumption by 2030[3].

Roadmap for the GHG emissions

In a ruling announced on 29 April 2021, the German Federal Constitutional Court delivered a ground breaking decision on national climate change legislation. Germany's Federal Court of Justice ruled that the country’s 2019 Climate Change Act, which required that greenhouse gas emissions be gradually reduced by the target year 2030 by at least 55% relative to 1990 levels, was partly ‘unconstitutional’ because it shifted the climate burden of making painful reductions to future generations. The Court instructed the German legislator to revise the Federal Climate Change Act by the end of 2022.

1 https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/energieeffiezienzstrategie-2050.pdf?__blob=publicationFile&v=12

2 https://www.bmwi-energiewende.de/EWD/Redaktion/EN/Newsletter/2021/06/en-newsletter_2021-06.html?__act=renderPdf&__iDocId=2720684

3 National Energy and Climate Plan, Page 11

On 24 June 2021, the Bundestag (Federal Parliament) adopted the reform of the Climate Change Act. With the amendment to the Climate Change Act, the German Federal Government intends to tighten climate regulations and enshrine in law the goal of achieving greenhouse gas neutrality by 2045.

The target for 2030 is to reduce emissions by 65% of 1990 levels by 2030[4]. This means that by the end of the decade, Germany is to reduce its greenhouse gas emissions by 65% of the 1990 levels.

The climate goals are reviewed through continuous monitoring. Every two years, the Council of Experts for Climate Matters will present a report of the goals achieved, as well as measures and trends. The first report is being prepared in 2022. If the targets are not met, the federal government will immediately adjust its approach.

For 2040 the reduction target is a minimum of 88%. Along the road to this goal, the Act lays down specific annual reduction targets during the 2030s. Germany is to become greenhouse gas neutral by 2045. This means that there must be a balance between greenhouse gas emissions and the removal of such gases. From 2050 onward, Germany aims to have a negative emissions balance, meaning that it would then remove more greenhouse gases using natural sinks than emit any.

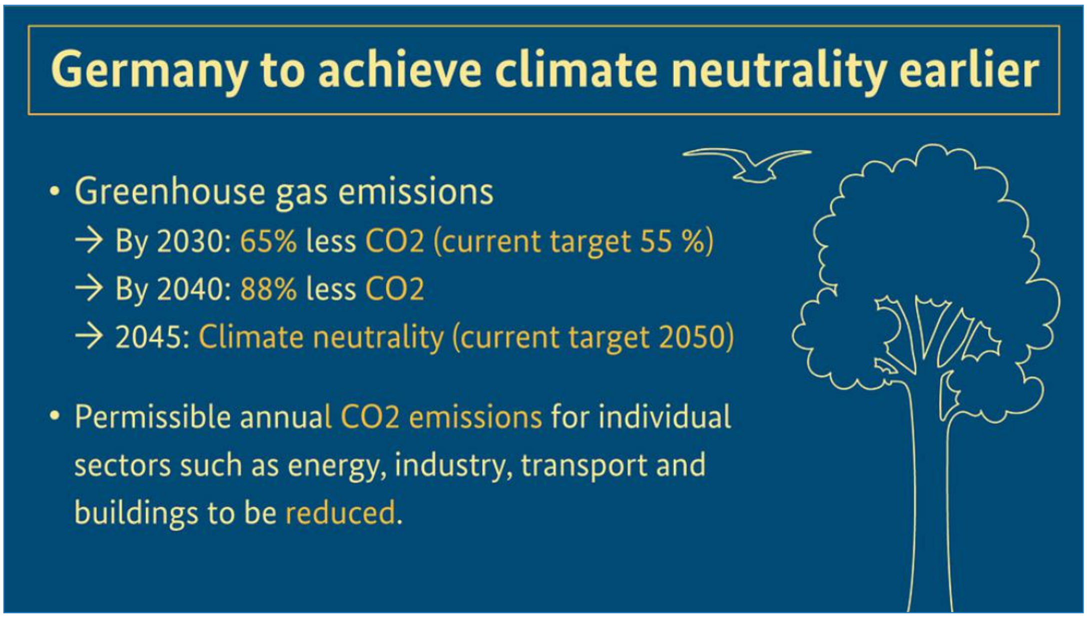

Fig. 5. Roadmap for achieving climate neutrality
Source: Federal Government of Germany (2021): Climate Change Act 2021 -Intergenerational contract for the climate, https://www.bundesregierung.de/breg-de/themen/klimaschutz/climate-change-act-2021-1936846, last accessed 13.02.2023
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With the amended Climate Change Act, the Federal Government does not only intend to provide for greater intergenerational justice. It will also put in place a more secure basis on which to plan. The road to climate neutrality is now set out in even more detail. Below is an overview of the milestones.

Cabinet decision of 12 May 2021: increase annual reduction targets per sector for the period 2023 to 2030 and enshrine the annual reduction targets for the period 2031 to 2040 in law.

2024: determine the annual reduction targets by sector for the period 2031 to 2040.

No later than 2032: determine the annual reduction targets for the period 2041 to 2045.

2034: determine the annual reduction goals by sector for the final phase leading up to greenhouse gas neutrality (2041 to 2045).

[4] https://www.bundesregierung.de/breg-de/themen/klimaschutz/climate-change-act-2021-1936846

Roadmap for the electricity mix

Germany's electricity supply is becoming 'greener' every year. The share of renewables in electricity consumption has been steadily growing over the last few years – rising from around 6% in 2000 to around 38% in 2018. This means that the 35% target for 2020 was reached earlier than expected.

Wind and solar energy are the most important forms of renewables. Biomass and hydropower are also valuable building blocks in our energy system. The role of wind and solar energy is expected to strongly increase in the future.

The expansion of renewable energy remains one of the key pillars of the energy transition. The share of renewable energy is to be increased from its present level of around 32%, up to 40-45% in 2025, and to 65% in 2030 according to the coalition agreement. The next phase of the energy transition will focus on bringing about more competition, a continuous expansion with effective steering, restrictions on costs, stakeholder diversity and dovetailing with grid expansion.

CO_2 emissions from electricity production

Permissible annual emission budgets for the years 2020 to 2030

Annual emission budgets in million tonnes of CO2 equivalent	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Energy	280		257								108
Industry	186	182	177	172	165	157	149	140	132	125	116
Buildings	118	113	108	102	97	92	87	82	77	72	67
Transport	150	145	139	134	128	123	117	112	105	96	85
Agriculture	70	68	67	66	65	63	62	61	59	57	56
Waste and Other	9	9	8	8	7	7	6	6	5	5	4

Table 4. CO_2 emissions from electricity generation
Source: Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (2021): Federal Climate Change Act, Annex 2, http://www.gesetze-im-internet.de/englisch_ksg/englisch_ksg.pdf last accessed 12.02.2023.
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According to the Climate Change Act 2021, emissions in the energy sector are to be reduced to 108 million metric tons CO_2 by 2030[5].

Energy balance (energy sources to end-uses)

Total primary energy consumption 2020

In 2020, due to the COVID-19 pandemic, primary energy consumption in Germany amounted to a total of 11 784 petajoules (PJ) or 3 273 TWh or 402.1 million tonnes of coal equivalents (Mtce); compared to the previous year, this equals a decrease of 8.0%[6].

5 Federal Climate Change Act (Bundes-Klimaschutzgesetz), Annex 2

6 AGEB Annual Report 2020: Energy Consumption in Germany Drops to Historic Low in 2020 Due to the Covid-19 Pandemic

AGEB
AG Energiebilanzen e.V.

Primary Energy Consumption in Germany in 2019 and 2020 [1)]

Energy Carrier	2019	2020	2019	2020	Changes in 2020 Compared to 2019			Proportions in %	
	Petajoules (PJ)		Million Tons of Coal Equivalents (Mtce)		PJ	Mtce	%	2019	2020
Mineral Oil	4,511	3,973	153.9	135.6	- 538	- 18.4	- 11.9	35.2	33.7
Natural Gas	3,214	3,136	109.7	107.0	- 78	- 2.7	- 2.4	25.1	26.6
Hard Coal	1,084	904	37.0	30.8	- 180	- 6.1	- 16.6	8.5	7.7
Lignite	1,164	956	39.7	32.6	- 207	- 7.1	- 17.8	9.1	8.1
Nuclear Energy	819	702	27.9	24.0	- 117	- 4.0	- 14.2	6.4	6.0
Renewable Energy	1,904	1,961	65.0	66.9	57	1.9	3.0	14.9	16.6
Electricity Exchange Balance	- 118	- 72	- 4.0	- 2.5	46	1.6	-	- 0.9	- 0.6
Other	228	224	7.8	7.6	- 4	- 0.1	- 1.8	1.8	1.9
Total	**12,805**	**11,784**	**436.9**	**402.1**	**- 1,021**	**- 34.8**	**- 8.0**	**100.0**	**100.0**

Table 5. Primary energy consumption in Germany in 2019 and 2020
Source: AG Energiebilanzen e.V. (2021): Energy Consumption in Germany in 2020, https://ag-energiebilanzen.de/wp-content/uploads/2022/06/AGEB_Jahresbericht2020_20220613_engl_Web.pdf last accessed 13.02.2023. Reproduced with permission.

The contributions of the diverse energy sources to the national energy mix shifted slightly in favour of renewables as well as natural gas in 2020 while total consumption volume turned out to be significantly smaller than it was in 2019.

Hard coal and lignite experienced further declines. Despite its slightly reduced share, mineral oil continued to be the most important energy source by far. A characteristic feature of the German energy supply continues to be its broad energy mix.

The level of energy consumption and its composition (energy mix) are also influenced by political and regulatory aspects. Significant for the medium-term to long-term development are, for example, the gradual phasing out from nuclear energy until the end of 2022, the scheduled exit from coal-fired power generation (by the end of 2038) as well as the continued undertaken promotion of renewable energy expansion.

Primary energy production in Germany

Renewable energy carriers managed to significantly expand their position as the most important indigenous energy source ahead of lignite; their proportion in total domestic production now amounted to well above 57.7%, followed by lignite, which accounted for approximately 28.6% of domestic energy production. Both energy carriers continued to rank far ahead of natural gas and petroleum.

In 2020, taking primary energy consumption into account, the proportion of domestic production increased, namely from 27.5% in 2019 to now about 29.1% (see *Table 6*). This development was due to the fact that the COVID-19 pandemic caused primary energy consumption to decrease by 8% in 2020 – a much more significant decline than was recorded for the domestic production of primary energy carriers.

AGEB
AG Energiebilanzen e.V.

Primary Energy Production in Germany in 2019 and 2020

	Production				Changes in 2020 Compared to 2019		Proportions	
	2019	2020	2019	2020			2019	2020
	Petajoules (PJ)		Million Tons of Coal Equivalents (Mtce)		PJ	%	%	
Mineral Oil	82	81	2.8	2.8	- 1	- 0.5	2.3	2.4
Natural Gas, Petroleum Gas	194	164	6.6	5.6	- 30	- 15.5	5.4	4.8
Hard Coal	0	0	0.0	0.0	0	0.0	0.0	0.0
Lignite	1,190	979	40.6	33.4	- 211	- 17.7	32.9	28.5
Renewable Energy	1,920	1,977	65.5	67.5	57	3.0	53.2	57.7
Other Energy Carriers	226	224	7.7	7.6	- 2	- 0.9	6.3	6.5
Total	**3,612**	**3,425**	**123.2**	**116.9**	**- 187**	**- 5.2**	**100.0**	**100.0**
For information purposes: Proportion of Primary Energy Consumption	-	-	-	-	-	-	27.5	29.1

Table 6. Primary energy production in Germany in 2019 and 2020
Source: AG Energiebilanzen e.V. (2021): Energy Consumption in Germany in 2020, https://ag-energiebilanzen.de/wp-content/uploads/2022/06/AGEB_Jahresbericht2020_20220613_engl_Web.pdf last accessed 13.02.2023. Reproduced with permission.

Dependence on energy imports

Germany is a considerable net importer of virtually all fossil fuels (i. e. hard coals, mineral oil, and natural gas). In 2019, domestic primary energy consumption was covered by imports which amounted to 98% for mineral oil and 94% for natural gas. 100% of hard coals were sourced from imports. In contrast, 100% of lignite had been made available from indigenous resources, and renewables also came almost entirely from domestic production. All told, nearly 72% of the German energy supply was dependent on imports in 2019. This situation remained basically unchanged in 2020: Germany's dependence on imports was estimated to still amount to more than 71% then.

KOREA

Table of Contents

1. National energy profile 2019

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	754.8	101.7	13.5
1995	1 217.5	175.0	14.4
2000	1 478.2	277.7	18.8
2005	1 633.5	373.8	22.9
2010	1 833.9	481.5	26.5
2015	2 014.5	534.7	26.5
2019	2 115.8	562.5	26.6

Table 1. Energy and electricity consumption
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

Energy consumption increased about 1.8 times in the last 30 years, and electricity consumption increased about 4.5 times. Therefore, the ratio of electric energy consumption to total energy consumption has doubled from 13.5% in 1990 to 26.6% in 2019. This is a significant increase in energy use, and even more so in electricity, considering that the population has increased by only 20%.

Per capita yearly final energy and electricity consumptions (MWh)

Year	MWh/year	MWh
1990	17.6	2.4
1995	26.9	3.9
2000	31.2	5.9
2005	33.5	7.7
2010	37.0	9.7
2015	39.7	10.5
2019	41.3	11.0

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=KR

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 Emissions per capita
1990	231.8	60.7	5.4
1995	357.3	90.1	7.9
2000	431.9	172.6	9.2
2005	457.7	206.8	9.5
2010	550.9	195.3	11.1
2015	582.1	155.3	11.4
2019	585.7	141.3	11.3

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=KR

Total CO_2 emissions from energy production and consumption also more than doubled during this period. In the case of carbon dioxide emissions from fossil energy sources, it was mainly the use of coal that produced the increases. In addition, CO_2 emissions from the electricity and heat production sector accounted for the most significant proportion, which can be related to the increase in electricity consumption. Total CO_2 emissions from all the sectors in Korea peaked at 727.6 $MtCO_2$ in 2018, and Korea submitted the NDC target of 40% reduction from the peak amount at the COP26 meeting in Glasgow in 2021.

CO_2 emissions by fossil energy source ($MtCO_2$)

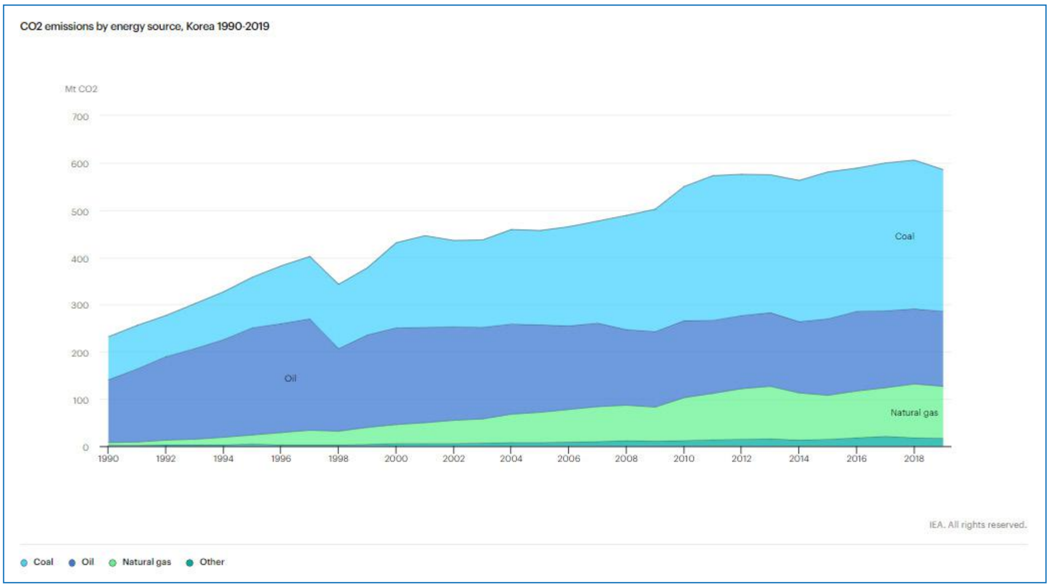

Fig. 1. CO_2 emissions by fossil energy source, **IEA**
https://www.iea.org/countries/korea

CO_2 emissions by sector ($MtCO_2$)

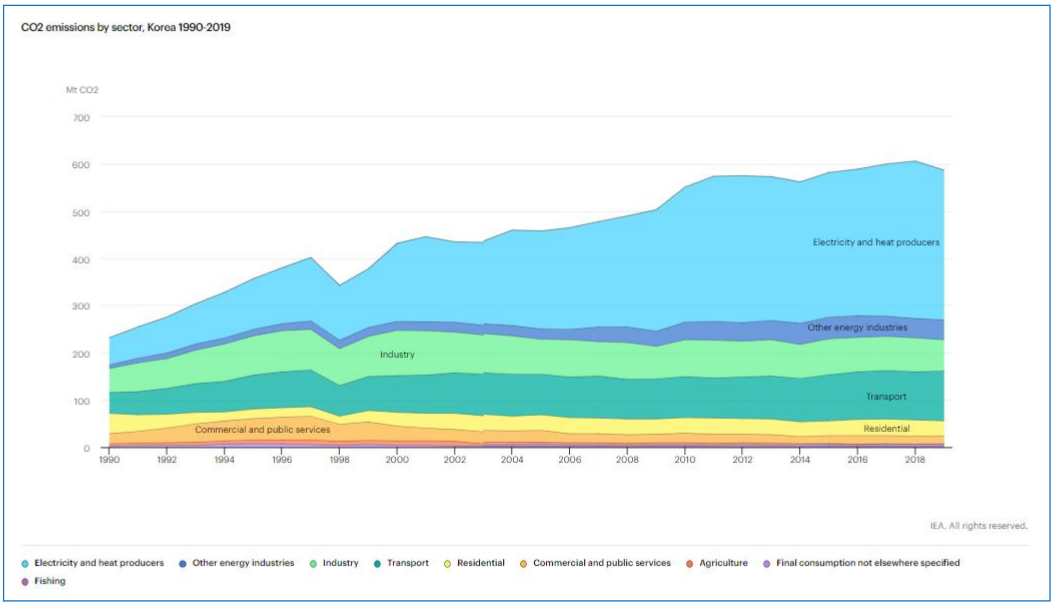

Fig. 2. CO_2 emissions by sector, **IEA**
https://www.iea.org/countries/korea

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 kilowatt hours)

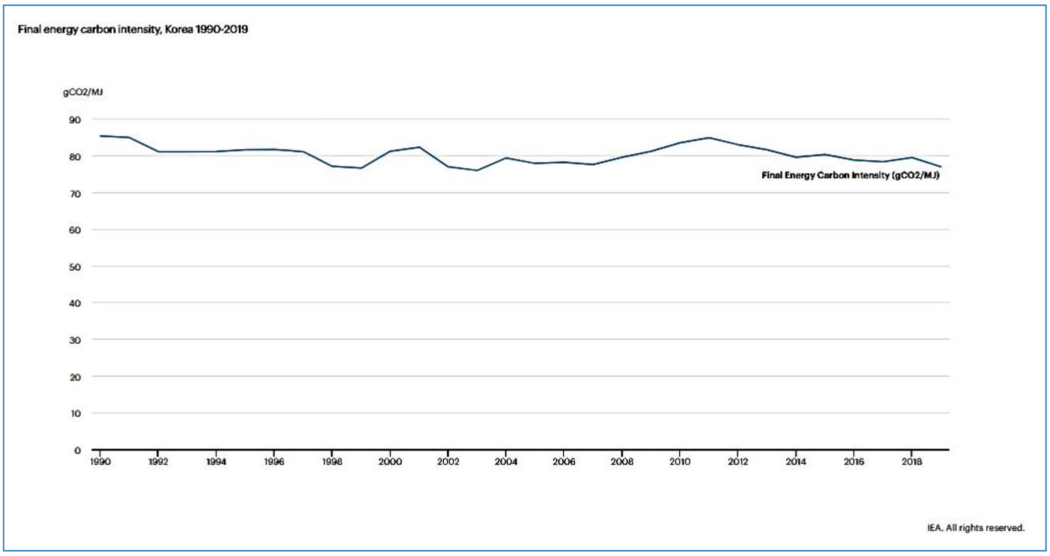

Fig. 3. Final energy carbon intensity, **IEA**
https://www.iea.org/countries/korea

Electricity Carbon intensity: gCO_2/kWh

The CO_2 content of electricity in 2019 was 515 gCO_2/kWh with a large use of coal (IEA Emissions factors)

2. Energy perspectives 2030 - 2050

If possible, give the national perspectives for 2030 and 2050 or the roadmap to 2030 and 2050 if they exist.

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

In October 2021, The Presidential Committee on Carbon Neutrality announced the '2050 Carbon Neutrality Scenario', consisting of two roadmaps for the net-zero emission goal by 2050.

The first scenario aims to shut down all electric power plants using coal and LNG for achieving net-zero emissions in the power sector. The second road map also aims to cease coal power generation but keep LNG as a flexible power source. In this case, the plan seeks to boost carbon capture, utilization, and storage (CCUS) and direct air capture (DAC) capabilities.

As part of its broader aim to realize carbon neutrality by 2050, the Korean Government recently suggested the 2030 NDC (Nationally Determined Contribution) target with the reduction in greenhouse gas emissions by 40 per cent against the national maximum output level in 2018. It was officially introduced to the international community at the 26th United Nations Climate Change Conference (COP26) in November 2021, and this governmental plan will be submitted to the UN in December 2021 accordingly. Prior to determining the NDC, the Korean parliament passed the Basic Carbon-neutral Act in October 2021 and set the emission reduction target to be at a minimum 35% or more.

Roadmap for the energy mix

Fig. 4. Energy Mix (Mtoe)

*RE includes solar thermal, geothermal, hydrothermal, and biomass, while solar PV and wind energy for power generation are included in the Power section.

Source: Korea 2050 Carbon-Neutral Scenario and 2030 NDC, October 18, 2021, Republic of Korea, Open Source
https://drive.google.com/file/d/11YQ5lrgAmaCLXS9Q7dwTIV5vLA9wZ3d1L/view?ts=641280f2

By 2050, the use of coal, oil, and LNG, which emit GHG, is anticipated to decrease significantly, whereas the demand for power and renewable energy as well as hydrogen is expected to increase considerably.

Roadmap for the GHG emissions (country, total)

According to the national roadmap, GHG emissions in 2030 will be reduced by 40% compared to that in 2018, and net-zero GHG emissions will be accomplished by 2050. In order to meet these targets, expanding the use of renewable power, green hydrogen, and electric vehicles will not be enough and the field application of various technologies to capture and store carbon dioxide (e.g. CCUS, DAC) will be needed. The CO_2 reduction and carbon sink outside Korea such as forests and the oceans should also be much enhanced, while avoiding further ocean acidification.

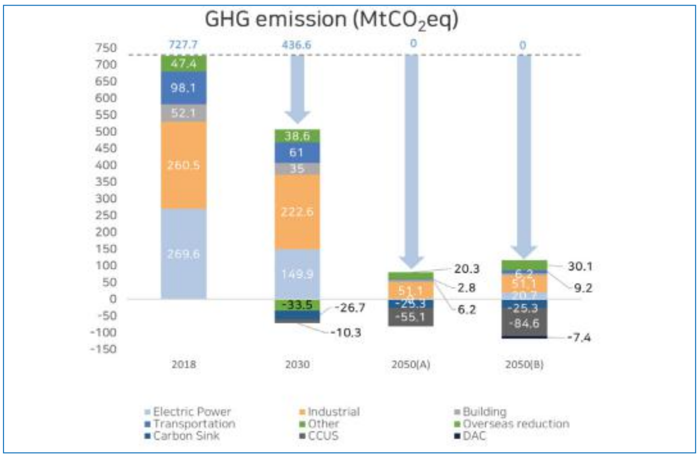

Fig. 5. GHG Emissions ($MtCO_{2eq}$)

Source of data: Korea 2050 Carbon-Neutral Scenario and 2030 NDC, October 18, 2021, Republic of Korea. Open Source
https://2050cnc.go.kr/eng/contents/view?contentsNo=43&menuLevel=2&menuNo=50
and: https://2050cnc.go.kr/eng/contents/view?contentsNo=42&menuLevel=2&menuNo=49

	Electric power	Industrial	Building	Transpor-tation	Other*	Overseas reduction	Carbon Sink	CCUS	DAC	Net Total ($MtCO_{2e}$)
2018	269.6	260.5	52.1	98.1	47.4					727.7
2030	149.9	222.6	35.0	61.0	38.6	-33.5	-26.7	-10.3		436.6
2050(A)	0.0	51.1	6.2	2.8	20.3	0.0	-25.3	-55.1		0.0
2050(B)	20.7	51.1	6.2	9.2	30.1	0.0	-25.3	-84.6	-7.4	0.0

Table 4. GHG reduction from 2018 to 2050 (Roadmap)

*Other includes waste, farming (agriculture, livestock farming and fisheries), and hydrogen.

Source of data: Korea 2050 Carbon-Neutral Scenario and 2030 NDC, October 18, 2021, Republic of Korea. Open Source

Roadmap for the electricity mix

To achieve carbon neutrality, renewable energy that does not emit GHG —solar and wind power in particular — should be the main source of energy. Under this scenario, energy use in industrial, transport, cooling and heating sectors should be electrified as much as possible. Therefore, it is assumed that electricity demand in 2050 will be more than double the amount of electricity consumption in 2018.

Electricity generated from fossil fuels such as coal and LNG must be minimized or zero. Until 2030, coal power plants will be gradually shut down, and renewable electricity will be substantially expanded. In addition, carbon-free fuels such as ammonia will be newly introduced to the electricity mix. It is assumed that coal power plants will be completely shut down before 2050 regardless of which of the two scenario plans in 1.2.2. is chosen. LNG will be completely stopped under the plan A, or will remain as a flexible power source under the plan B. As an alternative to coal and LNG, renewable energy, such as solar and wind power, is expected to hold the highest proportion in the power mix by 2050, where in plan A it is expected to increase to 70.8% and in plan B to 60.9%.

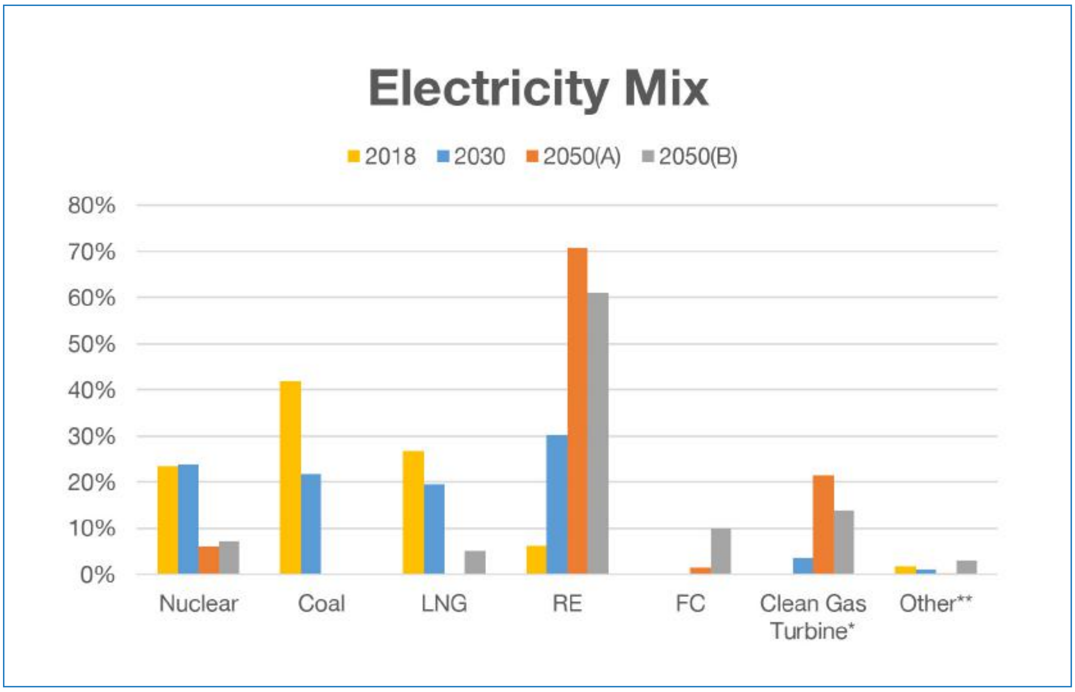

Fig. 6. Electricity Mix 2018 to 2050
Source of data: Korea 2050 Carbon-Neutral Scenario ad 2030 NDC, October 18, 2021, Republic of Korea. Open Source

		Nuclear	Coal	LNG	RE	FC	Clean Gas Turbine*	Other**	Total (TWh)%
2018		133.5	239.0	152.9	35.6			9.6	570.7
2030		23.4%	41.9%	26.8%	6.2%			1.7%	100.0%
		146.4	133.2	119.5	185.2		22.1	6.0	612.4
		23.9%	21.8%	19.5%	30.2%		3.6%	1.0	100.0%
2050	A	76.9	0.0	0.0	889.8	17.1	270.0	3.9	1 257.7
		6.1%	0.0	0.0	70.7%	1.4%	21.5%	0.3%	100.0%
	B	86.9	0.0	61.0	736.0	121.4	166.5	37.0	1 208.8
		7.2%	0.0	5.0%	60.9%	10.0%	13.8%	3.0%	100.0%

Table 5. Roadmap to 2050 for electricity production with in scenario A no coal and LNG based power generation and in scenario B keeping some power generation running on LNG
*Power generation by clean fuel including ammonia.
**Others include electricity supplied from pumped-hydro power generation (2030), north-east Asia super grid, and blast furnace gas (2050).
Source of data: Korea 2050 Carbon-Neutral Scenario ad 2030 NDC, October 18, 2021, Republic of Korea. Open Source

CO_2 emissions from electricity production

Depending on the electricity mix, GHG emissions from coal and LNG will still exist by 2030, but by 2050, such emissions will totally disappear (plan A) or continue in only very small amounts (plan B) by 2050.

Energy balance (energy sources to end-uses)

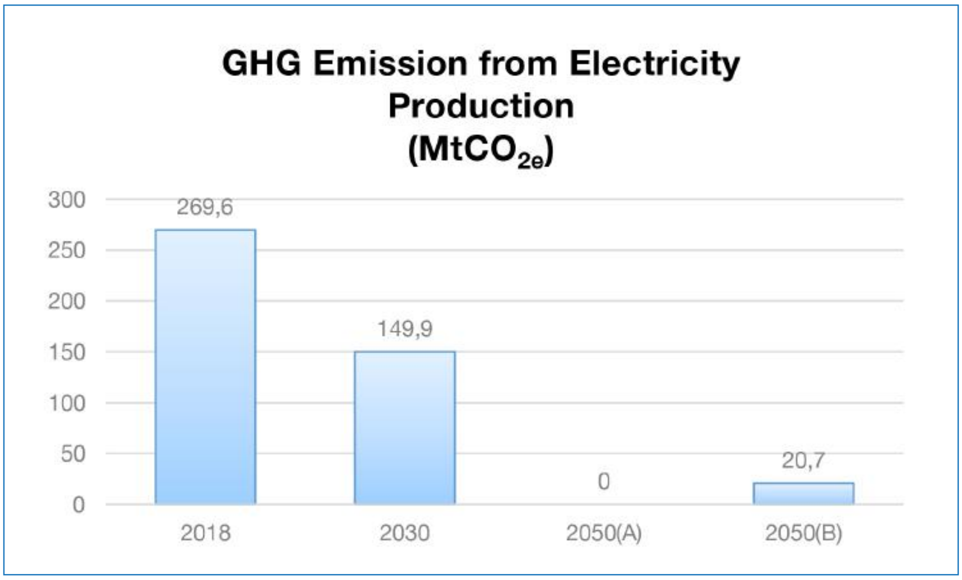

Fig. 7. GHG Emissions from Electricity Generation

Source of data: Korea 2050 Carbon-Neutral Scenario ad 2030 NDC, October 18, 2021, Republic of Korea. Open Source

By 2050, energy demand is anticipated to decrease by 5.0% compared to 2018. While on the one hand energy demand is expected to decrease mainly in buildings and transportation, on the other hand, it is expected to increase in the use of new technologies such as CCUS and hydrogen.

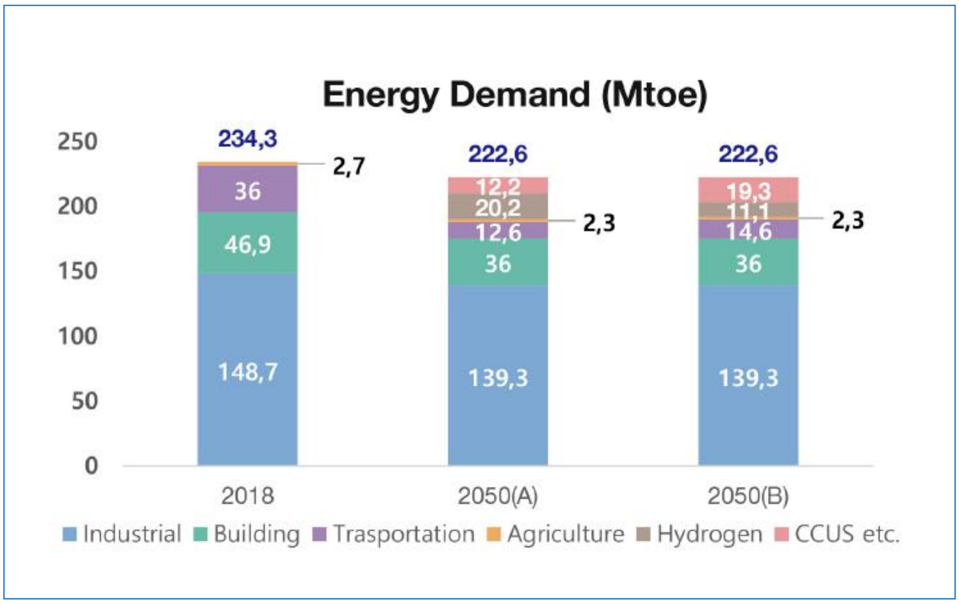

Fig. 8. Energy demand by sector in 2018 and 2050, including hydrogen production and CCUS
(1 Mtoe = 11.63 TWh, eg. 234.3 Mtoe = 2720 TWh)

Source of data: Korea 2050 Carbon-Neutral Scenario ad 2030 NDC, October 18, 2021, Republic of Korea. Open Source
https://drive.google.com/file/d/11YQ5lrgAmaCLX9Q7dwTIV5vLA9wZ3d1L/view?ts=641280f2

3. Building sector

3.1. Existing buildings

Energy balance 2019 (energy sources to end-uses)

The building sector consumes most energy in the form of electricity (45%), followed by city gas (31%). More than 80% of the energy used in the building sector is supplied by fossil fuels.

Sector/ Energy	Coal	Petroleum	LNG	City Gas	Hydro	Nuclear	Electricity	Heat	Renew-ables & Others1*	Total
	1 000 toe									
Residential	306	3 051	-	10 479	-	-	6 059	2 277	447	22 619
Commercial	-	1 773	-	3 630	-	-	11 628	306	132	17 469
Public	-	1 276	-	78	-	-	2 766	63	1 205	5 388
Total	306	6 100	-	14 187	-	-	20 453	2 646	1 784	45 476

Table 6. Energy consumption of residential, commercial, and public buildings
**Source:* Energy Statistics of 2020 published for 2019 consumption (unit 1 000 toe), Electricity 20 453 toe = 238 TWh, Open Source.

Energy partition between single houses, apartment buildings and office buildings

Apartment buildings account for the highest proportion of households in Korea, consuming about 49% of energy, while single houses consume about 35% of energy.

Residential Buildings						
Residential Total	Detached dwelling	Apartment	Row house	Apartment unit in a private house	House within Commercial Building	Commercial Building and Public
unit: 1 000 toe						
20 780	7 354	10 125	1 435	1 645	221	19 828

Table 7. Energy consumption by category of residential buildings, and commercial and public buildings
**Source:* Energy Consumption Survey of 2017 published for 2016 consumption that is the latest official statistics. 2021 Survey is not yet published.

Which systems are mostly used for heating?

For residential heating, city gas accounts for the highest proportion, followed by district heating. Commercial buildings have the highest percentage of electric heating mainly due to the use of electric heat pumps (EHP), followed by city gas heating.

Heating System and Energy Source for Heating		Residential*		Commercial and Public	
		Total Household Energy Consumption by Heating System Type		Heating and Hot Water	
		Tcal	%	Tcal	%
District Heating (Hot Water)		28 984	13.9	2 127	3.6
Boiler	City Gas	137 103	66.0	18 076	30.4
	Oil	24 253	11.6	4 720	7.9
	LPG	3 675	1.8	2 345	3.9
	Briquette	4 960	2.4	1 328	2.2
	Midnight Electricity	6 556	3.1	-	-
Heating by Electricity		600	0.3	30 238	50.9
Renewables and Others		1 667	0.8	615	1.0
Total		207 798	100.0	59 449	100.0

Table 8. Types of Energy consumption in Residential, commercial and public buildings (1 Tcal = 1.163 GWh)
Source: Table was prepared by Seung-eon Lee (one of the authors listed at the end of this Korean Submission).
* Estimated percentage from total household energy consumption by heating system type using Energy Consumption Survey of 2017 that is the latest official statistics (2021 survey is not yet published).

Which systems are mostly used for cooling? (local systems, cooling networks…)

The share of energy use for cooling in commercial buildings is 24%, and 87% of cooling is done by electric cooling. The share of energy use for cooling in residential houses is however very low. The major reason for this is that the household electricity bill is calculated based on the progressive pricing system. The household electricity progressive rating system has a great impact on reducing electricity consumption in residential houses.

Cooling System and Energy Source for Cooling		Residential*	Commercial and Public Building	
			Cooling Energy Consumption	
			Tcal	%
District Cooling		-	252	0.5
Absorption Chiller	City Gas		5 911	12.2
	LPG		40	0.1
Cooling by Electricity			42 207	87.2
Renewables and Others			3	0.006
Total			48 413	100.0

Table 9. Energy consumption in Residential, commercial and public buildings (1 Tcal = 1.163 GWh)
*There are no official statistical data on residential energy use for cooling. Air-conditioning in a household uses primarily electricity. Energy use for cooling is estimated to account for about 10% of residential heating energy consumption.
Source: Table was prepared by Seung-eon Lee (one of the authors listed at the end of this Korean Submission).

What are the main choices of the national policy – if there is one – to reduce the emissions from the existing stock of buildings? To make this reduction affordable?

From a technological point of view? (Insulation, heat pumps, low CO_2 district network, geothermal systems, local PV production, etc.).

Insulation (especially for windows) for a short-term strategy, heat pumps with green electricity (including local PV production) for a long-term strategy

From a regulatory point of view? Through land ownership regulations?

From 2020, zero-energy buildings became compulsory for all new public buildings, and private new buildings will also become zero-energy compulsory from 2025 onwards. There are some subsidy support systems for existing buildings but currently with no compulsory regulations. In the future, however, it is expected that policies based on the regulatory framework will be inevitable even for existing buildings. A green remodelling mandate for public buildings is being prepared.

Through subsidies, different financial mechanisms? Which are the priorities: reducing CO_2 or energy; better inclusivity.

Although some energy efficiency remodelling of existing buildings is being implemented with the aid of the national budget, a market-based carbon reduction mechanism in which all buildings participate is required for the carbon neutrality in the future. So far, mainly energy-based subsidies have been provided, but it is expected that CO_2-based subsidies will also be introduced in the near future.

Replacing parts of the existing stock of buildings?

Up to 30% of new construction is indeed reconstruction or redevelopment, thus some of the existing stock of buildings is already being automatically improved. However, as carbon neutrality requires renovation of all the stocks of buildings in Korea, a new strategy is required.

Is there a specific roadmap for this subject?

According to the 2050 Carbon-neutral Scenario of Korea, due to improved energy efficiency in buildings and the supply of highly efficient equipment, energy demand in the building sector will decrease by 23% compared to that in 2018, As a result, fossil fuel consumption would be reduced from 47% in 2018 to 8% in 2050, and electricity and renewables would cover more than 84% of the total energy demand in 2050. Under these premises, the annual GHG emissions from the building sector in 2050 are expected to be reduced by 88.1% compared to that in 2018. To this end, it is necessary to improve the energy intensities for cooling and heating by more than 30% by 2050 compared to those in 2018. This will be realised through 100% implementation of net-zero energy for newly constructed buildings and green remodelling for existing buildings. Furthermore, scaling up the deployment of highly efficient home/office appliances and lighting equipment and smart energy management systems for the building sector through HEMS and BEMS are expected to become effective mitigation strategies.

Is there some roadmap for making existing cities more sustainable?
Various urban regeneration projects are being implemented. However, a roadmap for decarbonizing the city's energy system or at least into a more sustainable system has not yet been established.

Are there some case studies or best practices you would like to share?
Korea has a national data platform that tracks the energy consumption of all the buildings nationwide on a monthly basis. This system was developed based on the billing information of the energy supplier. In the future, this platform will be used to support and manage the carbon neutrality of individual buildings in Korea.

3.2. New buildings

Does your country have a national policy regarding new buildings?
If yes, what are the priorities? (For housing and for office buildings)
Since the implementation of insulation standards in 1978, Korea developed an energy-efficient design standard that is applied to new buildings (except private housing/homes) for all uses and has been continuously strengthened. By 2025, the net-zero-energy building standard will become mandatory for new buildings/ homes in the private sector as well. In the case of a residential house, the efficiency of energy for heating is emphasized, while for office buildings, efficiency improvement in air conditioning and lighting is relatively more important. Regarding the energy design standards for buildings, different weights on different energy-saving items are set for each destination/use of a building.

Are some technologies prioritised, in particular for heating and cooling?
At the building level? At the infrastructure level?
(Development of district networks, prohibiting connection to the gas network)
From a building perspective, it is most important that insulation and airtightness are well designed and constructed. For future new buildings, it will be more important to improve the acceptability of renewable energy systems than to install such systems right away. From an energy supply point of view in the building sector, electricity use was curbed, and priority was given to gas and local heat sources. However, in order to meet carbon neutrality, all fossil fuels must be phased out and replaced by green electricity.

How are they supported? Through regulations? Subsidies?
Early legislation was implemented based on obligatory measures. Incentives were provided to induce buildings to improve their performance beyond the statutory level. A characteristic of Korea's incentive measures is that it uses a method of easing legal regulations, such as raising the floor area ratio (FAR), rather than direct support through subsidies.

Are there some recommendations and regulations for sustainable districts and cities?

Are there some case studies or best practices you would like to share?
As mentioned in the previous question, it is suggested to use non-financial incentives. And in the process of continuous regulatory upgrade, it is important to maintain close communication with the building-related industry.

4. Industry

Please choose three or four industries that are important for your country in the following list:

- Steel industry (including mining),
- Cement industry,
- Chemical industry (Petro-chemistry),

For each of these industries:

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

Steel, Petro-chemistry and Cement are placed as top 3 carbon emission industries in Korea, and their emission accounts for ~70% of total industry sector's emission in Korea. They are not only energy intensive but also their main inputs contain carbon. Thus, it is a huge challenge to reduce carbon emissions from these sectors.

Steel: In 2018, Steel industry emitted 101.2 million metric tons of CO_2, of which 95.3 million tons are direct emissions and 5.9 million tons are process emissions. 29 906 thousand toe energy were used in steel production. Coal is the main energy source with 25 182 thousand toe, which is used as a reducing agent to remove oxygen from the iron ores. The steel industry's GHG emission intensity is 4 909 tons CO_2 per billion KRW value-added production.

Petro-chemistry: The total amount of Petro-chemistry's CO_2 emissions and energy use was 47 million tons and 56 385 thousand toe, respectively in 2008. 98% of their emissions came from direct emissions; using petroleum-based naphtha as a main input and fossil fuel for making about 800 °C heat in NCC (Naphtha Cracking Center). For this reason, their energy consumption is concentrated on oil. Carbon intensity of petro-chemistry is 1 377 ton per billion Korean Won (KRW) value-added production.

Cement: 34.1 million tons of CO_2 is emitted from the Cement industry. About 1400 °C of heat is needed to remove carbon from limestones, and in that process, CO_2 is emitted. Moreover, the heat is beeing supplied by burning huge amounts of bitumi-nous coal. This is why the cement industry has both large direct and process emission levels.

1 000 toe	Steel	Petro-chemistry	Cement
Coal	25 182	219	2 196
Oil	68	46 582	138
LNG	1 659	4 226	151
Electricity	2 997	5 359	582
Total	29 906	56 385	3 067

Table 10. Energy Usage of the Top 3 GHG Emission Industries in Korea
Source: Table was prepared by Seung-eon Lee (one of the authors listed at the end of this Korean Submission).

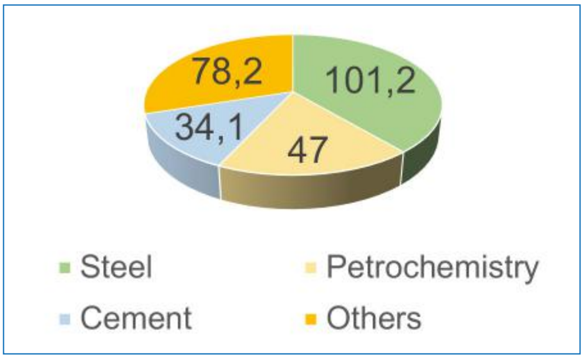

Fig. 9. GHG Emissions of the industrial sector as a whole and the share due to Steel, Cement, and the Petrochemical Industry
Source: Table was prepared by Seung-eon Lee (one of the authors listed at the end of this Korean Submission).

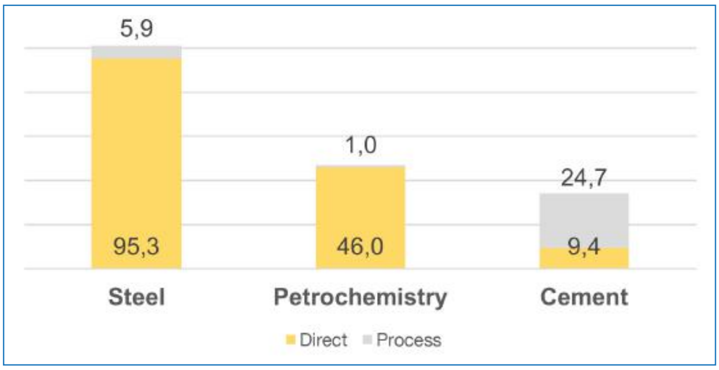

Fig. 10. GHG Emissions of Steel, Petrochemistry and Cement in 2018 (million tons CO_{2e})
Source: Table was prepared by Seung-eon Lee (one of the authors listed at the end of this Korean Submission).

	Steel	Petro-chemistry	Cement
GHG Intensity (ton/billion KRW value-added)	4 909	1 377	25 658

Table 11. Energy Usage of Top 3 GHG Emission Industries in 2018
Source: Table was prepared by Seung-eon Lee (one of the authors listed at the end of this Korean Submission).
2015 price-based real value-added production

Are the best available low carbon technologies used/considered?
If not, is it an economic problem? A matter of regulation? Or some social issues?

Steel: Despite many current technical obstacles, hydrogen-reduction-based steel making is considered as the best method to obtain the most eco-friendly steel making. Since the major emission source comes from using carbon-based reduction processes, the key is to find an alternative technology with noncarbon-related reduction, and hydrogen is in the spotlight as one of the best alternatives. Thus, global steel manufacturing companies are putting their resources into developing this alternative steel-making technology. Korea's steel industry is also making every effort to develop and commercialize the technology and aims to achieve net-zero direct emissions by 2050.

Petro-chemistry: Substituting petroleum-based naphtha with bio-based material is the first major approach for emission reduction while replacing fossil-oil based Naphtha Cracking Centers (NCC) with electric-powered facilities is another major one. The petrochemical industry is characterized by using crude oil as both its main fuel and raw material. Hence, it is indispensable in a net-zero world to decrease CO_2 emissions by introducing non-carbon input. Korea's petrochemical industry has a plan that by 2050, over half of the total amount of traditional naphtha will be replaced with bio-based raw materials, and electric furnaces will be introduced to minimize carbon emissions.

Cement: For reducing CO_2 emissions, changing the main heat source and increasing the use of non-carbonate materials are key for the cement industry. Korea's cement industry is trying to replace coal with combustible wastes, and its share in total heat sources will be minimised until 2050. The remaining part of the heat sources will also be entirely replaced with eco-friendly sources such as biomass and hydrogen. In addition, the use of limestone is going to be minimised until 2050 by expanding the share of non-carbonate materials like slag and ash.

Is there a roadmap to decrease GHG emissions for 2030 - 2050
If yes, what are the intermediary steps?

According to 2030 NDC and 2050 Carbon-neutral Scenario of the Korean government, the annual GHG emission of the industry sector in 2030 and 2050 is planned to be reduced by 14.5% and 80.4%, respectively compared to those in 2018. According to these plans, the steel industry will reduce its emission by 2.3% by 2030 and 95% by 2050. The petrochemical industry's reduction rates of annual greenhouse gas emissions in 2030 and 2050 are 20.2% and 73% compared to those in 2018. Finally, the cement industry has targeted to lower its emissions by 12% in 2030 and 53% in 2050.

Fig. 11. GHG Emission Reduction Roadmap of the Industry Section (Million ton CO_{2e})
Source of data: Korea 2050 Carbon-Neutral Scenario and 2030 NDC, October 18, 2021, Republic of Korea. Open Source

Is the implementation of low-carbon technologies helped by the government? For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

The Korean government allocated 11.9 trillion Korean Won (KRW) in 2022 as a budget for supporting the carbon-neutral transition. This budget includes support for the development and distribution of innovative carbon emission reduction technologies such as hydrogen-reduction-based steel making. Furthermore, the government expresses its intention to support the entire R&D streams from basic research to the establishment of pilot facilities in the long run. Recently, the Korean government legislated the 2030 NDC goal which targets 40% reduction of the annual GHG emission level compared to that in 2018. However, there are not sufficient measures or incentives to force companies to bear the cost of emission reduction. Instead, Korea's 2030 NDC is regarded as a benchmark, and the Korean government is trying to establish diverse incentive-based policies and financial support measures for companies to voluntarily participate in the net-zero transitions.

Are there incentives for carbon capture, utilization, and storage? How?

CCUS is not regarded as the main method of reducing emissions from the industry sector. Instead, the industry sector and CCUS were dealt with separately when the GHG emission reduction strategy of Korea was established. It was a prior premise to minimize the burden of CCUS by maximizing direct and process emission reduction levels of the industry. The Korean government is currently preparing support schemes to foster the CCUS service market in the near future.

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

The Korean government recently announced ten tasks for achieving a Carbon-neutral society, which comprise the promotion of a circular economy. The "K-Circular Economy Innovation Roadmap" is going to be released before the end of 2021. It includes detailed plans for maximizing recycling and minimizing wastes, henceforth reducing GHG emissions from new product manufacturing. In addition, the 2050 Carbon-neutral Scenario for Korea includes the petrochemical industry going to pyrolyze 50% of all waste plastics in Korea and recycle them as plastic raw materials. Also, 60% of bituminous coal used by cement industry will be replaced by synthetic waste resins in 2050.

Author Acknowledgements

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MEXICO

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1. National energy profile 2020

Mexico is a country with 126 014 024 inhabitants, energy production of 1 347 TWh and electricity production of 307.5 TWh. It had an average GHG emission of 381 Mt CO_2 equivalent in 2020. An overview of energy production by source of generation can be seen in the following graphs *Fig. 1.* and *Fig. 2.*

Mexico energy supply

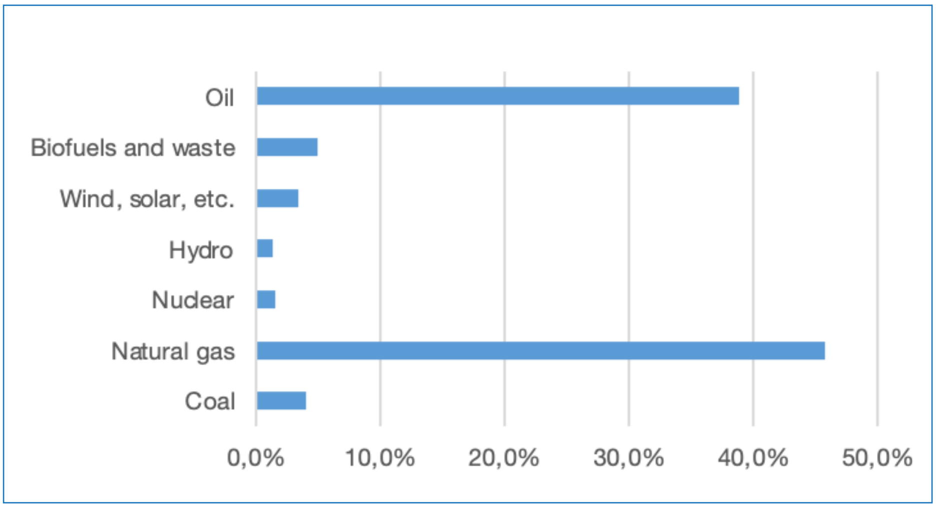

Fig. 1. Mexico energy supply by source 2020. **IEA**, World Energy Balances:
https://www.iea.org/data-and-statistics/data-product/world-energy-balances
https://iea.blob.core.windows.net/assets/20a89a1b-634c-41f1-87d1-d218f07769fb/WORLDBAL_Documentation.pdf

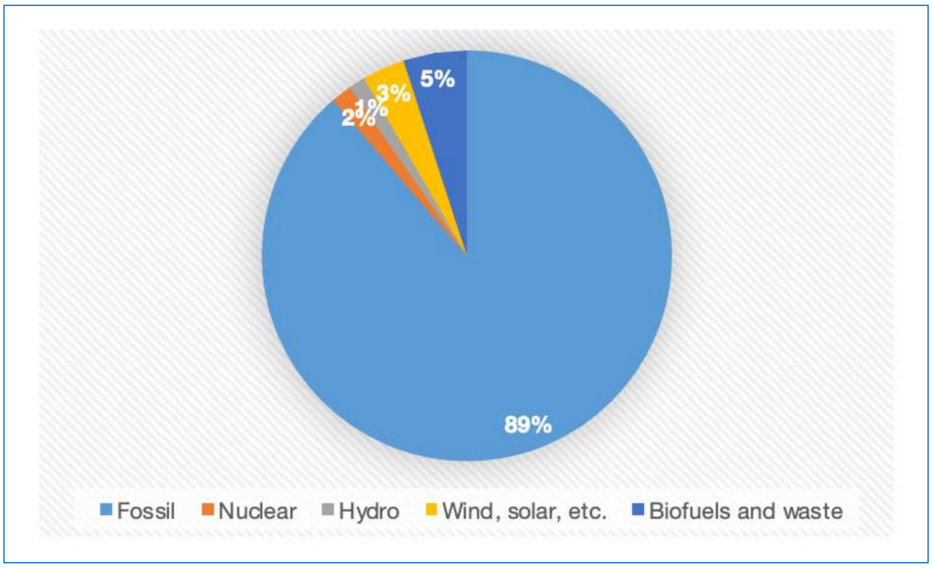

Fig. 2. Fossil energy supply in Mexico 2020, data from **IEA**

Fig. 1. and *Fig. 2.* show that energy supply in Mexico is fundamentally based on fossil fuels (87% to 89% – natural gas, oil and coal).

Fig. 3. below displays the evolution of the share of the various sources in the energy supply from 1990 to 2020.

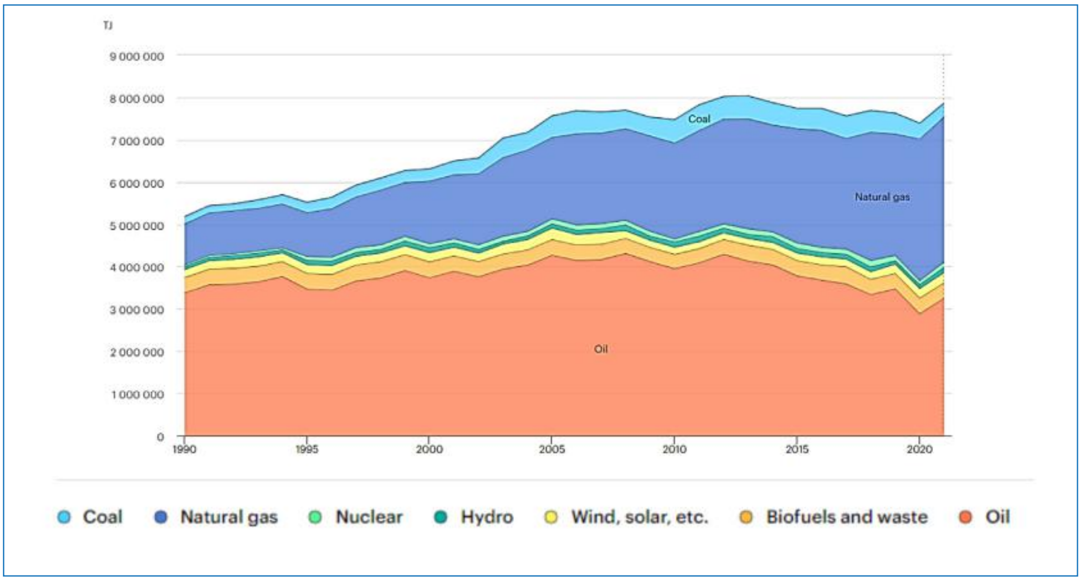

Fig. 3. Mexico energy supply by source 1990-2020, in TJ (1 MTJ = 278 TWh, **IEA**
https://www.iea.org/countries/mexico

In 1990, energy supply depended mostly on oil; towards 2020, the use of natural gas was growing faster than oil. From 2004 to 2020, all sources together never produced more than 8 million TJ and, in the last 5 years, total supply decreased. It is important to mention that, while coal always remained a minor energy source, clean energies (wind, solar, biofuels and waste) also stagnated at a low level without growth in 30 years, unlike what happened in other countries such as France and Germany. It is also worth mentioning that other low-carbon energies are represented by hydraulics and nuclear.

Mexico yearly consumption

Table 1. below shows electricity consumption growing at a fast rate, more than tripling, between 1990 and 2020, while total energy consumption grew by only 39%. This is reflected in the ratio of electricity to total energy consumption increasing from 9.8% in 1990 to 22.8% in 2020.

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	969	95.5	9.8
1995	1 012	130.2	12.9
2000	1 108	178.1	16.1
2005	1 233	211.7	17.1
2010	1 364	230.3	16.9
2015	1 394	269.6	19.3
2019	1 346	305.0	22.7
2020	1 347	307.5	22.8

Table 1. Mexico yearly consumption: final energy, electricity (TWh)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

However, during that period of 30 years, population grew by 55.2%, from 81.2 million to 126 million. The next graph indeed presents data from INEGI, the Mexican Institute of Statistics and Geography (*Instituto Nacional de Estadística y Geografía*), on population growth from 1910 to 2020.

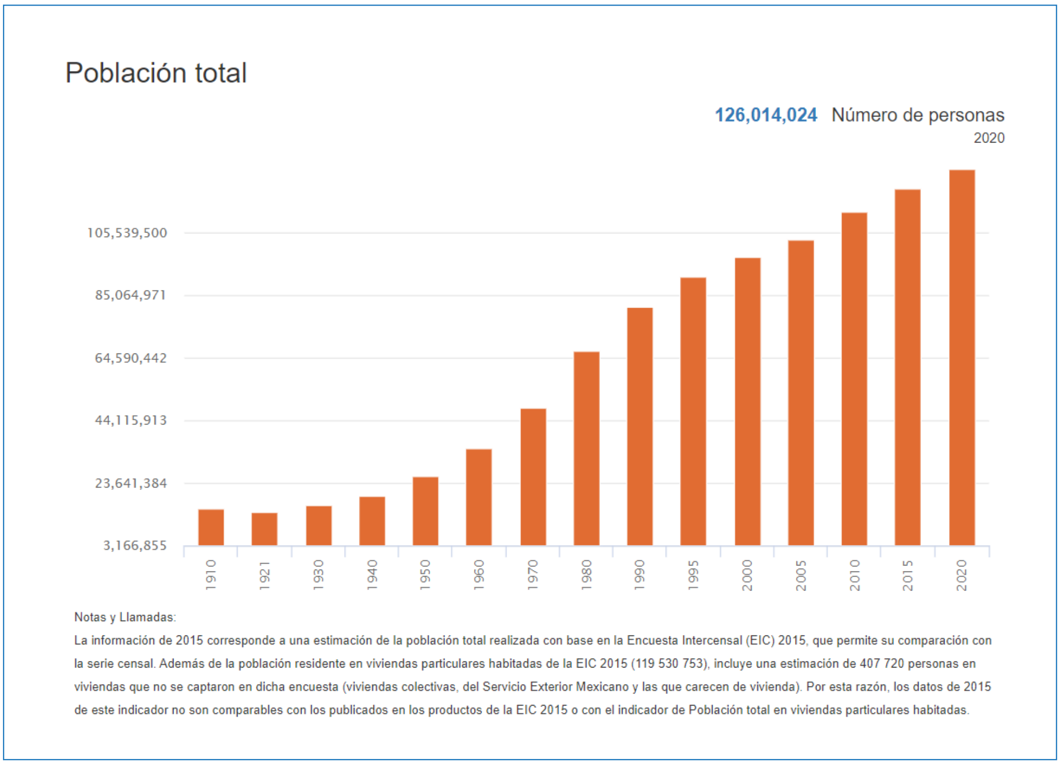

Fig. 4. Mexico Yearly population growth 1910 to 2020 by INEGI
(for copyright information regarding Mexico, see "General Note" at the end of this Mexican submission)

Such increase in population leads us to consider per capita consumption, (energy and electricity consumption in the period 1990-2020).

Year	Inhabitants (millions)[1]	Energy consumption (TWh)	Energy consumption per person and per year (MWh/capita)	Electricity consumption (TWh)	Electricity consumption per person and per year (MWh/capita)
1990	81.2	969	11.9	95.5	1.17
1995	91.2	1 012	11.0	130.2	1.43
2000	97.5	1 108	11.4	178.1	1.83
2005	103.3	1 233	11.9	211.7	2.05
2010	112.3	1 364	12.1	230.3	2.05
2015	119.9	1 394	11.6	269.6	2.25
2019	125.3	1 346	10.7	305.0	2.40
2020	126.0	1 347	10.7	307.5	2.40

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year).
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=MX

As can be seen in *Table 2.*, per capita energy consumption remained fairly stable over the years from 1990 to 2010 with a slight decrease thereafter, whereas per capita electricity consumption about doubled up to 2020. The cause for the decline of total per capita energy consumption in 2019 is attributed to the effect of COVID-19. A similar trend is observed in the table 3 below.

[1] Actualisation from INEGI (Instituto Nacional Estadistica Geografía) and the International Energy Agency (IEA).
https://www.iea.org/data-and-statistics/data-tables?country=Mexico&energy=Balances&year=2019
and: https://www.iea.org/data-and-statistics/data-browser/?country=Mexico&fuel=Energy%20consumption&indicator=TotElecCons

CO_2 emissions, fossil fuel emissions and energy carbon intensity

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	257.0	63.942	3.00
1995	291.3	83.127	3.10
2000	359.7	121.553	3.60
2005	412.4	134.662	3.90
2010	440.5	138.320	5.23
2015	442.4	142.927	4.50
2019	419.4	136.638	4.36
2020	381.0	124.920	3.05

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2).
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=MX

Fig 5. shows the various sources of CO_2 generation:

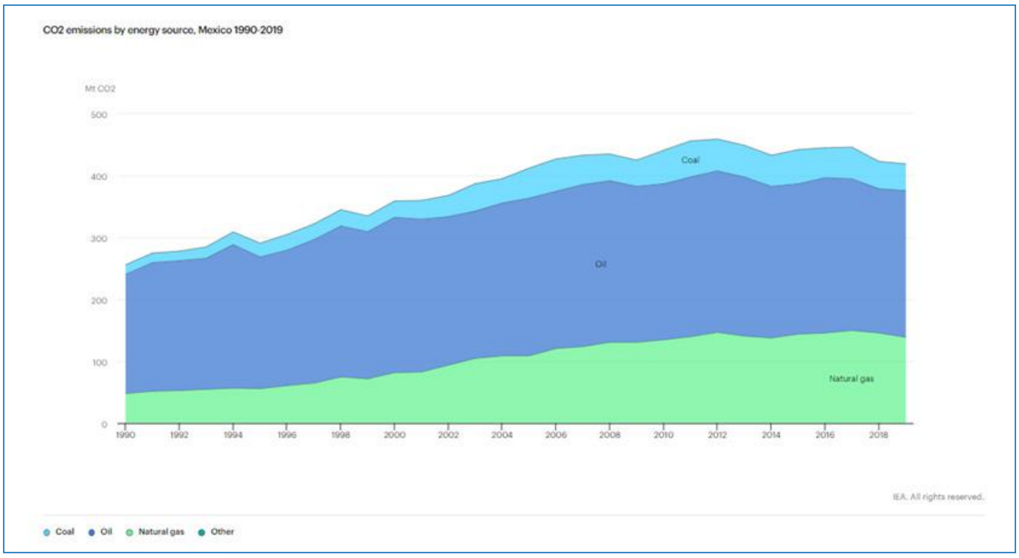

Fig. 5. Evolution of CO_2 emissions by fossil energy source ($MtCO_2$), **IEA**
https://www.iea.org/countries/mexico

Fig. 5. draws attention to the following situations: 1) Emissions declined after 2012; 2) CO_2 emissions from liquid fuels have been at a higher level than those from gas.

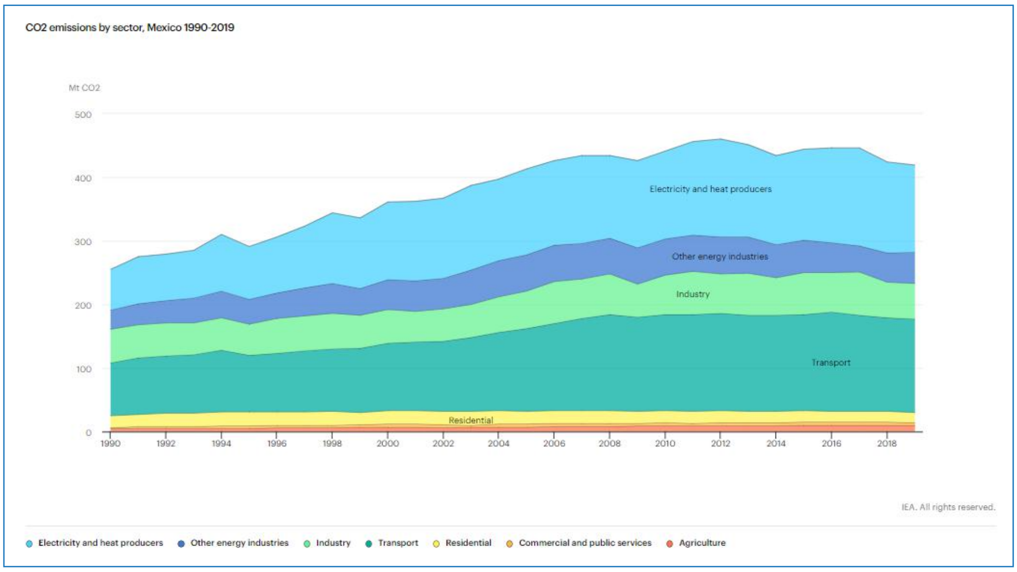

Fig. 6. Evolution of CO_2 emissions by sector ($MtCO_2$), **IEA**
https://www.iea.org/countries/mexico

Fossil fuel emissions have risen for electricity and heat producers, as well as in transport. Emissions from industry and other sources have remained stable. This graph is consistent with high fossil fuel-consuming countries.

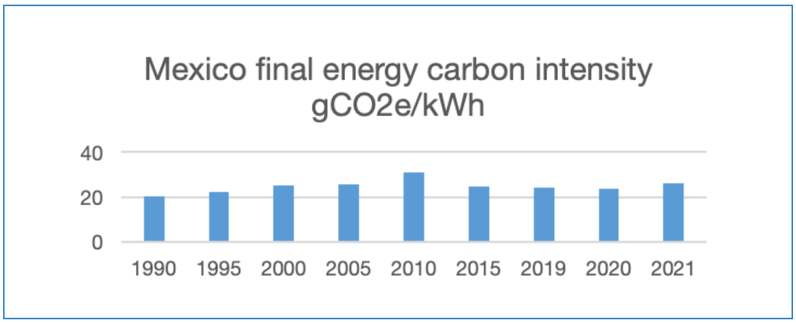

Fig. 7. Mexico final energy carbon intensity: gCO_{2e}/kWh. Data from **IEA**

2. Energy perspectives 2030 - 2050

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

The Mexican Ministry of Energy (SENER) published the **Program for the Development of the National Electric System 2022-2036 (May 2022)**, (Programa para el Desarrollo del Sistema Eléctrico Nacional 2022-2036). In this publication, the planning of the National Electric System is defined, which includes the relevant elements of other planning instruments, such as the Indicative Program for the Installation and Retirement of Power Plants, as well as the programs for the expansion and modernisation of the National Transmission Network and the General Distribution Networks.

Although it is a very detailed planning work, the vision of the future is based on a closed economy that limits the possibilities for further growth. The reason for this is that the current government intends to change the Hydrocarbons and Electricity Law passed in 2013-2014, which was designed on the basis of free competition in the electricity market, including the state-owned company Comisión Federal de Electricidad (CFE). A reform of the electricity industry aims at the centralisation of electricity generation up to 54% for CFE, regardless of KW-h prices, and leaves the remaining 46% to small private industrial companies as long as their production capacity does not exceed one MW and do not involve self-supplying partners.

Independently of the above-mentioned programme, the Mexican Academy of Engineering has carried out an exercise of electricity generation by source to the year 2050 within a global stochastic forecast. The results are shown below.

Forecast electric generation in Mexico

Year	Coal	Natural gas	Nuclear	Hydro	Geo-thermic	Wind	PV	Biofuels & Waste	Oil	Total TWh
2025	**8.70**	190.89	11.61	36.00	4.24	23.18	18.78	1.00	136.99	431.39
2030	**8.70**	219.60	11.61	40.00	4.88	30.14	28.35	1.50	119.08	460.85
2035	0	191.60	23.20	45.84	5.59	54.25	47.65	2.00	90.96	461.10
2040	0	167.74	23.20	52.37	6.39	100.36	92.92	2.50	70.32	515.79
2045	0	147.28	34.80	59.64	7.27	130.46	185.85	3.00	35.16	603.47
2050	0	129.67	34.80	67.74	8.26	221.79	241.60	3.50	17.58	724.94

Table 4. Mexico Forecast* Electric generation by source 2020-2050 in TWh
Source: Own calculations.

*This forecast was made on the basis of a stochastic β modelling (Beta x=<98%), taking into account upper and lower limits of economic and demographic trends as assumed by SENER. The projections for each production source were based on observed framework conditions, with a mixed private-CFE investment. In the case of nuclear production, it was assumed that full life-cycle external financing will exist.

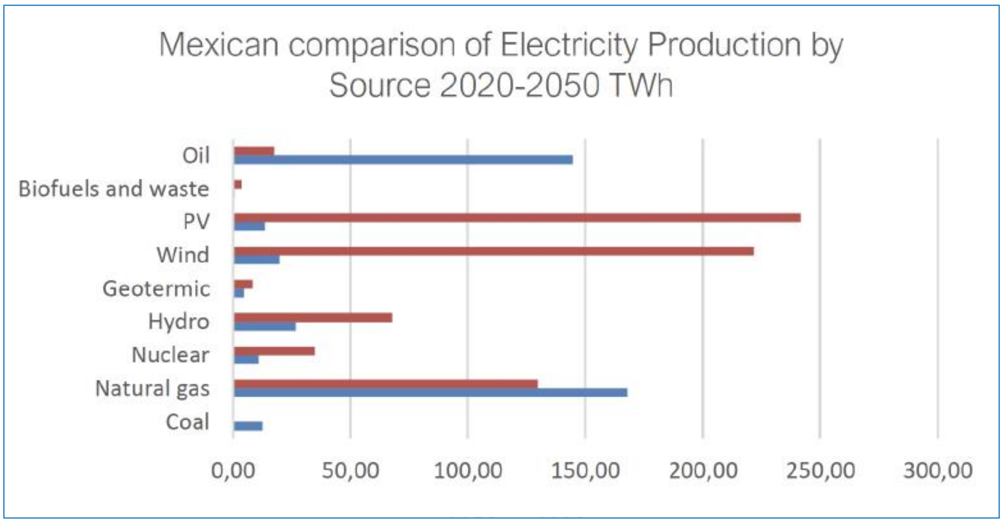

Fig. 8. Mexico electric generation by source 2020-2050
Source: National Academy of Engineering, Mexico (AIM). Constructed from various data.

Figure 8 shows that in 2050 three sources with on-demand electricity production may compensate for the intermittency of the renewable sources wind and solar (PV). Of a total of 724.94 TWh, these sources represent 4.8% (nuclear), 9.3% (hydro) and 1.1% (geothermic power). In these cases, it is very important to contemplate full-cycle financing as GHG emissions must be as much reduced as possible. The following graph shows the electricity generation forecast in terms of greenhouse gas reduction.

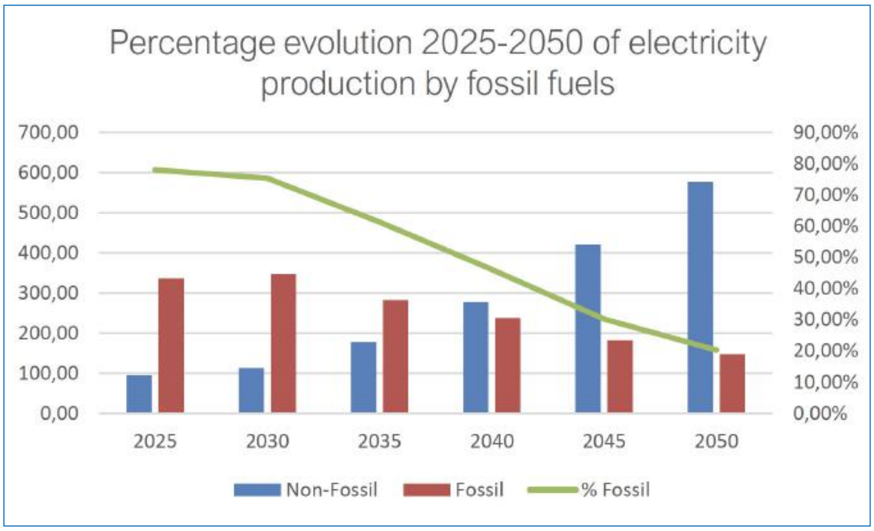

Fig. 9. Percentage evolution 2025-2050 of electricity production by fossil fuels
Source: National Academy of Engineering, Mexico (AIM). Constructed from various data

Regardless of the investment effort in the generation of electricity from sources other than fossil fuels, by the year 2050 we will still have around 15% of greenhouse gas emissions, short of the zero-emission target.

Roadmap for the energy mix

Mexico signed the Paris and Glasgow Agreements, and committed to significantly reducing GHG and using clean energy. However, Petróleos Mexicanos (Pemex) is building a new 340 000 barrels per day (340 Kbd) Gulf Coast refinery, has purchased the remaining 50% of the Dear Park refinery in Texas USA and will complete a coker plant in central Mexico.

It is believed that even under these new foreseeable emissions, solutions must be proposed to reduce GHGs. The following possibilities are expressed below:

1) suspend the operation of three of the oldest of the six existing refineries;
2) provide intensive maintenance to the remaining refineries and upgrade the control systems;
3) complete the coker plant;
4) invest in gasification plants with the intention of producing a) Methanol, b) Ammonia for petrochemicals and fertilisers;
5) reduce the use of fuel oil in electricity production as much as possible;
6) encourage the use of hydropower;
7) encourage the use of nuclear power;
8) campaign for the use of wind and solar energy (PV).

According to our estimate, if this or other comparable solutions are not implemented, Mexico will not reach 40% of fossil fuel utilisation by 2050.

In order to understand the answers to this questionnaire, it is important to take into account that the different, partly toxic compounds that form GHGs in Mexico reach a very high concentration level in the Mexico Basin (Mexico City).

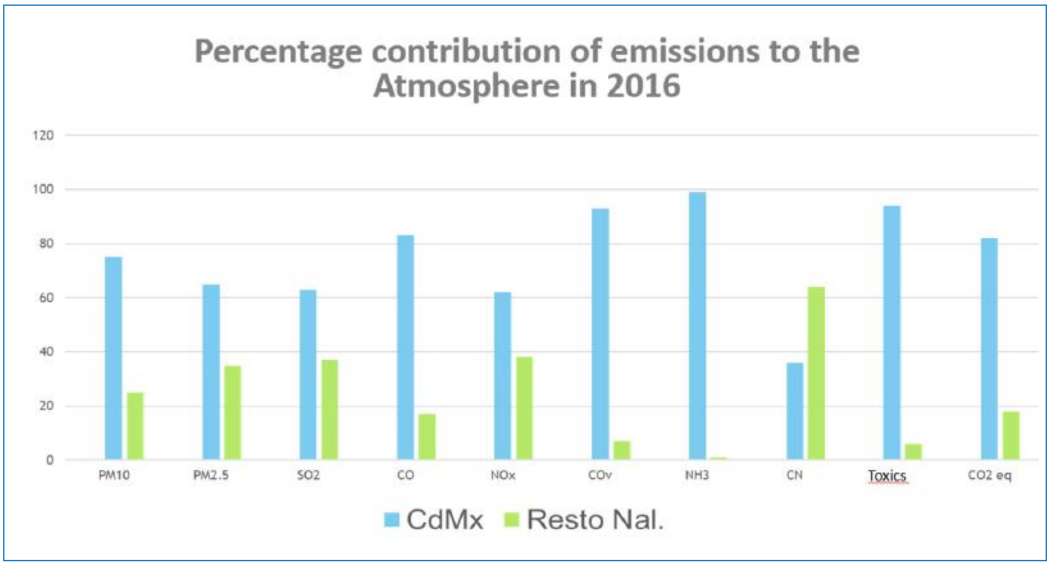

Fig. 10. Percent contribution of emissions of Mexico City (Ciudad de México, CdMex), and rest of Mexico SECC (Resto Nal.)
(Translated from Spanish. For copyright information regarding Mexico, see "General Note" at the end of this Mexican submission)

Fig. 10. shows that this is a phenomenon in which the concentration of emitted gases becomes highly hazardous to health. To control the toxic concentrations around the population, an hourly monitoring procedure has been implemented in several laboratories in Mexico City (and in other places too) and an indicator has been established, the Metropolitan Air Quality Index IMECA (Índice Aire y Salud).

As an example, *Fig. 11.* IMECA (Índice Aire y Salud) shows values for PM_{10} (particle size <10 microns) and Ozone are presented. Other examples are shown in *Table 5.*, where the tolerated upper limits for some contaminants, microbiological and COVID-19 are listed.

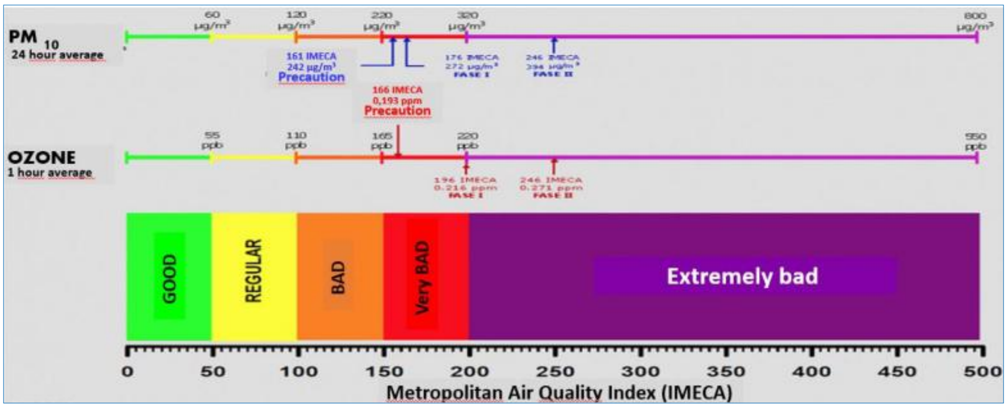

Fig. 11. IMECA (Índice Aire y Salud) value for PM_{10} and Ozone
(Translated from Spanish. For copyright information regarding Mexico, see "General Note" at the end of this Mexican submission)

Indoor Air Quality (IAQ) measurements with calibrated measuring instruments		State	Limit value
Carbon dioxide	CO2		Lim. 2500ppm
Carbon monoxide	CO		< 5ppm
Relative humidity	HR		30%-70%
Indoor temperature	Tª		21º-23º (+/- 1ºC)
Particulate matter PM 2.5	PM2,5		<20µg/m3
Particulate matter PM 10	PM10		<40µg/m3
Particle count PM 0.5	PM0,5		<35.200.000p/m3
Particle count PM 5	PM5		<293.000p/m3
Inspection of the Heating, Ventilation, and Air Conditioning system (HVAC)		**State**	**Limit value**
Visual inspection of the HVAC system			Clean
Microbiological inspection - Environmental monitoring			<800 ufc/100m3
Microbiological inspection - Surface control			<100 ufc/25cm2
Particulate Matter Inspection Impulse/Return			<10 µg/100cm2
Inspection of particulate matter Extraction			<60 µg/100cm2
Continuous monitoring		**State**	**Limit value**
Carbon dioxide	CO2		Lim. 2500ppm
Relative humidity	HR		30%-70%
Indoor temperature	Tª		21º-23º (+/- 1ºC)
Volatile Organic Compounds	COV		<220ppb
Formaldehyde			<120µg/m3
Microbiological measurements and detection of COVID-19		**State**	**Limit value**
Aerobic counts at 22°C on the surface			<4 UFC/cm2
Aerobic count at 22°C in air			<600 UFC/m3
Fungi count on the surface			<1 UFC/cm2
Fungi count in breathing air			<200 UFC/m3
SARS-CoV-2 detection			Detectable

Table 5. Tolerated upper limits for some contaminants, microbiological and COVID-19 (Translated from Spanish. For copyright information INDICE AIRE Y SALUD Air and Health Index. For copyright information regarding Mexico see "General Note" at the end of this Mexican submission)

CO_2 emissions from electricity production

See also *Table 3.* Total CO_2 emissions from electricity production (MtC_{O2}).

Electricity to end-uses 2020

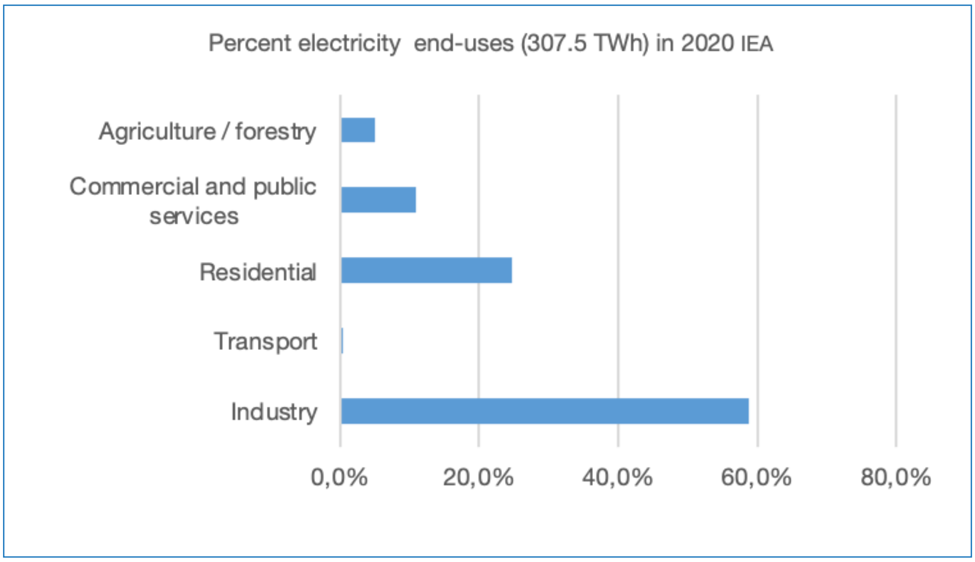

Fig. 12. Percent electricity end uses (307.5 TWh) in 2020, **IEA**

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All Mexican governmental organizations cited in the responses to this questionnaire have issued publishable information that may be made available to the public as long as it is correctly referenced in subsequent non-commercial publications.

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https://ai.org.mx/

Ciudad de México, CdMex (Mexico City)

INEGI National Institute of Statistics and Geography

INDICE AIRE Y SALUD Air and Health Index

ACADEMIA DE INGENIERÍA MÉXICO (AIM). ACADEMY OF ENGINEERING MEXICO.

NIGERIA

Table of Contents

1. National energy profile 2019

The national energy profile discussed herein is based primarily on data obtained from the IEA website. In a few cases where the relevant information is unavailable, the required data is sourced from other reliable agencies with independent strong data correlation to the IEA database. In such cases, appropriate referencing is provided.

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	692	10.8	1.6
1995	784	12.7	1.6
2000	911	11.8	1.3
2005	1 088	18.8	1.7
2010	1 237	22.2	1.8
2015	1 465	27.6	1.9
2019	1 576	26.7	1.7

Table 1. Comparison between total energy and electricity consumption between 1990-2019
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

It is obvious that despite the increase in final energy consumption (130%) and electricity usage (145%) over the period shown, there has only been a marginal improvement (12.5%) in the ratio of electricity-to-total energy consumption in the country probably because of the relatively low grid infrastructure development over that period.

Per capita yearly final energy and electricity consumptions (MWh)

Year	Inhabitants (per million)	Energy Consumption (TWh)	Energy Consumption per person and per year (MWh)	Electricity Consumption (TWh)	Electricity Consumption per person and per year (MWh)
1990	95.2	690	7.2	10.8	0.1
1995	107.9	784	7.3	12.7	0.1
2000	122.3	911	7.5	11.8	0.1
2005	138.9	1 088	7.8	18.8	0.1
2010	158.5	1 237	7.8	22.2	0.1
2015	181.1	1 465	8.1	27.6	0.2
2019	201.0	1 576	7.8	26.7	0.1

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=NG

The relatively low per capita electricity consumption trend (from 0.113 to 0.152 MWh/person) between 1990 to 2019 seen in Table 2 is consistent with the previous inference from data in Table 1. By comparison, both South Africa and Egypt reflect an average per capita electricity consumption of 4.3 and 1.2 MWh/person respectively over the same period.

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	28.1	5.7	0.3
1995	32.8	5.4	0.3
2000	43.7	6.7	0.4
2005	56.6	8.0	0.4
2010	56.9	7.9	0.4
2015	84.8	13.5	0.5
2019	92.0	12.9	0.5

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=NG

CO2 emissions, mainly from anthropogenic activities, include release from the energy industries such as oil and gas, transport, heat and electricity producers, residential buildings and other industries (e.g. chemicals and cement manufacturing). *Table 3* shows that CO_2 released from electricity accounts for 14-20% during this period. The emissions history is an S-shaped behaviour which suggests that the growth in CO_2 emissions from fossil fuels utilization in the first two decades has nearly plateaued in recent years but not declined indicating weak government efforts on carbon reduction since other economies have revealed a steady downward trend in annual CO_2 emissions within the past decade.

CO_2 emissions by fossil energy source ($MtCO_2$)

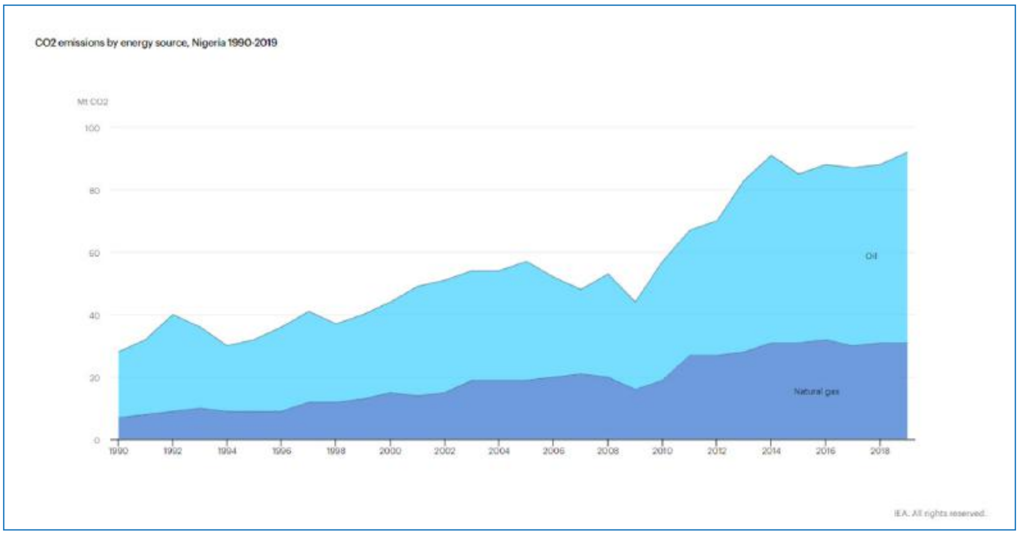

Fig. 1. CO_2 emissions trend by source from 1990 to 2019, **IEA**
https://www.iea.org/countries/nigeria

This plot implicates Nigeria's strong reliance on fossil fuel combustion for energy provision since the trend essentially parallels the growth in energy consumption. The higher amounts of CO_2 released through oil utilization compared to natural gas seems consistent with the fact that Nigeria is the largest user of oil-fired generators (backup for electricity) on the continent while most (80%) of its power production is derived from natural gas.

CO_2 emissions by sector ($MtCO_2$)

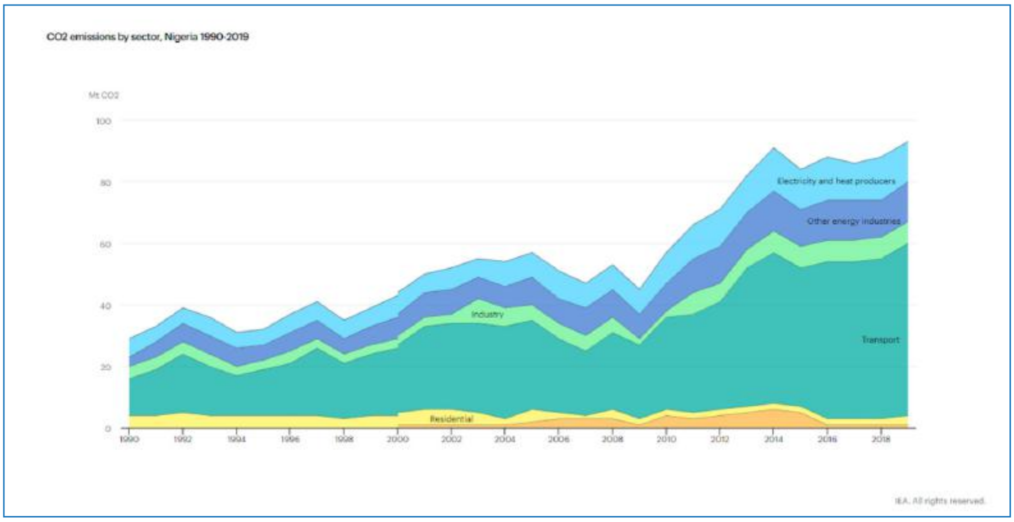

Fig. 2. CO_2 emissions profile according to the producing sector over the period, 1990-2019, **IEA**
https://www.iea.org/countries/nigeria

From this figure, the most significant polluter is the transport sector, contributing between 40-60% of the annual CO_2 emissions. This suggests that the incentive for nationwide electric vehicle adoption as a means of attaining the global zero GHG emissions target should be part of the decarbonization strategy, especially since Nigeria has the second largest automotive market on the continent.

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

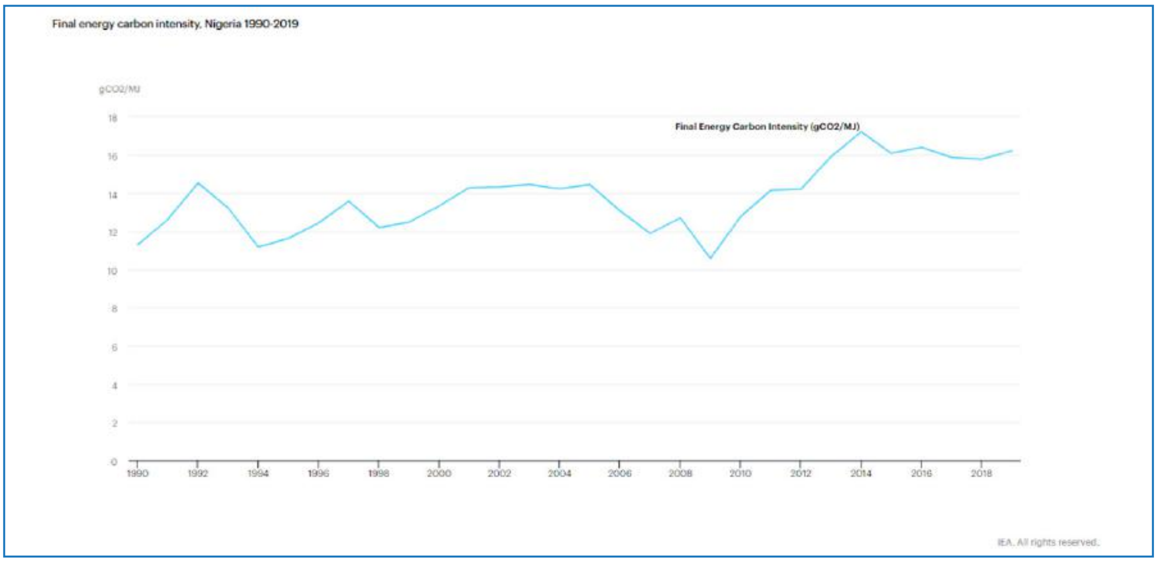

Fig. 3. History of the final energy carbon intensity between 1990 to 2019, **IEA**
https://www.iea.org/countries/nigeria

This energy metric is an indicator of the impact of GHG release per unit energy consumed in the economy. The comparison with other big economies on the continent is shown in *Fig. 4*. The comparatively lower value for Nigeria is probably due to the low dependency on coal as a principal contributor to the national energy consumption compared to South Africa.

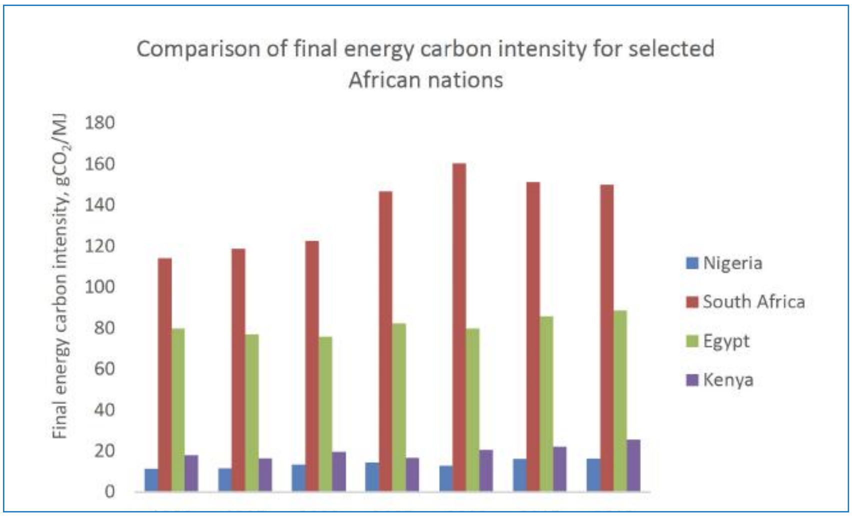

Fig. 4. Comparison of final energy carbon intensity between some African countries, **IEA**
https://www.iea.org/data-and-statistics/data-product/iea-energy-and-carbon-tracker-2020

Electricity Carbon intensity: gCO_2/kWh

Year	Electricity consumption (TWh)	CO_2 Emissions from electricity ($MtCO_2$)	Electricity carbon intensity (gCO_2/kWh)
1990	10.8	5.7	528.3
1995	12.7	5.4	424.0
2000	11.9	6.7	569.7
2005	18.8	8.0	422.7
2010	22.2	10.0	449.1
2015	27.6	13.5	488.8
2019	26.7	12.9	481.8

Table 4. Electricity consumption & carbon metrics for the period, 1990 to 2019, **IEA**
https://www.iea.org/data-and-statistics/data-product/iea-energy-and-carbon-tracker-2020

The electricity carbon intensity measures the impact of CO_2 release from electricity consumption alone. These values are about an order of magnitude higher than the final energy carbon intensity when compared with data from *Fig. 3* (using a conversion factor of 1 MJ= 0.2778 kWh). This suggests that the impact of CO_2 due to electricity consumption is about 10 times higher than that for final (overall) energy consumption in Nigeria even though it is not the biggest contributor to CO_2 emissions. However, as may be seen in *Fig. 5*, both South Africa and Egypt (the continent's second and third largest economies respectively) surpassed Nigeria. Clearly, there is a need for more serious adoption of low-carbon electricity technologies in Nigeria.

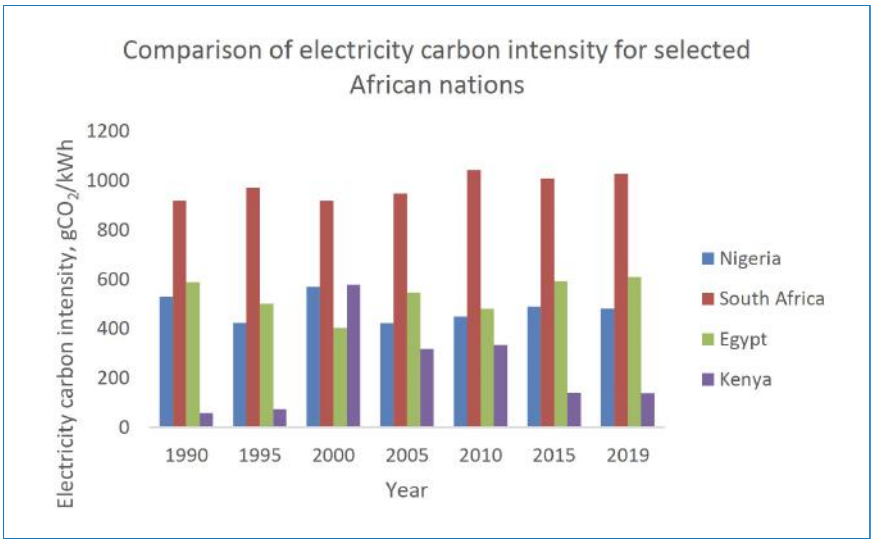

Fig. 5. Time trajectory of electricity carbon intensity for some African countries, **IEA** https://www.iea.org/data-and-statistics/data-product/iea-energy-and-carbon-tracker-2020

2. Energy perspectives 2030 - 2050

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

Nigeria relies on natural gas to meet a large proportion (ca. 80%) of its energy needs. In 2020, the country adopted a National Economic Sustainable Plan[1] which includes the National Gas Expansion Program (NGEP) which will accelerate the development of petroleum liquified gas for domestic consumption and compressed natural gas for the global export market. Based on the 2019 Presidential Power Initiative, the country has instituted an electrification roadmap (in partnership with Siemens AG) that consists of three phases to achieve 80% electricity access by 2025. This 6-year program is on track so far (Phase 1 – 2021) to deliver the expected outcomes (25 GW).

At present, the country's per capita GHG emissions are estimated at 3.37 t CO_2,equiv. However, Nigeria has a 2050 zero emissions target and a nationally determined contribution (NDC) of 442.5 M t CO_2,equiv by 2030 which translates to a per capita GHG release of about 1.7 t CO_2,equiv. Nigeria is also a signatory to the Global Methane Pledge and has committed to reducing emissions by 2030. The country's current GHG efforts have produced a 5-year (2012-2017) drop of about 6.4% in per capita emissions according to the 2020 Climate Transparency Report.

The Federal government also launched a National Renewable Energy Master Plan in 2015. Among others, the aim is to improve the diversification of the national energy mix through increased renewable energy resource (hydro, solar-PV, solar-thermal, wind, biomass, etc). Although hydro-generation has been the main renewable electricity source in Nigeria since 2015 the input from solar has grown from about 7% to 14% (2019) of the total electricity supply. It is anticipated that an installed capacity for combined renewable electricity production should reach 2940 MW (small hydro – 2000 MW, solar- 500 MW, biomass – 400 MW, wind – 40 MW) by 2025 to account for, at least, 10% of the total electricity. To accelerate the implementation of the renewable energy plan, the government has instituted a dedicated body, Nigerian Renewable Energy Agency (NREA) to look after its affairs in this respect. It has also provided custom duty exemption for imported renewable energy technologies, tax credits, capital incentives and preferential loan opportunities as catalysts for the development of the renewable energy sector.

[1] https://budgetoffice.gov.ng/index.php/nigeria-economic-sustainability-plan

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Roadmap for the energy mix

Nigeria's roadmap for energy mix is based on the African Union's Agenda 2063 announced in 2015. This is a strategic framework for guiding the continent in its realisation of inclusive and sustainable development for its people by 2063. The National Energy Policy for Nigeria has among its objectives,

- To ensure the development of the nation's energy resources, with diversified energy resource options, for the achievement of national energy security and an efficient energy delivery system with optimal resources mix.
- To guarantee an adequate, reliable and sustainable supply of energy at appropriate costs and in an environmentally friendly manner, to the various sectors of the economy for national development
- To successfully use the nation's abundant energy resources to promote international cooperation.

As a result, the country has embarked on a multilateral energy transition timetable that allows for continuing investment in African gas energy resources (as a transition fuel) while recognizing the global shift towards a renewable energy platform. Specifically, Nigeria's planned energy demand mix based on the continent's Agenda 2063 is:

Year	Coal (TWh)	Oil (TWh)	Natural Gas (TWh)	Hydro (TWh)	Solar-PV (TWh)	Other Low-carbon tech. (TWh)	Bioenergy (TWh)	GDP (2018 US$ bn)
2010		244	93			N.A.	1 140	919
2018		302	174			N.A.	1 326	1 169
2030	70	500	233	12	12	N.A.	442	2 058
2040	105	616	407	35	23	N.A.	512	3 678

Table 5. Projection for the Nigeria energy demand (2010-2040) for the Africa Case* **IEA**
https://www.iea.org/articles/nigeria-energy-outlook

*Africa Case (Agenda 2063) assumes rapid economic and industrial development with complete realization of key UN Sustainable Development Goals including 100% electricity accessibility clean cooking by the populace as well as substantial reduction of infant mortality due to pollution.

It is obvious from *Table 5* that Nigeria (and African nations in general) still intends to include significant carbon-based energy in its short- and medium-term strategy for energy supply while transitioning to a completely renewable energy mix before the end of the 21st century.

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https://www.iea.org/articles/nigeria-energy-outlook

Roadmap for the GHG emissions (country, per capita)

The country's roadmap for GHG emissions is intricately tied to its national energy policy as implicated in the preceding section. While the strong dependence on natural gas as an energy resource will be evident in the short- and medium-term strategies for the country, the present policy that has produced a continuing decrease (-6.4%) in GHG emissions suggests that planned improvement in renewable energy content of the supply mix would lead to further drop in GHG emissions till about 2040. This is deducible from the IEA data displayed below.

			State Policies Case**		Africa Case	
	2000	**2018**	**2030**	**2040**	**2030**	**2040**
Population (million)	122	196	263	329	236	329
% with electricity access	40	60	80	85	100	100
% with access to clean cooking	1	10	28	38	100	100
CO_2 emissions (Mt CO_2)	37	83	134	191	181	257
GDP (2018 US$ bn, PPP)	392	1 169	1 636	2 420	2 258	3 678

Table 6. Nigeria key indicators and policy initiatives, **IEA**
**Stated Policies Case: is representative of IEA's assessment of the country's current policy frameworks and plans, taking into account the regulatory, institutional, infrastructure and financial circumstances that shape the prospects for their implementation.

It is apparent that if the current Nigerian government policies (Stated Policies Case) are maintained into the next two decades (up to 2040), GHG emissions will be further cut back than if the continent's Agenda 2063 (Africa Case) strategy was adopted. This may be due to the fact that the entire population is expected to have access to clean cooking than under the SPC where the accessibility to clean cooking is relatively lower (28% and 38% for 2030 and 2040 respectively). However, the country's expected GDP values are higher under the AC scenario than for the SPC. In view of the population growth over the next two decades, the per capita CO_2 emission and carbon cost to the economy have also been evaluated as shown in *Fig. 6*. This bar chart indicates that the average Nigerian may have reduced carbon footprint on the environment under the SPC regime than the AC although the carbon cost (2018 US$ basis) will be stable (0.078 kg CO_2/$) over the two-decade period.

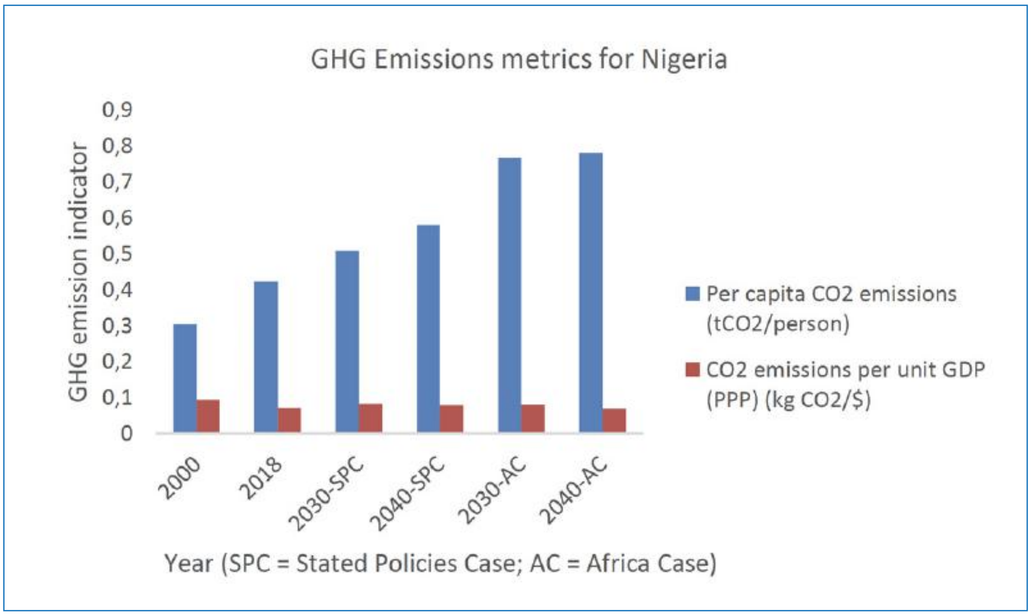

Fig. 6. Trajectory of GHG emissions metrics between 2000-2040 for SPC and AC scenarios, **IEA**
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Roadmap for the electricity mix

Fig. 7 shows the IEA data for the projected electricity generation mix for Nigeria using the country's Stated Policies and Agenda 2063 scenarios.

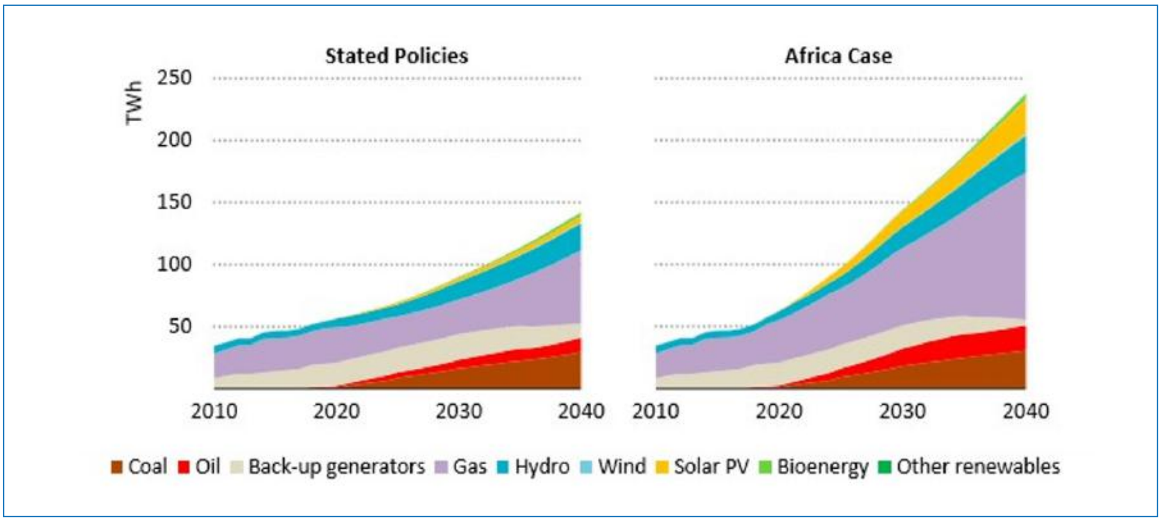

Fig. 7. Electricity generation projection from different technologies under SPC and AC scenarios, **IEA**
https://www.iea.org/articles/nigeria-energy-outlook

As expected, electricity generation ramped up significantly between 2020 to 2040 in the AC scenario more than in the SPC since the former assumes total electricity accessibility by 2030 compared to the latter which hopes for 80% accessibility in the same year. Although electricity from back-up generators peaks (at ca. 20 TWh) around 2030 under both scenarios, by 2040 this would have dropped to just 5 TWh for AC while SPC would still allow production at 11 TWh. Even so, under the two cases, reliance on fossil fuels continues to grow until 2040 while the percentage contribution to electricity mix decreased (from 82% to 78% for SPC and 82% to 72% for AC between 2010 to 2040). Accordingly, *Fig. 8* reveals that renewable electricity contribution is better under the AC than the SPC.

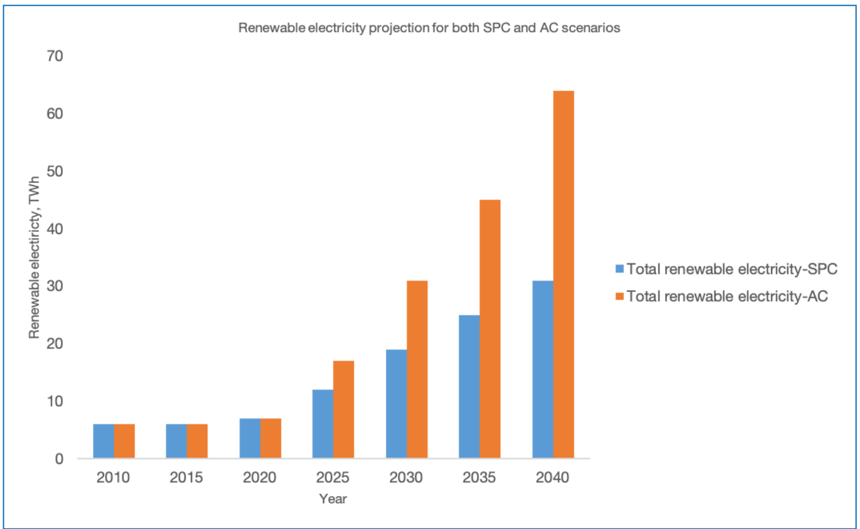

Fig. 8. Role of renewable electricity in the supply mix between 2010 to 2040 under SPC and AC, **IEA**
https://www.iea.org/articles/nigeria-energy-outlook

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CO_2 emissions from electricity production

Nigeria's dependence on gas-powered generators for electricity supply will continue into the foreseeable future as implicated in the previous sections although the share of renewable electricity in the supply mix will creep up till 2040 (18% to 27% depending on the scenario). Thus, there will be associated CO_2 emissions from the electricity supply industry. The electricity carbon intensity has varied between 450 and 488 gCO_2 kWh from 2010 till date. Given that in both the SPC and AC, coal, oil and gas will still play a major role in the electricity supply mix, significant decarbonization of the sector is not expected till about 2060. At this time, the renewable electricity production would have increased to about 111 TWh (SPC) and 394 TWh (AC) if the anticipated growth rates for SPC (0.063 per yr) and AC (0.091 per yr) are upheld. During the recent COP26, Nigeria announced a national policy that will achieve zero GHG emissions target by 2050. Specifically, there will be complete electrification of the economy and increased solar PV utilisation as replacement to gas-powered facilities to facilitate emissions reduction to the zero target.

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Energy balance (energy sources to end-uses)

Fig. 9. shows the projected energy sources for the SPC and AC. Consistent with earlier discussion, fossil fuels will continue to be in demand, theTWhrise in renewable electricity is evident from the increased presence of hydro and solar PV particularly from 2030 onwards. Fig. 10 demonstrates that fossil fuels consumption by industrial producers and chemicals manufacturing as well as the transport sector will be a big feature of the future market. The fossil fuels demand in the transport sector could be mitigated by a favourable policy shift towards the electric vehicles since Nigeria is the second largest auto-market on the continent. For example, based on the AC, by 2040 there will be about 37 million vehicles in the country (a 164% increase from the present 14 million vehicles).

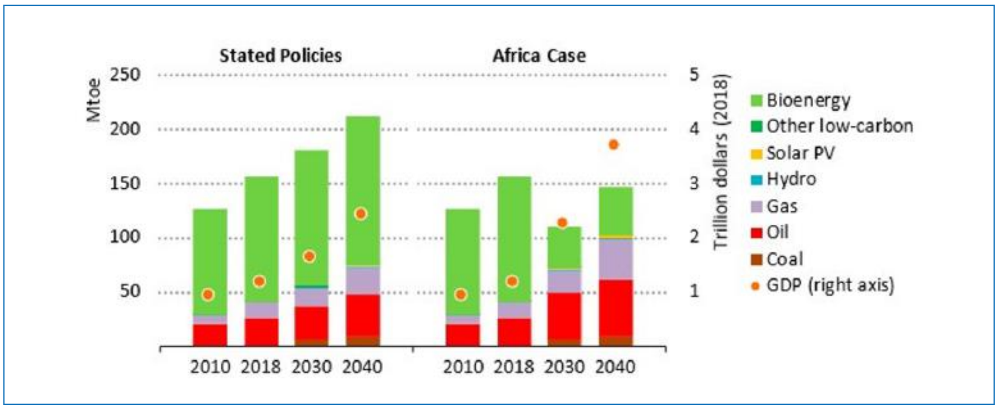

Fig. 9. Primary energy demand trajectory according to SPC and AC scenarios, **IEA** www.iea.org/reports/africa-energy-outlook-2019

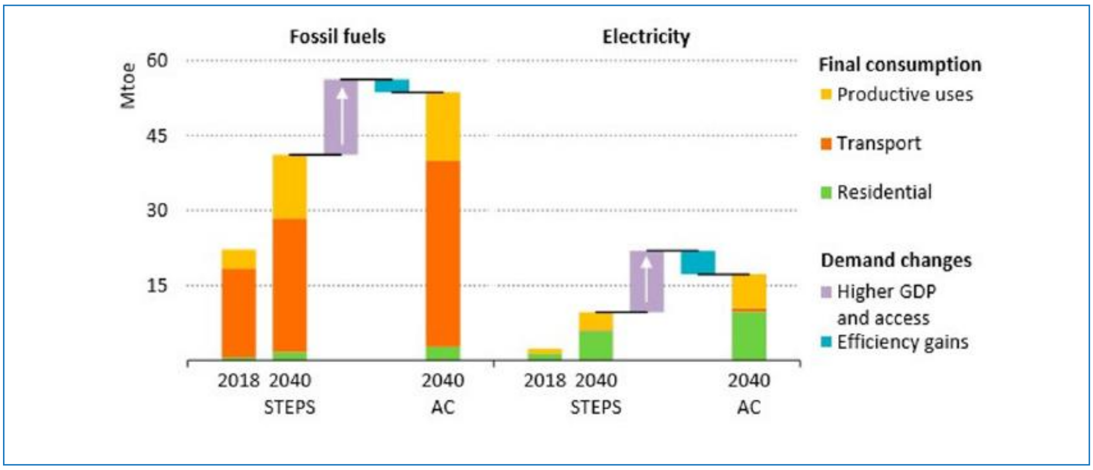

Fig. 10. Expected energy consumption pattern in different sectors of the economy, **IEA**
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3. Industry, Buildings, and Agriculture

3.1. Food & Agriculture

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

The agricultural sector in Nigeria has access to less than 1% of the total energy supply in the country[2]. This is concerning given the exponential rise in total energy demand with population growth over the next three decades under either the Stated Policies Case (SPC) or the Africa Case (AC). Not surprisingly, the agricultural sector does not appear to be a major contributor to the national GHG emissions. According to the IEA database, the principal GHG emitters of the Nigerian economy are the transport, electricity & heat producers, residential and manufacturing sectors. However, with the introduction of the 2013 Agricultural Transformation Agenda, there has been a growing emphasis on farm mechanization and associated GHG emissions from fossil fuels consumption by agricultural machinery and equipment.

Are the best available low carbon technologies used/considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

The Federal Ministry of Agriculture and Rural Development (FMARD) has released a “Green Alternative” document that supports the government’s policy towards climate change and environmental sustainability in its efforts to promote agricultural sector productivity. Presently, off-grid solar PV installations, small wind turbines (<50 MW) and continuing construction of small dams in some rural farming communities across the country constitute the only evidence for low-carbon technologies being encouraged by the government. However, more still needs to be done. Better funding and superior management transparency are lacking.

[2] Onyema M-A. C., (2016), International Food Policy Research Institute: Nigeria Strategy Support Program, Policy Note No. 24.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

As previously alluded to (cf. *Sec. 1.2.3*), the overall economy has witnessed a 6.4% drop in GHG emissions in the past decade. Even so, the complete decarbonisation of the economy and hence, the food and agricultural industries, is not expected until about 2050 based on the recent government policy (2050 zero GHG emissions target) announced during COP26 in November 2021. As part of the implementation efforts, the Nigerian government is commissioning the 3050 MW Mambilla Hydropower Project in 2030. Among others, the facility will have four dams which will support present irrigation needs, especially in the agriculturally intensive Middle Belt states of Nigeria and also increase the share of renewable electricity supply thereby reducing GHG emissions. Additional installation on solar PV-based mini-grids is also envisioned from 2030 as seen in *Fig. 9.* These benefits and more will have flow-on effect into the agricultural sector of the economy.

Is the implementation of low-carbon technologies helped by the government? For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

As indicated in *Sec. 3.2*, the Agricultural Promotion Policy (APP) of the present FMARD has produced the "Green Alternative" document[3]. Although the new policy highlights eleven national priorities, only one of them, "Factoring climate change and environmental sustainability" carries the explicit notion that the policy instrument may engage low-carbon technologies to mitigate GHG emissions as well as land, soil and natural ecosystems for improved agricultural sector productivity. Attitude towards the adoption of low-carbon technologies is driven more by national goals, namely:

- lifting 100 million people out of poverty and accelerated economic growth,
- bringing modern energy services to the entire population, and,
- managing the long-term job loss in the oil sector that will result from reduced global demand as the world transitions to zero emissions economy,

than by international benchmarking.

Nigeria's commitment to rollout solar powered technologies and end gas flaring seems to be working (a reduction in gas flaring by 70% between 2000 to 2019) albeit slowly. Developments in agricultural mechanization are being spear-headed by nearly 40 government agencies involved with various food and agricultural technologies such as National Agency for Science & Engineering Infrastructure (NASENI) and National Centre for Agricultural Mechanization (NCAM). For example, through collaboration with state governments, agricultural innovations promoting decarbonization are being deployed at NASENI[4]. While government efforts in the implementation of the Agricultural Transformation Agenda (ATA) have been largely fruitful, international benchmarking activities are somewhat diffused. It is also apparent that public authorities are somewhat lethargic in pushing low carbon economic transformation. This may be seen in the Petroleum Industry Act (PIA 2021) which places emphasis on increased prospecting of fossil fuels rather than on renewable energy investments in frontier locations and without targeted emphasis in the Economic Recovery & Growth Plan (2017-2020)[5].

Are there incentives for carbon capture, utilisation, and storage? How?

Nigeria's energy transition program does not indicate explicit incentives for CCUS. However, it has identified a domestic market for CCUS technologies for the mitigation of industrial emissions to facilitate achievement of its 2050 zero target. As a result, the government is partnering with the International Finance Corporation and the World Bank[6]. The initiative involves:

- World Bank collaboration with the government to develop policies and regulations to speed the adoption of CCUS technologies while concurrently assisting the domestic industry to meet international standards.

3 https://agra.org/wp-content/uploads/2017/12/agra-nigeria-final.pdf
4 https://naseni.org
5 https://www.cbn.gov.ng/Out/2017/CCD/Financial%20Inclusion%20Newsletter_%20MAY%202017_Volume%202%20Issue%202-final%20-%20Review%20%20%20.pdf
6 https://pressroom.ifc.org/all/pages/PressDetail.aspx?ID=26819

- IFC in partnership with the government, will produce a database of key CO_2 emissions sources and possible sites for underground sequestration. This will include identifying the most promising sectors and private companies that can pilot new CCUS technologies.

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

A recycling program is under the auspices of the Federal Ministry of Environment, embedded in the department's Clean & Green Initiative. In practice, however, solid waste management (collection, processing and recycling) is often a state affair (there are 36 states in Nigeria). Lagos State, where Africa's largest city, Lagos, is located, runs an enviable recycling program under the agency of the Lagos State Waste Management Authority. The program has become a model for other big cities such as Ibadan, Abuja, Kano and Port-Harcourt. The LAWMA recycle program is decentralized to the 57 local government areas (LGAs) in the state where private recycling companies handle the waste collection, processing and materials recovery. Over 40 million tonnes of waste are produced annually in Nigeria with about 30% of this as recyclable plastics, electronic wastes and other PVC materials. The recycling business is principally organized by the informal sector through social participation (waste pickers subcontracted by private companies). Thus, the absence of a central policy on solid waste management has led to a proliferation of private recycling companies operating with little or no regulation[7]. Despite the central government's relative apathy towards recycling, private Nigerians have developed a niche market for waste-to-wealth technologies as exemplified by young entrepreneurs like Victor Boyle-Komolafe whose company, GIVO, is processing plastic bottles into plastic face shields[8]. By same token, partnership between the Nigeria's National Environmental Standards & Regulation Enforcement Agency, the UN Environment and a private company, Global Environment Facility, has led to the first e-waste processing facility in Nigeria[9]. Other developments are found in public institutions where both recycling and waste valorisation activities are providing parallel revenue streams in the overall waste management arm. With its burgeoning population, continuing advocacy with the Federal government on a robust policy for education on recycling, is essential to avoid a degenerative or even chaotic market environment.

Are there some case studies or best practices you would like to share?

In terms of smart technology embrace, development and business practices, the Lagos State Waste Management Authority provides inspiration for the future of sustainable resource harnessing in Nigeria. LAWMA has received both national and international awards for its adventures.

7 Nzeadibi T.C. & Adama O. (2013), "Improved recycling performance: Policy options for Nigerian cities", The Nordic Africa Institute, Policy Note 2.

8 https://www.government.nl/latest/news/2021/04/08/%E2%80%98over-the-next-five-years-we%E2%80%99re-going-to-recycle-150-million-plastic-bottles%E2%80%99

9 https://www.unep.org/news-and-stories/press-release/nigeria-turns-tide-electronic-waste

SPAIN

Table of Contents

1. National energy profile 2019

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	708	126	19.4
1995	802	141	19.4
2000	994	188	21.1
2005	1 185	242	22.7
2010	1 071	245	24.8
2015	925	232	27.4
2019	995	235	25.6

Table 1. Total yearly consumption: final energy, electricity (TWh)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

During this period, three major factors regarding the developments in energy and electricity consumption have been: (a) an increase in the population from 38.8 million to 46.9 million (+ 20.9%); (b) a decrease in the share of industry in GDP from 22% to 16%; (c) an increase in energy consumption up to 2005 and a decrease thereafter. The result is a 40.5% increase in final energy consumption over the period 1990-2019.

Concerning electricity, after an increase of around 94,2% between 1990 and 2005, the consumption has stabilised and was slightly decreasing from 2005 to 2019.

As in the other countries, the significant trend is an increase in the ratio of electricity consumption / final energy consumption. However, during the last few years, the trend reversed to some extent. The explanation is probably in an increasing GDP inducing higher fossil energy consumption principally in transport and industry.

Per capita yearly final energy and electricity consumptions (MWh/person per year)

Year	MWh/person	MWh/person
1990	18.1	3.5
1995	20.2	3.9
2000	24.4	5.1
2005	27.0	6.1
2010	22.8	5.7
2015	19.8	5.4
2019	21.3	5.5

Table 2. Total yearly consumption per person: final energy, electricity (MWh per person per year)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=ES

Energy consumption and electricity per capita increased up to 2005 and decreased after, following the economic crisis after 2008.

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 Emissions per capita
1990	202.7	66.283	5.2
1995	228.2	60.820	5.8
2000	278.6	98.990	6.9
2005	333.7	118.221	7.6
2010	262.1	72.064	5.6
2015	247.1	82.306	5.3
2019	230.9	54.104	4.9

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=ES

The important reduction of emissions after 2005 is the consequence of a decrease in coal consumption on one side and strong increase in renewable energy generation on the other. The emission level per capita follows a similar tendency.

CO_2 emissions by fossil energy source ($MtCO_2$)

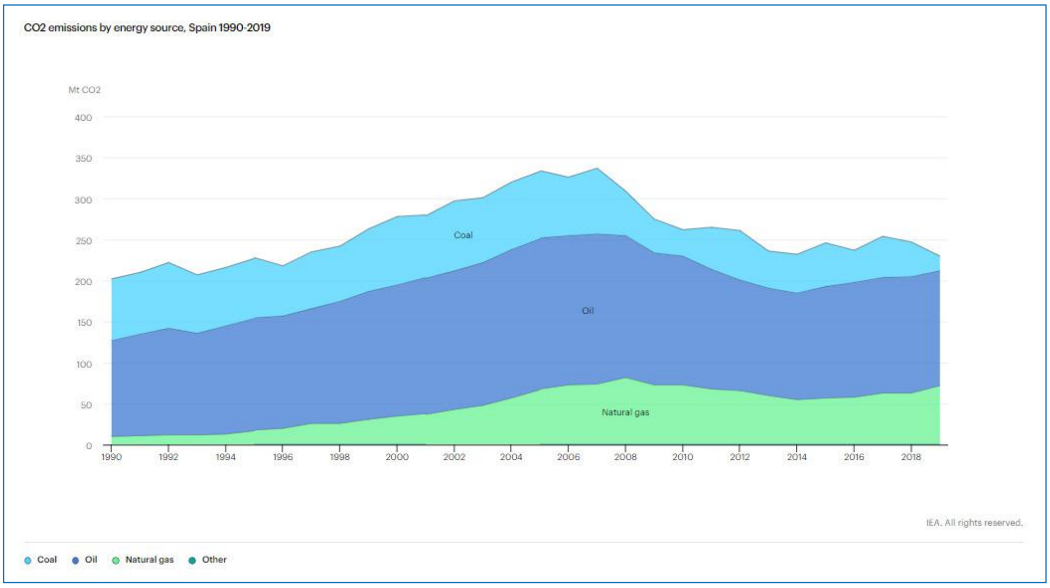

Fig. 1. CO_2 emissions by fossil energy source, **IEA**
https://www.iea.org/countries/spain

As in many other OECD countries, the use of coal has been strongly reduced since 2005, while the use of oil slightly decreased and the use of natural gas remained stable or slightly decreased after 2010, reaching its minimum level around 2014.

CO_2 emissions by sector ($MtCO_2$)

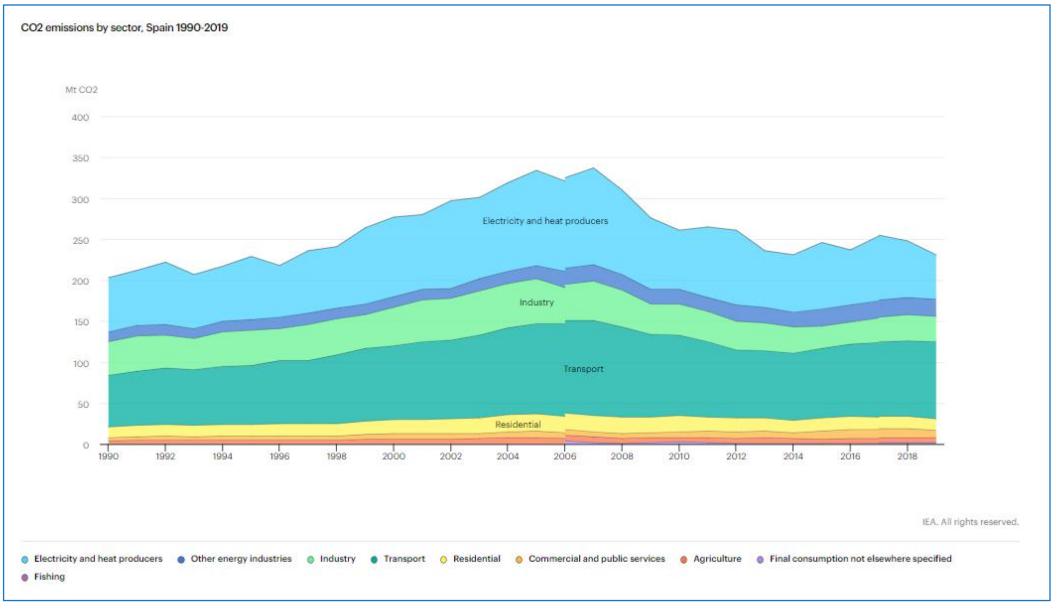

Fig. 2. CO_2 emissions by sector, **IEA**
https://www.iea.org/countries/spain

Emission from all sectors, except from commercial services and other energy industries, which have slightly increased over the period, have followed similar tendencies: an increase up to 2005/07 and a decrease thereafter.

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 kilowatt hours)

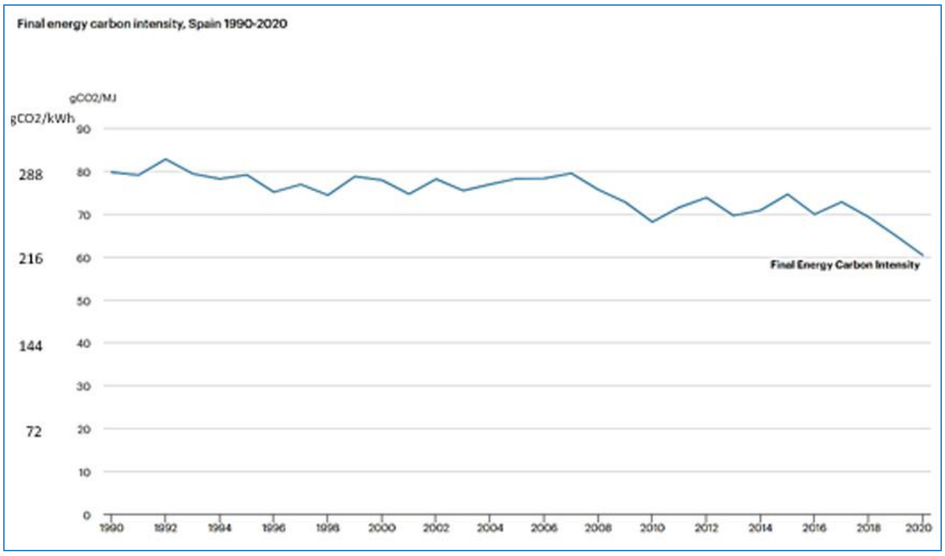

Fig. 3. Final energy carbon intensity, Spain 1990-2019, **IEA**
https://www.iea.org/countries/spain

Electricity Carbon intensity: gCO_2/kWh

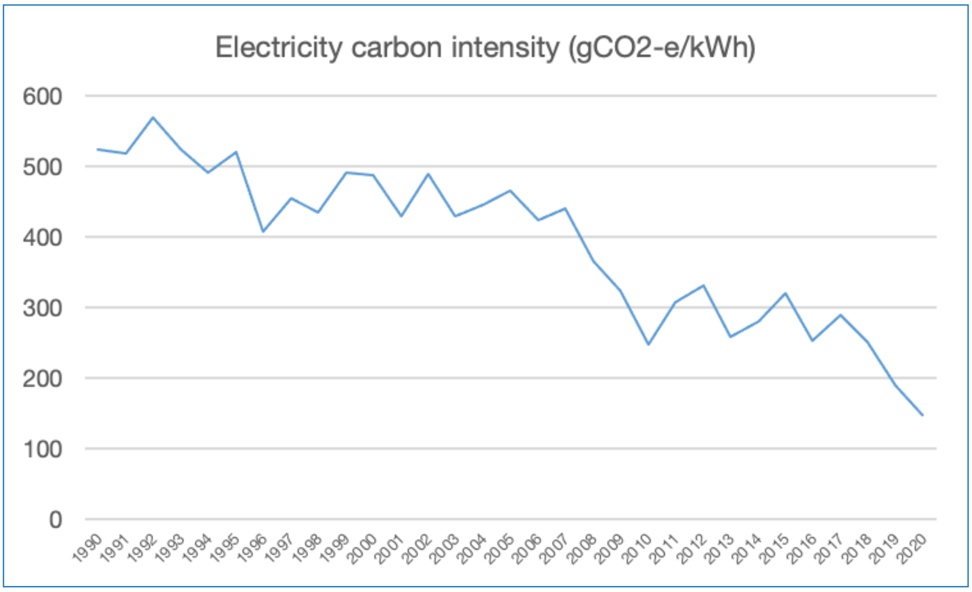

Fig.4. Electricity Carbon Intensity Spain 1990 - 2020, **IEA**
https://www.iea.org/countries/spain

Electricity carbon intensity has dropped during the period 1990-2020 because of the reduction in coal-based electric power generation and a strong increase in renewable electricity production.

2. Energy perspectives 2030- 2050

The Regulation 2018/1999 adopted by the European Union (EU), requires Member States to implement strategies and measures designed to meet the objectives and targets of the EU for energy and its long-term GHG commitments, in consistency with the Paris Agreement and, from 2021 to 2030, the EU's targets for energy and climate.

Spain, as a member of the EU and according to its regulation, has developed a National Integrated Energy and Climate Plan 2021-2030 *(Plan Nacional Integrado de Energía y Clima (PNIEC) 2020-2030)*. This document was later supplemented with the *Long-Term Strategy for a Spanish economy competitive and climatically neutral in 2050*, which develops a roadmap to reach net zero emissions in 2050 with intermediate steps in 2030 and 2040.

Both of the above regulations are included in Law 7/2021 on Climate Change and Energy Transition (see also https://www.boe.es/boe/dias/2021/05/21/pdfs/BOE-A-2021-8447.pdf). This law sets the following emissions reduction, renewable energy and energy efficiency targets for 2030:

a. reduction of GHG emissions by, at least, 23% with respect to 1990,
b. reach at least 42% of energy from renewable resources in the final energy consumption,
c. reach 74% of renewable energy generation in the electricity generation mix,
d. improve energy efficiency with the aim of reducing primary energy consumption by 39.5% with respect to the baseline.

These regulations include the long-term objective of reaching climate neutrality before 2050, or within the shortest possible timeframe.

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

As mentioned above, Law 7/2021 establishes:

1) The specific objectives to reach by 2030, which are: a) reduce GHG emissions by 23% with respect to 1990; b) reach a renewable energy penetration in the final energy consumption of, at least, 42%; c) reach an electrical generation mix with, at least, 74% from renewable sources; and d) improve energy efficiency for reducing primary energy consumption by at least 39.5% with respect to the baseline; and
2) The obligation to achieve carbon neutrality by 2050,

Roadmap for the energy mix

Roadmaps by energy source and use for the reduction of total final energy consumption are included in the table below; a reduction in the use of fossil fuels of 25% for 2030 and 95% for 2050 is anticipated, whereas the non-energy uses of feedstocks (e.g. for petrochemicals) will slightly increase.

	2019	2020	2025	2030	2035	2040	2045	2050
Non energy uses	61.8	61.6	64.0	64.0	64.0	69.8	69.8	69.8
Renewable thermal energies	72.7	69.2	81.4	87.2	104.7	151.2	232.6	279.1
Electricity	234.5	220.9	232.6	238.4	255.9	302.4	314.0	325.6
Fossil energies	694.1	572.5	628.0	523.4	418.7	244.2	127.9	34.9
Total	1 063.2	924.2	1 006.0	913.0	843.2	767.6	744.3	709.4

Table 4. Roadmap for the energy mix (TWh)
Renewable thermal energies are Solar thermal, geothermal, biomass, biogas and biowaste.
Ministerio para la Transición Ecológica: Decarbonization Strategy to 2050, Annex E-5: Climate neutrality scenario:
https://www.miteco.gob.es/es/prensa/anexoelp2050_tcm30-516147.pdf.- Public information and own analysis/compilation.

Roadmap for GHG emissions (country)

The roadmap for national GHG emissions in the present Integrated National Energy and Climate Plan is presented in the following table:

2020	2025	2030	2035	2040	2045	2050
270.9	282.7	222	162	102	56	29

Table 5. Roadmap for the GHG emissions ($MtCO_{2e}$)
Ministerio para la Transición Ecológica: Decarbonization Strategy to 2050, Annex E-5: Climate neutrality scenario
https://www.miteco.gob.es/es/prensa/anexoelp2050_tcm30-516147.pdf. Public information.

Roadmap for the electricity mix

Specific data have not yet been developed. However some important milestones of the long-term strategy to 2050 regarding generation capacity have been set, among which are the following:

- Nuclear generation capacity will reach a 60% reduction by 2030 and be completely shut down by 2035.
- Fossil generation capacity will continuously decrease up to 2050, then disappear.
- Electrical storage capacity will grow to 6 GWh in 2030 and by a further 300% in 2050.
- Renewable generation capacity will be doubled by 2030 and experience a fourfold increase by 2050.

CO_2 emissions from electricity production

Currently, the Spanish electricity generation has an emissions value of 0.15 $kgCO_2/kWh$, which is lower than many other EU countries. It is foreseen to steadily decrease up to 2050 when climate neutrality will be achieved

2020	2025	2030	2035	2040	2045	2050
32.5	27	21	11	7	1	0

Table 6. Roadmap for the GHG emissions of the electricity sector ($MtCO_{2e}$)
Ministerio para la Transición Ecológica: Decarbonization Strategy to 2050, Annex E-5: Climate neutrality scenario: https://www.miteco.gob.es/es/prensa/anexoelp2050_tcm30-516147.pdf. Public information.

Energy balance (energy sources to end-uses)

Final energy consumption reached its peak in 2005. It decreased thereafter until 2015 and from there remained almost stable with a slight increase in 2019.

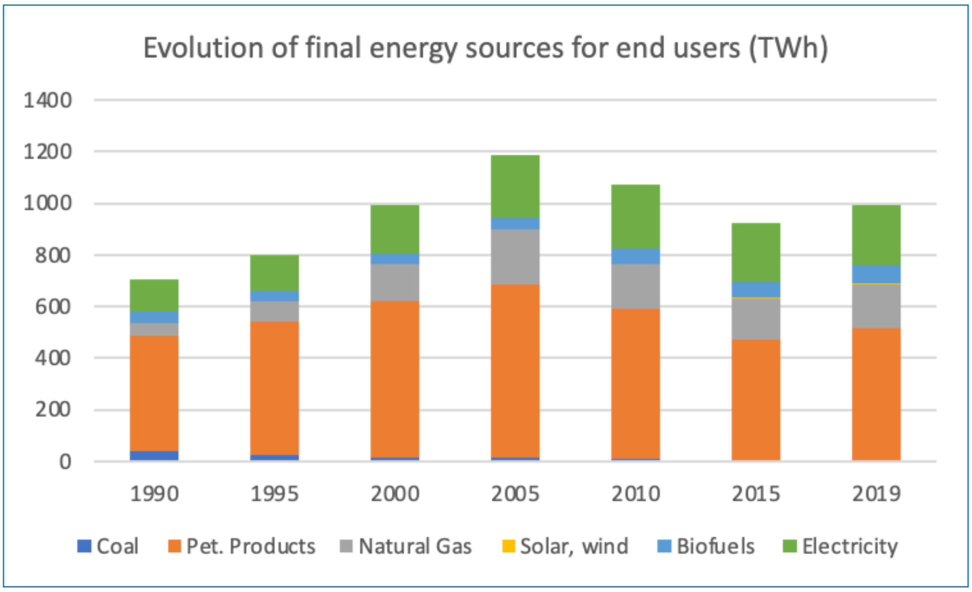

Fig. 5. Evolution of final energy sources for end users (TWh)
Source of data: https://www.iea.org/data-and-statistics/data-browser/?country=SPAIN&fuel=Energy%20consumption&indicator=TotElecCons.
Own analysis and compilation from **IEA** data

3. Building sector

3.1. Existing buildings

Energy balance 2019 (energy sources to end-uses)

Electricity, natural gas and petroleum products are the major energies in both commercial and household sectors. The share of renewable energy (e.g.solar thermal, biomass and some geothermal; wind and solar PV are in electricity) is increasing and, in the household sector, it has reached a level similar to that of petroleum products (*Table 7.*)[1].

	Commercial and public services	Households
Coal		64.92
Petroleum Products	1 248.72	2 397.48
Natural gas	2 322.83	3 009.24
Non renewable wastes	4.80	
Renewable energies	667.85	2 833.52
Electricity	6 416.72	6 275.27
Total	**10 660.91**	**14 580.44**

Table 7. Existing Buildings: energy balance (2019) (ktoe)
1 ktoe = 0.01163 TWh, 10 661 ktoe = 124 TWh, 14 580 ktoe = 170 TWh)
Source: Eurostat. https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_c&lang=en. Open Source

Energy partition between single houses, apartment buildings and office buildings

Table 7. shows energy partition between households (houses and apartment buildings) and commercial buildings, which include office buildings. There is no other segregation by energy consumption.

Which systems are mostly used for heating?

Local systems: mainly boilers and electric heating, and, to a lesser extent, heat pumps, solar thermal panels, geothermal systems, etc.

Which systems are mostly used for cooling?

Local systems.

What are the main choices of the national policy – if there is one – to reduce the emissions from the existing stock of buildings? – to make this reduction affordable?

Buildings renovation to increase efficiency and making it affordable by public subsidies

- *From a technological point of view? (Insulation, heat pumps, low CO_2 district network, geothermal systems, local PV production, etc.).*
  Insulation improvement, replacing old boilers with new more efficient ones, installing thermal and PV solar panels for auto- and small-scale consumption, replacing solid and liquid fuels with natural gas and heat pumps
- *From a regulatory point of view? Through land ownership regulations?*
  Through regulations on energy performance in buildings, according to the EU directive 2018/844 amending directives 2010/31[2] on energy performance of buildings and directive 2012/27[3] on energy efficiency. This directive reinforces the establishment of long-term renovation strategies by the EU countries to support the renovation of existing buildings in order to transform them to near zero energy buildings. The directive has been transposed into Spanish legislation by Royal Decree (RD) 390/2021 (see also: https://www.boe.es/buscar/pdf/2021/BOE-A-2021-9176-consolidado.pdf).

1 Eurostat: https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_c&lang=EN
2 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN
3 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0027&from=EN

- *Through subsidies, different financial mechanisms? Which are the priorities: reducing CO_2 or energy; Better inclusivity.*
  Subsidies to reduce energy consumption.
- *Replacing parts of the existing stock of buildings?*
  No.
- Is there a specific roadmap for this subject?
  Reducing energy consumption by *a)* renovating the thermal installations of 300 000 homes/year; and *b)* improving the thermal envelope of 120 000 homes/year, from 2020 to 2030.

Is there some roadmap for making existing cities more sustainable?

According to Law 7/2021 on Climate Change and Energy Transition, municipalities with more than 50 000 inhabitants shall develop sustainable urban mobility plans aimed at reducing emissions resulting from mobility. These shall include:

- the setting of low emission zones within the cities before 2023,
- measures to improve and promote public transport,
- measures for the electrification of the public transport network,
- measures to promote the use of private electrical transport means including recharging points,
- the promotion of electrical car-sharing mobility,
- measures aimed at promoting sustainable means of distributing goods.

Are there some case studies or best practices you would like to share?

-

3.2. New buildings

Does your country have a national policy regarding new buildings?
If yes, what are the priorities? (For housing and for office buildings)

Yes: a) RD 314/206, Technical Building Code [4], establishes the basic requirements with which new buildings shall comply, and b) RD 178/2021, Regulation on the Thermal Installations of Buildings[5].

Are some technologies prioritised, in particular for heating and cooling? At the building level? At the infrastructure level? (Development of district networks, prohibiting connection to the gas network…)

Energy supply by renewables and electrification are regarded as the main tools for the decarbonisation of the building sector

How are they supported? Through regulations? Subsidies?

Both regulations and subsidies: a) regulation, by the modification of the technical building code (RD 732/2019); and b) subsidies, expected from the Next Generation EU fund.

Are there some recommendations and regulations for sustainable districts and cities?

-

Are there some case studies or best practices you would like to share?

-

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[4] https://boe.es/buscar/pdf/2006/BOE-A-2006-5515-consolidado.pdf

[5] https://www.boe.es/eli/es/rd/2021/03/23/178/dof/spa/pdf

4. Industry

Three sectors of industry are considered below:

- Iron and Steel industry (including mining),
- Oil & Gas industry,
- hemical industry (in particular petrochemicals: ammonia, ethylene, plastic…)

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

Energy balances (2019)[6]

Fossil fuels, especially petroleum products and natural gas and electricity are the main energies in all three sectors; renewable energies has not been playing an important role so far.

a) Chemical industry

Natural gas is the main energy supply in the chemical industry, coal and coke are used in carbochemical plants

	Chemical & petrochemical
Coal and Coke	121.63
Petroleum Products	81.47
Natural Gas	2 593.14
Renewable energy	5.91
Electricity	790.63
Total	3 592.78

Table 8. Energy balance of Chemical sector (ktoe/year
(1ktoe = 0.01163 TWh, 3593 ktoe = 41.8 TWh))
Source of data: Eurostat. https://ec.europa.eu/eurostat/web/main/data/database. Open source

b) Steel industry

Coal and coke are used in blast furnaces, which account for about 25% of steel production

	Iron and Steel	Mining and quarrying*
Coal and Coke	77.28	
Blast furnace and coke oven gases	72.95	
Petroleum Products	79.33	145.94
Natural Gas	574.40	158.02
Renewable energy	0.03	0.94
Electricity	1 141.36	176.78
Total	**1 945.35**	**481.68**

Table 9. Energy balance of Steel industry (including Mining) (ktoe/year) (1945 ktoe = 22.6 TWh, 482 ktoe = 5.6 TWh)
* Includes mining activities of other metalic ores
Source of data: Eurostat. https://ec.europa.eu/eurostat/web/main/data/database. Open source

Note. - Data for the general mining sector, although including other activities than iron ore mining, are provided here to show the importance of their energy consumption relative to the purely industrial activities.

6 Source of data: Eurostat; https://ec.europa.eu/eurostat/web/main/data/database

c) Oil industry

Petroleum products include residual fuels and refinery off gases that are produced during the refining processes.

	Oil refining*
Coal and Coke	
Petroleum Products	4 719.212
Natural Gas	2 775.559
Renewable energy	
Electricity	355.546
Total	**7 850.32**

Table 10. Energy balance of Oil industry (ktoe/year) (7 851 ktoe = 91.3 TWh)
* Petroleum products include 4552 ktoe of refinery fuel gas
Source of data: Eurostat. https://ec.europa.eu/eurostat/web/main/data/database. Open source

GHG emissions and emission intensity

Emission intensities, calculated with respect to the production value, are similar to those of other countries (see *Tables 11, 12, 13*)

a) Chemical industry

	Chemical & petrochemical
GHG emissions from energy (ktCO_2-e)	9 645.66
GHG emission intensity (tCO_2-e/M€)	236.48

Table 11. Chemical Industry, GHG emissions and emission intensity
Source of data: Eurostat. https://ec.europa.eu/eurostat/web/main/data/database. Open source

b) Steel industry

	Iron and Steel
GHG emissions from energy (ktCO_2-e)	5 649.91
GHG emission intensity (tCO_2-e/M€)	426.56

Table 12. Steel Industry, GHG emissions and emission intensity
Source of data: Eurostat. https://ec.europa.eu/eurostat/web/main/data/database. Open source

c) Oil industry

	Oil refining
GHG emissions from energy (ktCO_2-e)	11 053.02
GHG emission intensity (tCO_2-e/M€)	289.91

Table 13. Oil industry, GHG emissions and emission intensity
Source of data: Eurostat. https://ec.europa.eu/eurostat/web/main/data/database. Open source

Are the best available low carbon technologies used / considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

In the European Union, according to the directive 2008/1/EC (the IPPC Directive), amended by directive 2010/75/EC, all installations of these sectors must implement Best Available Techniques (BAT) to minimise their impact on the environment.

Both directives have been transposed into the Spanish legislation; therefore, BATs have been considered and implemented in all aspects related to energy and pollutant emissions.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

As discussed above, Section 1, there is a long-term roadmap to 2050 that fosters the reduction / elimination of GHG emissions from 2020 up to 2050, with 2030 as an intermediate step. It then foresees reaching net-zero emissions in 2050 for those sectors, although there are no specific figures for intermediate steps.

Is the implementation of low-carbon technologies helped by the government? For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

The EU promotes the implementation of low carbon technologies trough a carbon pricing mechanism, which has allowed to create a carbon emissions market for the whole EU: the EU Emissions Trading System (EU ETS); all three sectors covered in this questionnaire response are mandatorily subjected to the system. The mechanism works under the cap-and-trade system by which a cap is set on the amount of greenhouse gases that can be emitted by the installations covered by the system. The cap is then reduced over time and so is the amount of emission permissions in the market. This flexible system promotes investment in low-carbon technologies when carbon costs exceed investment costs in such technologies.

Are there incentives for carbon capture, utilisation, and storage? How?

Carbon pricing through the EU ETS system acts as an incentive to promote carbon capture and storage (CCS); so far, it was only used in connection with a power station operating via coal gasification.

There are no other incentives for the moment, although the recently created Next Generation EU Fund could support the development of carbon capture projects, especially in hydrogen production plants.

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increasing recycling? Is a policy to increase recycling already in place or projected?

In 2020, Spain adopted the 'Circular Economy Strategy' *España Circular 2030* (Estrategia Española de Economía Circular: https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/economia-circular/espanacircular2030_def1_tcm30-509532_mod_tcm30-509532.pdf), which sets objectives for this decade, aligned with those of the European Action Plans, and aims, among others, reducing the national consumption of materials by 30%, improving the efficiency of water use by 10%, and cut waste generation by 15%, with respect to 2010. This will allow the GHG emissions from the waste sector to be below 10 million tonnes in 2030 (it was 13.5 in 2018).

Recycling is specifically important for chemicals, although there are no specific figures for it. Regarding steel, about 70% of production comes from scrap material. Recycling is much less important in the case of oil products.

SWEDEN

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Answer from the Royal Swedish Academy of Engineering Sciences (IVA).

Experts from authorities, industrial organisations and members of the IVA Academy have contributed to answering the questionnaire. The compilation has been made by Lennart Fredenberg, Member of the Royal Swedish Academy of Engineering Sciences (IVA)[1].

1. National energy profile 2019

Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consump-tion (TWh)	Elec/Energy (%)
1990	373.5	135.5	36.3
1995	416.4	136.6	32.8
2000	410.5	139.1	33.9
2005	398.5	139.3	35.0
2010	404.5	140.1	34.6
2015	375.2	132.5	35.3
2019	377.5	131.4	34.8

Table 1. Total yearly consumption: final energy, electricity (TWh)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factor

In the 2010s, total final energy consumption was still at a relatively steady level but decreased slightly. In both the housing and service sectors and the industrial sector, energy consumption remained at about the same level for a long period, although in the industrial sector, energy consumption fell slightly between 2010 and 2019. In the short term, the use of energy in residential and service towers is mainly affected by outdoor temperature, as a large part of it goes to heating. In the transport sector, energy use generally decreased in the 2010s, following the sharp increase it had been experiencing since the 1970s. Decrease in recent years is mainly due to improved energy efficiency in the sector, including through more energy-efficient vehicles.

Electricity use has been declining despite an increasing population. Since the beginning of the 2000s, the trend in electricity use has been slightly decreasing, although its level slightly varied over the years. Since 1990, the Swedish population has increased by more than 1.6 million. Just over half of the electricity is used in the housing and service sectors, followed by industry.

Another factor is the outdoor temperature as a large part of heating in Sweden, almost half of it, is based on electricity. Population changes and the development of energy prices are additional factors that affect the use of electricity.

[1] lennart.fredenberg@telia.com

Per capita yearly final energy and electricity consumptions (MWh)

Year	Inhabitants (per million)	Energy Consumption (TWh)	Energy Consumption per person and per year (MWh)	Electricity Consumption (TWh)	Electricity Consumption per person and per year (MWh)
1990	8.6	373.5	43.4	135.5	15.8
1995	8.8	416.4	47.3	136.6	15.5
2000	8.9	410.5	46.1	139.1	15.6
2005	9.0	398.5	44.3	139.3	15.5
2010	9.4	404.5	43.0	140.1	14.9
2015	9.8	375.2	38.3	132.5	13.5
2019	10.0	377.5	37.7	131.4	13.1

Table 2. Per capita yearly final energy and electricity consumptions (MWh)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=SE

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	52.1	1.6	6.1
1995	56.9	3.3	6.5
2000	52.0	3.5	5.9
2005	48.9	3.0	5.4
2010	46.8	3.9	5.0
2015	37.7	1.6	3.8
2019	33.7	2.0	3.1

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=SE

The main decrease occurred in the period 2003-2014. The largest contributions to the emission reduction since 1990 result from heating homes and premises and, in recent years, from industry and domestic transport.

CO_2 emissions by fossil energy source ($MtCO_2$)

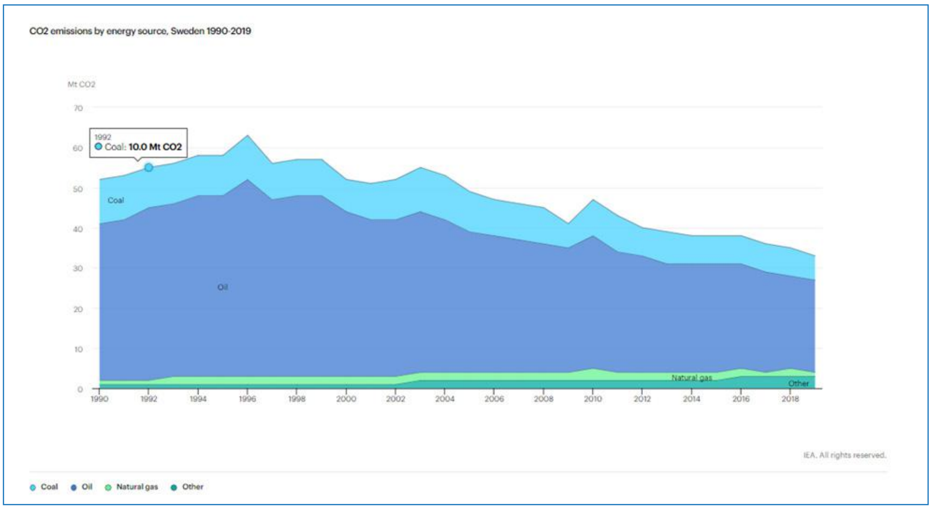


Fig. 1. CO_2 emissions by fossil energy source ($MtCO_2$), **IEA**
https://www.iea.org/countries/sweden

CO_2 emissions by sector ($MtCO_2$)

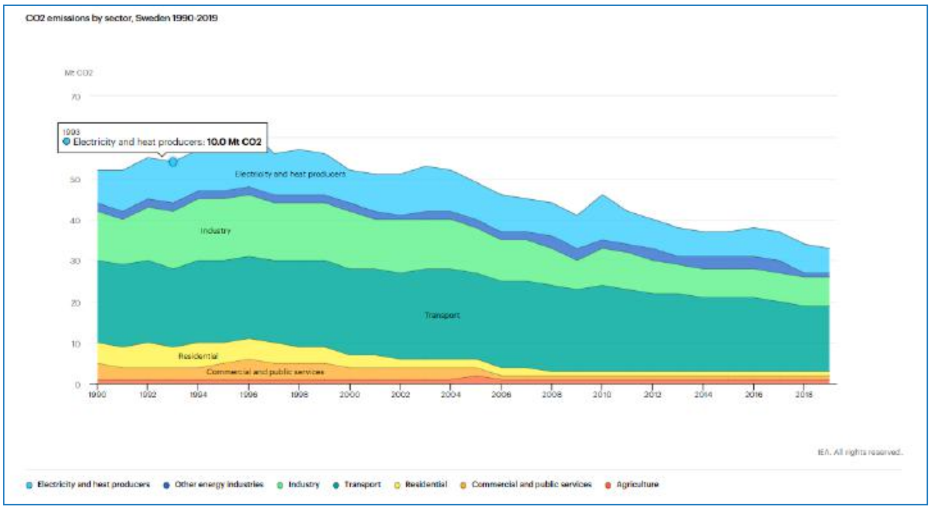


Fig. 2. CO_2 emissions by sector ($MtCO_2$), **IEA**
https://www.iea.org/countries/sweden

The emission reduction in the heating of homes and premises, residential uses, and commercial and public services, as well as electricity production and district heating, is largely a result of policy instruments and measures, such as investments in infrastructure for district heating, taxes on energy and carbon dioxide emissions, support for the installation of heat pumps and the electricity certificate programme that promotes the production of renewable electricity.

The reduction in emissions from domestic transport may largely be explained by the increasing use of biodiesel and biofuels, both through the declining use of fossil diesel and the increased share of pure biodiesel. Substituting new, more energy-efficient passenger cars for older vehicles also helped to reduce emissions. At the same time, mobile work increased during the period, which had a dampening effect on emission reduction.

Total emissions from the industry varied since 1990. To a large extent, such variations are due to fluctuations in production volumes linked to the economic cycles. Emissions from the industry then stabilised in the early 2000s despite a continued economic upturn in many industries. The decrease since 2006 is mainly due to changes in fuel use and reduced production volumes, as well as ongoing energy efficiency measures.

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

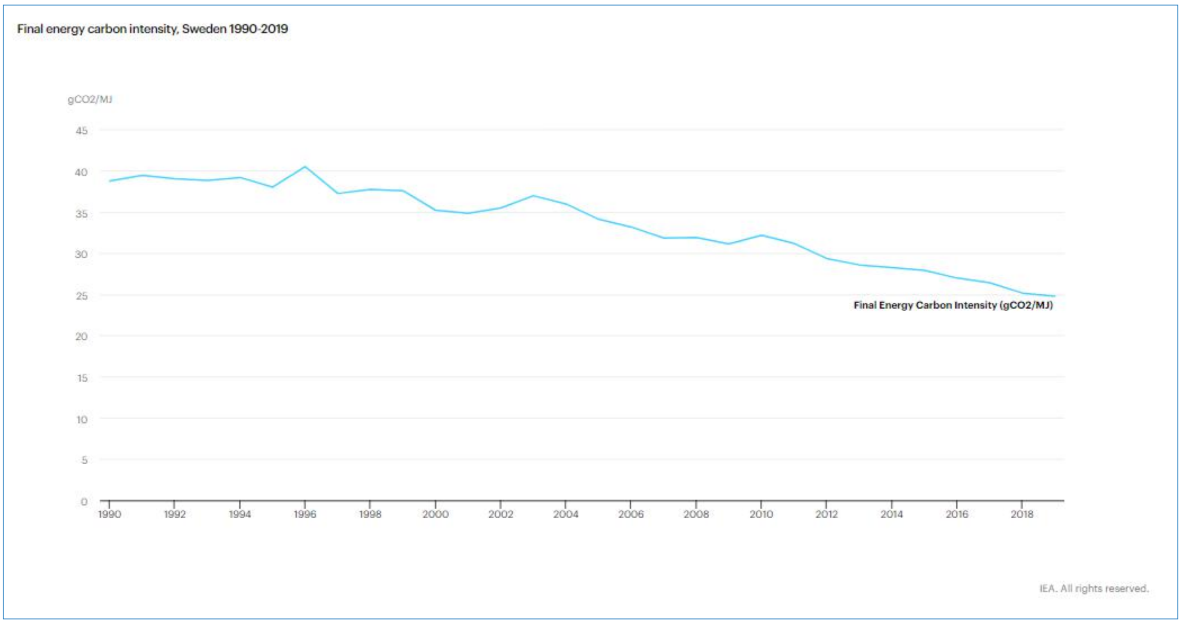


Fig. 3. Final energy carbon intensity, **IEA**
https://www.iea.org/countries/sweden

Since around 1985, energy supply has been relatively constant. Despite this, carbon intensity has been steadily falling. The main reasons include the increasing use of biofuels and electricity and district heating. The supply of biofuels has tripled over the last 40 years. During the same time span, the supply of crude oil and petroleum products has considerably decreased. The main reason for it is that residential buildings and facilities are rarely heated using petroleum today. From mid-1975, almost every new built one-family house was equipped with direct electricity heating. This happened during the introduction of nuclear electricity generation.

Electricity Carbon intensity: gCO_2/KWh

Swedish electricity production is currently 98% free of fossil fuels. Total generation in 2020 was 161 TWh (hydro 44%, nuclear 30%, wind 17%, cogeneration 8% - mostly bioenergy).

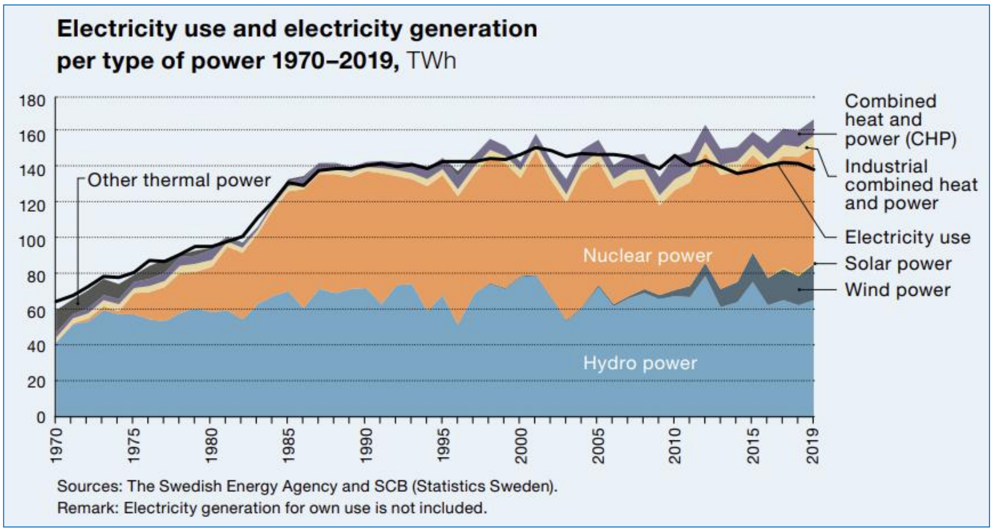


Fig. 4. Electricity generation per type of power
Source: "Energy in Sweden 2021. An Overview", to be automatically downloaded here: https://energimyndigheten.a-w2m.se/FolderContents.mvc/Download?ResourceId=198022 CC BY-NC

Electricity generation in Sweden mainly comes from hydropower and nuclear power. This has been the case since the 1980s. However, windpower has increased signicantly over the last ten years.

The dramatic increase in Swedish electricity production and usage from around 1970 to 1990 coincided with the introduction of nuclear power substituting for fossil fuel-fired condensing power plants. The increase in cogeneration for district heating is also mainly fossil-free, as biomass and waste constitute the fuel supply. Over the last 10 years, the share of wind power has substantially been growing while nuclear power plants have successively been shut down.

Overview of Sweden's energy supply and use

The Swedish official energy statistics are published by The Swedish Energy Agency.

The Swedish Energy Agency has given permission to use illustrations and diagrams in non-commercial contexts. Source: The Swedish Energy Agency "Energy in Sweden 2021 - an overview" (ET 2021:11).

The latest data collected has been published in *Energy in Sweden* 2021 - an overview, now available[2]. In Sweden, we use domestic renewable energy sources such as water, wind, the sun and biofuels. We also import nuclear fuels, biofuels and fossil fuels such as oil and natural gas. The energy system in Sweden may be categorised as supply-side and consumption-side. The following diagram illustrates energy system flows in 2019.

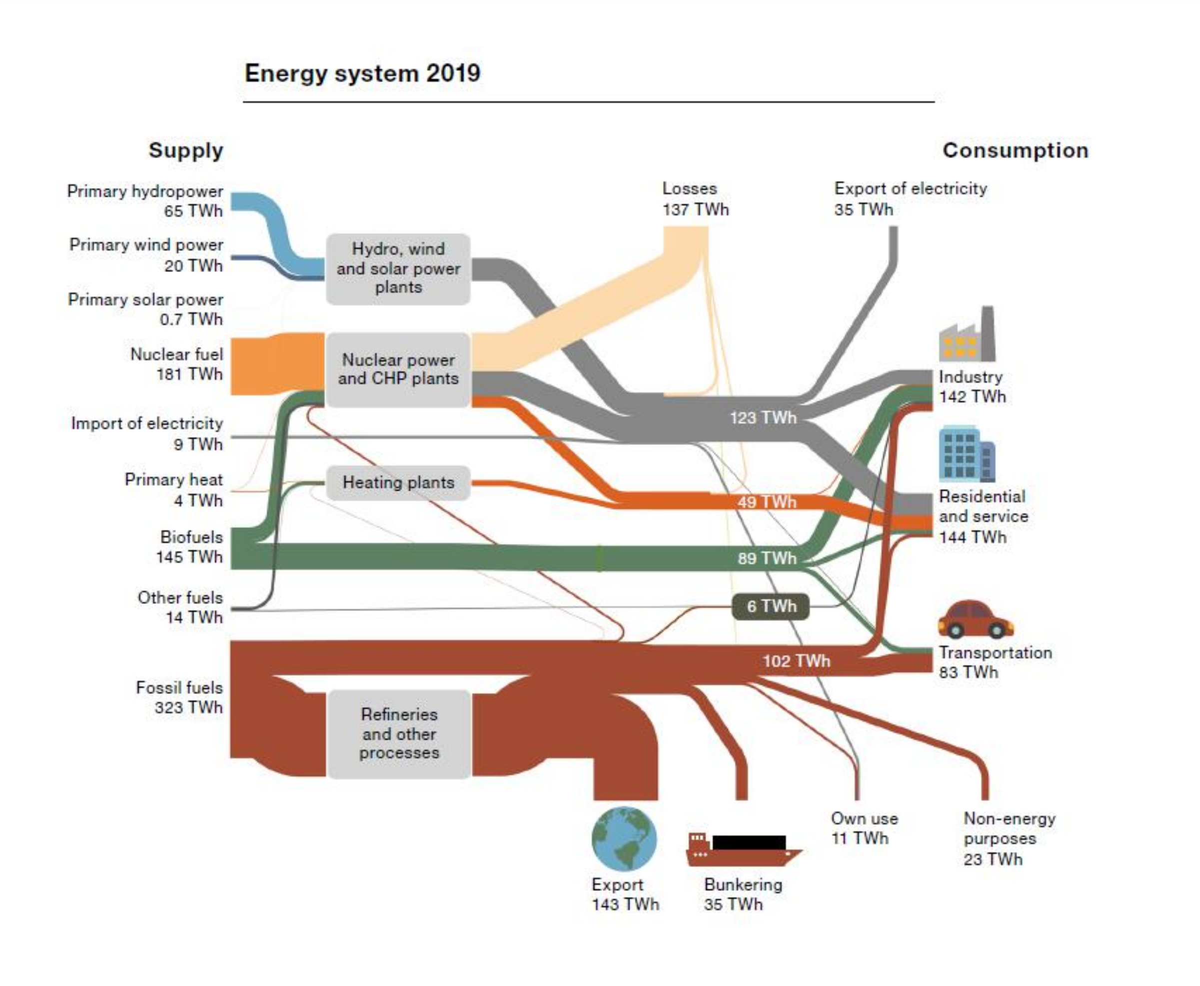
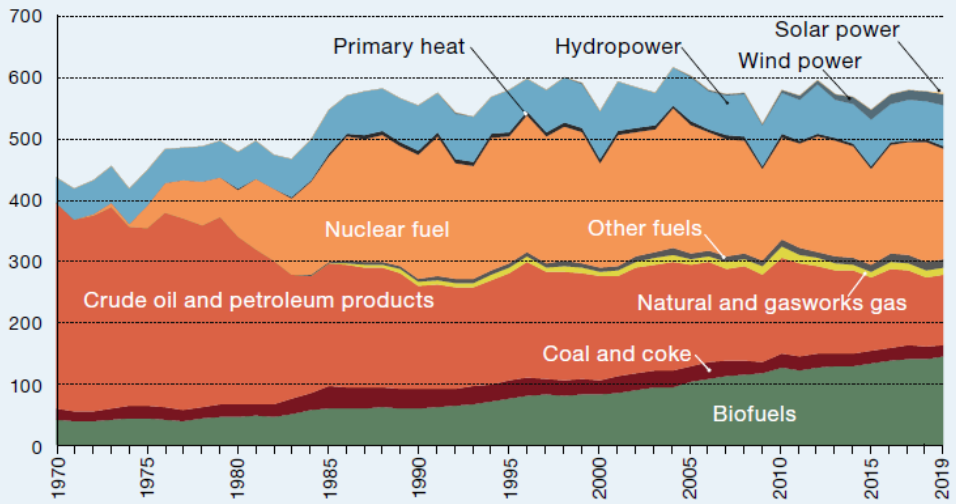


Fig. 5. Energy Systems 2019
Source: Energy in Sweden 2021 - an overview (4).pdf. CC BY-NC

2 https://energimyndigheten.a-w2m.se/Home.mvc?ResourceId=198022

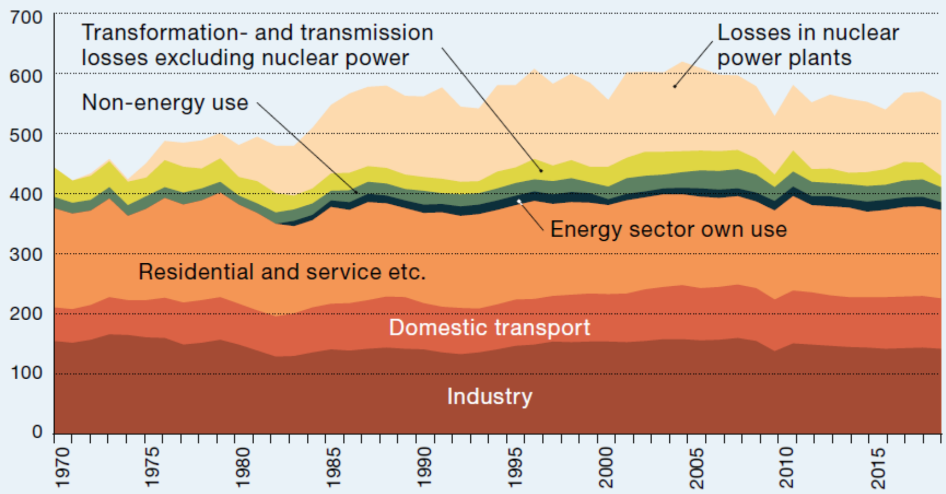
Total supplied energy 1970–2019, TWh



Sources: The Swedish Energy Agency and SCB (Statistics Sweden).
Remarks: 1) Other fuels are included in biofuels until 1983. 2) Domestic aviation fuel is included in crude oil and petroleum products until 1989. 3) Nuclear fuel is calculated according to the method used by the UN/ECE for calculating supplied energy from nuclear power.
4) Primary heat refers to heat pumps in district heating.
5) Wind power is included in hydropower until 1989.

Fig. 6. Total energy supply by energy carrier
Source: Energy in Sweden 2021 - an overview (4).pdf.

Total final energy use, 1970–2018, TWh



Sources: The Swedish Energy Agency and SCB (Statistics Sweden).
Remarks: 1) Foreign aviation was included in final energy use until 1989.
2) Own use within the energy sector was included in transformation- and transmission losses until 1982. 3) Losses in nuclear power plants are calculated according the method used by the UN/ECE to calculate supplied energy from nuclear power.

Fig. 7. Total energy use in different sectors
Source: Energy in Sweden 2021 - an overview (4).pdf.

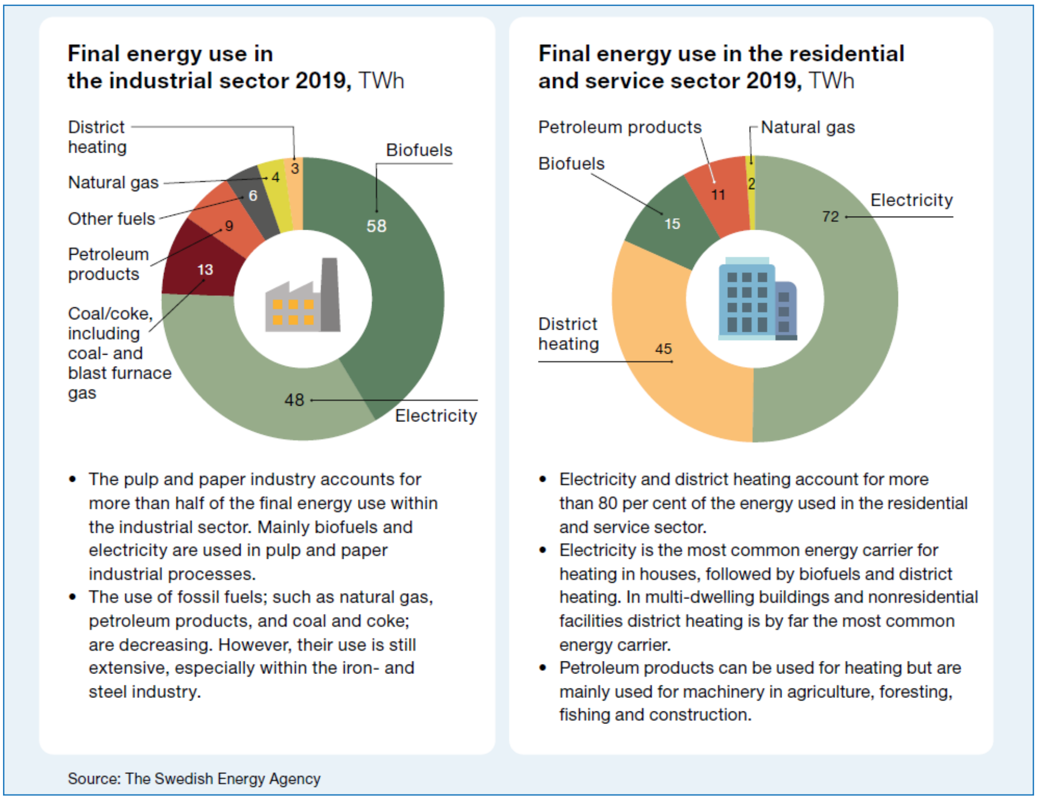


Fig. 8. Final energy use in industrial (left) and residential and service (right) sectors
Source: Energy in Sweden 2021 - an overview (4).pdf. CC BY-NC

2. Energy perspectives 2030 - 2050

If possible, give the national perspectives for 2030 and 2050 or the roadmap to 2030 and 2050 if they exist.

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?
In 2017, Sweden adopted a new climate policy framework. It consists of a climate act, climate targets and a climate policy council. Sweden's long-term target is net zero greenhouse gas emissions by 2045 at the latest. **The framework was adopted by the Parliament with a broad majority of the political parties**[3].

The long-term target for Sweden is net zero greenhouse gas emissions by 2045 at the latest. After 2045, Sweden is to achieve negative net emissions.

Roadmap for the energy mix
The share of renewable energy shall be at least 50% of total energy consumption by 2020.

Roadmap for the GHG emissions (country, per capita)
Specific targets are set for the non-EU-ETS[4] sectors:

- by 2020, emissions are to be 40% lower than in 1990,
- by 2030, emissions are to be 63% lower than in 1990,
- by 2040, emissions are to be 75% lower than in 1990.

Roadmap for the electricity mix
100% of electricity production shall be from renewable sources by 2040. This is however not a cut-off date for banning nuclear power.

[3] Source: the-swedish-climate-policy-framework.pdf (government.se)
[4] EU Emissions Trading System

Energy balance (energy sources to end-uses) – see also *Electricity Carbon intensity: gCO$_2$/KWh*, page 116

- By 2020, energy consumption shall be 20% more efficient than in 2008;
  - the share of renewable energy shall be at least 50% of total energy consumption,
  - the share of renewable energy in the transport sector shall be at least 10%.
- Moreover, by 2030, energy consumption shall be 50% more efficient than in 2005, expressed as primary energy vs. GDP.

SWITZERLAND

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1. National energy profile 2019

In this report, the indicators for the national energy profiles (GHG emissions, energy mix, electricity mix, energy sources to end-uses) are based on figures from the IEA database.

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	204.7	50.0	24.4
1995	216.6	51.3	23.7
2000	224.1	56.4	25.2
2005	236.0	61.8	26.2
2010	239.1	64.0	26.8
2015	216.5	62.1	28.7
2019	210.7	63.1	30.0

Table 1. Total annual consumption: final energy, electricity (TWh)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors

During this period, three main factors in the evolution have been: (a) an increase of the population from 6.7 million to 8.6 million (+ 28.4%); (b) a decrease in the manufacturing industry; (c) progress in energy efficiency measures. There was a peak in energy consumption around 2010 and a slow decline down to 2019. The result is an overall increase of 3% in final energy consumption over the period 1990-2019.

Electricity consumption increased by 26 per cent between 1990 and 2019, however electricity consumption per person and per year peaked around 2005 and returned to 1995 levels in 2019.

The ratio of electricity consumption to final energy consumption increased continuously, to a value of 30% in 2019.

Year	Inhabitants (per million)	Energy Consumption (TWh)	Energy Consumption per person and per year (MWh)	Electricity Consumption (TWh)	Electricity Consumption per person and per year (MWh)
1990	6.7	204.7	30.6	50.0	7.5
1995	7.0	216.6	30.1	51.3	7.3
2000	7.1	224.1	31.6	56.4	7.9
2005	7.4	236.0	31.9	61.8	8.3
2010	7.8	239.1	30.7	64.0	8.2
2015	8.3	216.5	26.1	62.1	7.5
2019	8.6	210.7	25.5	63.1	7.3

Table 2. Total annual consumption per capita: final energy, electricity (MWh per capita per year)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=CH.

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	40.8	1.0	6.0
1995	41.5	1.3	5.8
2000	42.0	1.5	5.8
2005	44.0	1.7	5.9
2010	43.3	1.6	5.5
2015	37.4	1.6	4.5
2019	35.6	1.8	4.2

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Source: Based and/or calculated from the following data: **International Energy Agency** - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region **IEA** (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=CH

The significant reductions in CO_2 emissions over the last 20 years are both a consequence of the decrease in industrial activities in Switzerland on one side and of measures to improve energy efficiency. The emissions level per capita is low compared to many other industrialised countries since the electricity production mix is largely decarbonised due to a big share of nuclear and hydraulic generation.

CO_2 emissions by fossil energy source ($MtCO_2$)

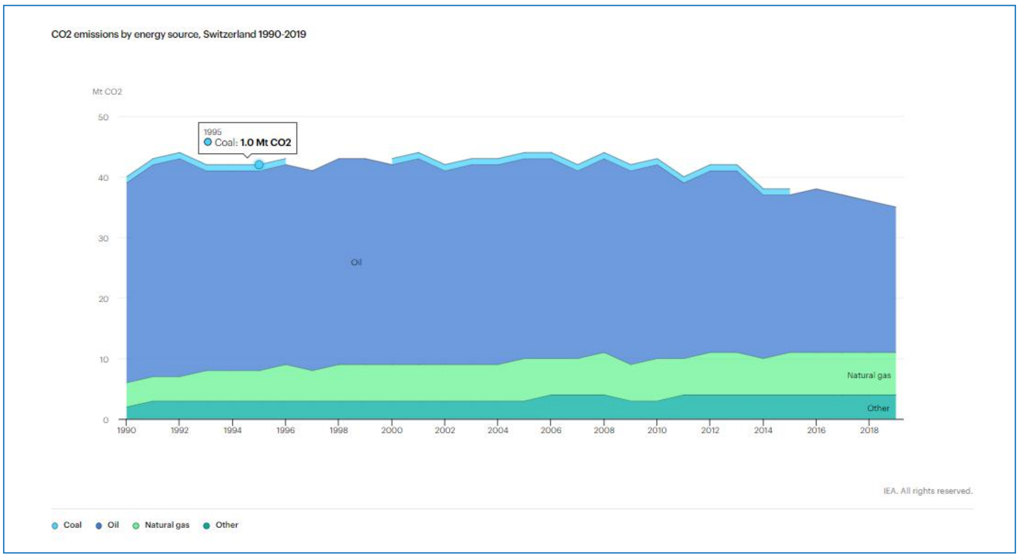

Fig. 1. CO_2 emissions by fossil energy source ($MtCO_2$), **IEA**
https://www.iea.org/countries/switzerland

The share of power generation based on fossil fuels (oil and gas based) is very low in Switzerland. Coal is not used for this application. Fossil fuels are mainly used for heating, industry and mobility. The use of oil is slightly decreasing as heating is moved to heat pumps and other non-fossil sources, but the use of natural gas has been slightly increasing.

CO_2 emissions by sector ($MtCO_2$)

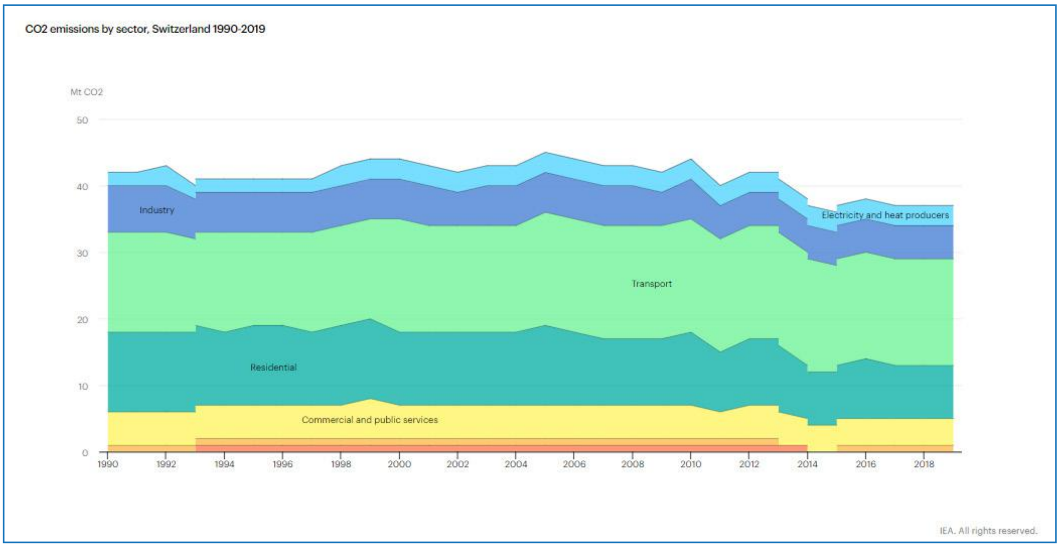

Fig. 2. CO_2 emissions by sector ($MtCO_2$), **IEA**
https://www.iea.org/countries/switzerland

CO_2 emissions in all sectors have slightly decreased but their ratio stays rather constant.

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

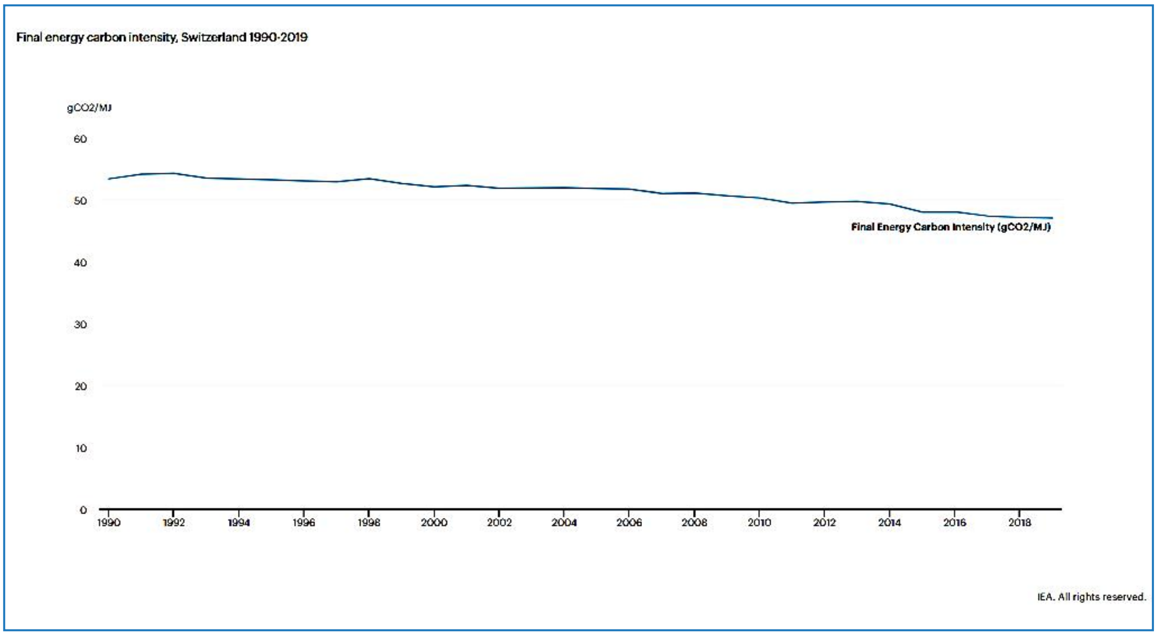

Fig. 5. Final energy carbon intensity, **IEA**
https://www.iea.org/countries/switzerland

Final energy carbon intensity decreased from 15.2 gCO_2/kWh in 1990 to 13.4 gCO_2/kWh in 2019.

Electricity Carbon intensity: gCO_2/kWh

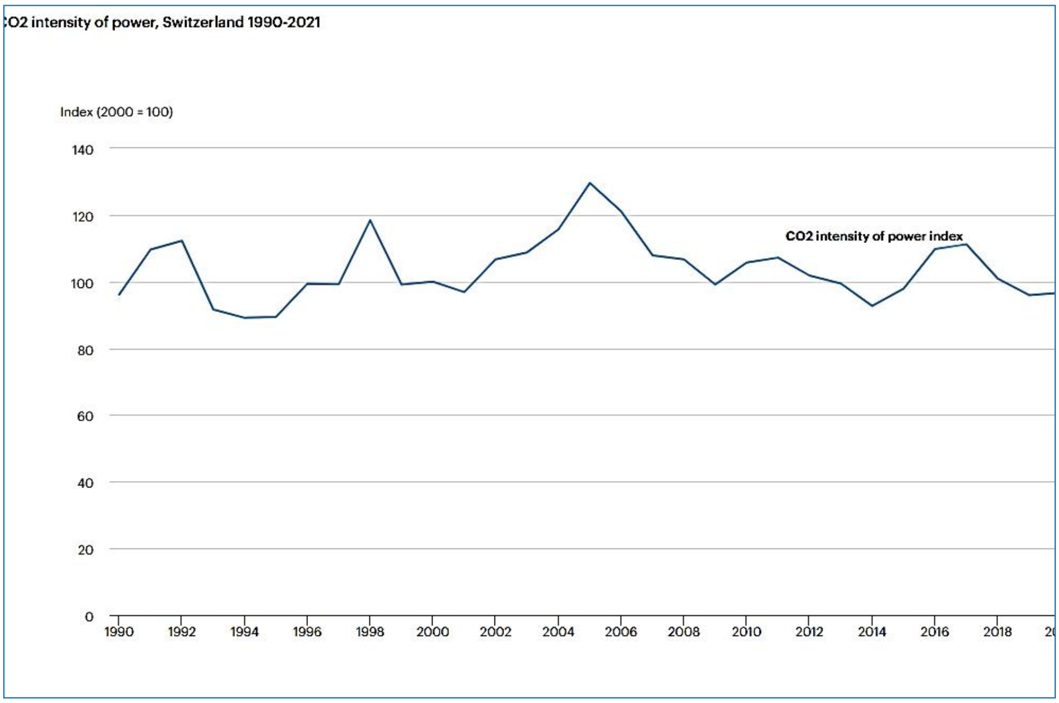

Fig. 4. Electricity carbon intensity (gCO_2/kWh), **IEA**
https://www.iea.org/countries/switzerland

Switzerland has one of the lowest electricity carbon intensities among IEA countries, owing to a carbon-free electricity sector dominated by nuclear and hydro generation. However, following a 2017 referendum where the Swiss voted to gradually phase-out nuclear power, Switzerland's energy sector has thus to undergo a considerable transition.

2. Energy perspectives 2030 - 2050

In Switzerland, the goal is net zero emissions by 2050.

The Swiss Energy Strategy 2050 aims at maintaining the high supply standard and at the same time contributes to reducing Switzerland's energy-related environmental impact. Based on the strategy, a new Federal Energy Act entered into force on 1 January 2018. The main strategic objectives of the energy strategy are:

- measures to increase energy efficiency in buildings, mobility, industry and appliances,
- measures to increase the use of renewable energy by promotion and improved legal framework,
- withdrawal from nuclear energy (required by a popular vote in 2017). No new licenses will be given and there will be a step-by-step withdrawal – with safety being as sole criterion.

The energy strategy is based on the Energy Perspectives to 2050[1]. For these perspectives, various scenarios were modelled and analysed with respect to energy sources and electricity production, final energy consumption by sector, greenhouse gas emissions, etc.

[1] https://www.bfe.admin.ch/bfe/en/home/policy/energy-perspectives-2050-plus.html

Does your country have national roadmaps regarding energy production and GHG emissions? What legal status do these documents have? What is their timeline?

Switzerland has a long-term climate strategy to 2050[2] to fulfil the terms of the Paris Agreement and to aim for the net zero emissions target for 2050.

Switzerland has a roadmap for electricity production and GHG reduction. In 2017, the country decided to discontinue nuclear power production and ban the construction of new nuclear plants. However, there is a discussion to prolong the use of existing nuclear plants beyond 2030 as originally decided. Part of the strategy is to import power for a time span, 2020 to 2045, until enough renewable energy is available. The amount of fossil electricity generation is already negligible today.

One pillar of the energy strategy is to improve energy efficiency per capita and raise the percentage of renewable energy.

Key indicative energy efficiency and renewable targets of the ES 2050

Energy efficiency (indicative/non-binding targets)	Per capita energy consumption	-16% by 2020 vs. 2000 level -43% by 2035 vs. 2000 level -54% by 2050 vs. 2000 level
	Per capita electricity consumption	-3% by 2020 vs. 2000 level -13% by 2035 vs. 2000 level -18% by 2050 vs. 2000 level
Renewable electricity (indicative/non-binding targets)	Average yearly production of renewable electricity excluding large hydro	By 2020: 4 400 gigawatt hour (GWh) By 2035: 11 400 GWh By 2050: 24 200 GWh
	Average yearly production of large hydropower	By 2035: 37 400 GWh By 2050: 38 600 GWh

Source: Swiss Federal Office for Energy.

Table 4. Key indicative efficiency and renewable targets of the ES 2050, **IEA**.
https://www.iea.org/reports/energy-policies-of-iea-countries-switzerland-2018-review

Roadmap for the energy mix

Switzerland projects and plans a reduction in Total Final Consumption (TFC) of more than 50% by 2050.

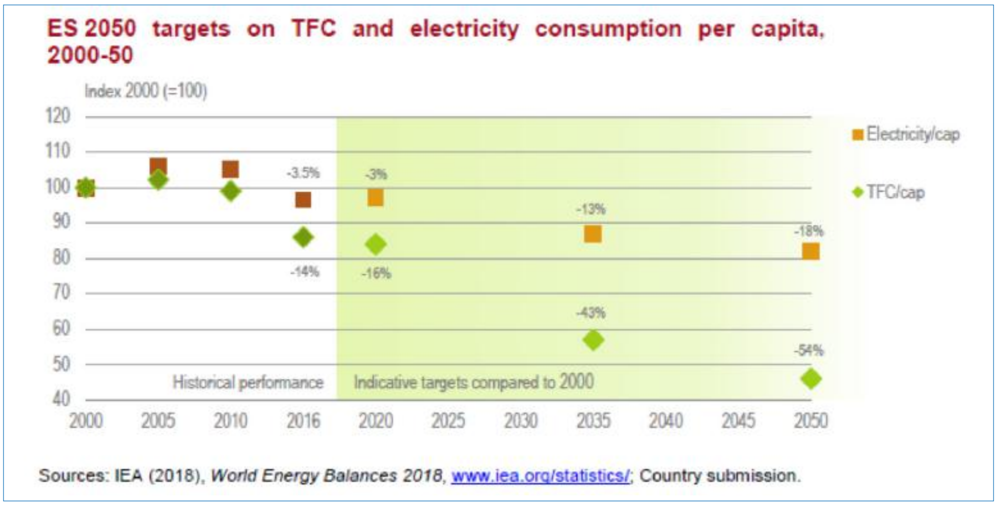

Fig. 5. ES 2050 targets on TFC and electricity consumption per capita 2000-2050, **IEA**.
https://www.iea.org/statistics/

2 https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/emission-reduction/reduction-targets/2050-target/climate-strategy-2050.html

Roadmap for the GHG emissions (country, per capita)

Sectoral emissions reductions, 1990 and to 2020 and 2030

Sectoral emissions ($MtCO_2$-eq)	1990	2020	2030 (business as usual)	2030 (additional policies)
Buildings	17.1	12.0	10.6	6.9
Industry	13.0	10.7	10.4	8.7
Transport	14.9	15.7	14.9	13.6
Agriculture	7.3	6.5	6.5	5.7
Others	1.4	2.2	1.6	1.4
Total	53.7	47.1	44.0	36.3
Total (%)	100	87.7	81.8	69.5

Source: Information provided by the Swiss Federal Office for Energy.

Table 5. Roadmap for GHG emissions (country and par capita), **IEA**
https://www.iea.org/reports/energy-policies-of-iea-countries-switzerland-2018-review

The measures of the existing CO_2-law from 2000 are not sufficient to reach the targets of the climate strategy but a revised CO_2-law (to encourage additional policies) was rejected in a national vote on June 13, 2021. Other options to build a legal basis for the net-zero target are currently being discussed in the Swiss parliament.

Roadmap for the electricity mix

TWh		Realised 2019	2030 Scenario	2050 Scenario
Nuclear		25.3	8.8	0.0
Fossil	Coal	0.0	0.0	0.0
	Fuels/gas	1.9	1.6	1.0
Renewable	Hydro	40.6	41.7	44.7
	PV / wind / other renewable	4.2	10.9	39.1
Total		72.0	63.0*	84.8

Table 6. Roadmap for the electricity mix
Source: Energieperspektiven 2050+ (admin.ch) Public data
*The missing 7.5 TWh of electricity are planned to be imported.

CO_2 emissions from electricity production

The present Swiss electricity sector is highly decarbonised with 28 $MtCO_2$ equivalent in 2019.

Energy balance (energy sources to end-uses)

The overall energy balance of Switzerland can be illustrated as shown in the graphic below. Major flows are fossil fuel imports, mainly used in transport, and electricity (generated from hydro and nuclear and other sources), mostly used in households, industry and services.

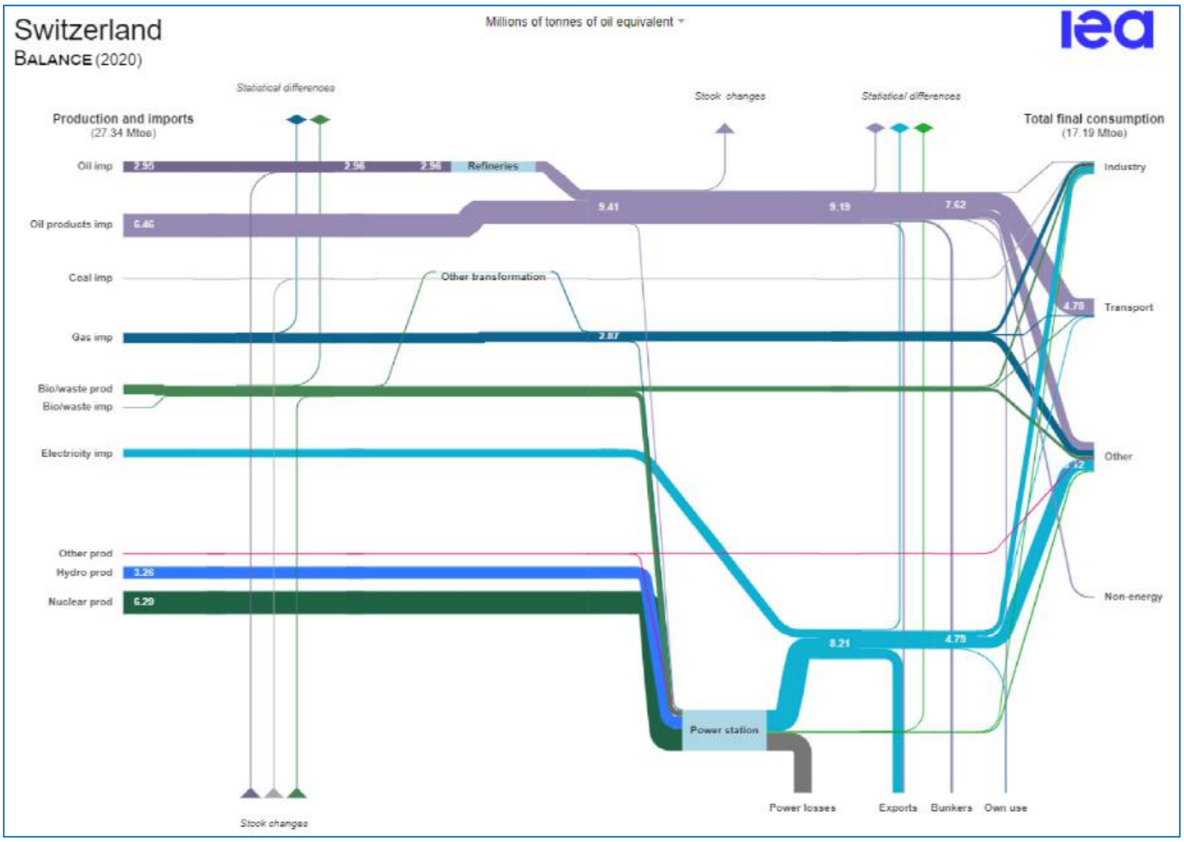

Fig. 6. Sankey diagram: Swiss EnergyBalance, **IEA**
https://www.iea.org/sankey/#?c=Switzerland&s=Balance

3. Building sector

3.1. Existing buildings

Energy balance 2019 (energy sources to end-uses)

According to the SFOE, the Swiss buildings stock consumes approximately 100 TWh, i.e. 45% of the total end energy demand in Switzerland. Buildings also account for about one third of Switzerland's CO_2 emissions[3]. 75% of the energy consumption are used for heating purposes, 50% being based on oil and 25% on gas.

The Swiss data are based on a report from 2014.

Energy partition between single houses, apartments buildings and office buildings

Type of building	number / Million	Million m² inhabited
All	1.8	800
Apartment buildings	0.5	350
single family homes	1.0	160
offices		60
business		40
industry		80

Table 7. Energy partition: single houses, apartment buildings, office buildings
Source: https://www.bfe.admin.ch/bfe/en/home/efficiency/buildings.html. Open Source

There is no statistics for all Switzerland. The data above are estimates.

The building sector consumes about 50% of the energy demand in Switzerland. The goal is to reduce this consumption by 50% by 2050. An international comparison is shown below.

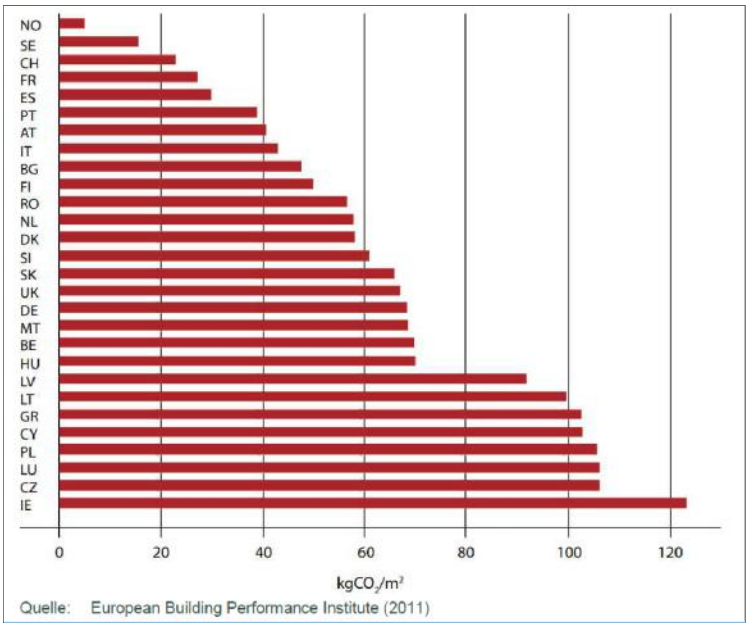

Fig. 7. CO_2 emissions per m² and by country
Source: CO_2 emissions from residential buildings and commercial and public services (% of total fuel combustion) - Switzerland | Data (worldbank.org)
CC BY-NC

[3] See https://www.bfe.admin.ch/bfe/en/home/efficiency/buildings.html.

Which systems are mostly used for heating?

- Local systems (Furnaces, electric heating, heat pumps, solar thermal panels, geothermal systems, etc.)?

The mix depends on the year of construction, for modern houses, heat pumps are the most frequent sources of heat.

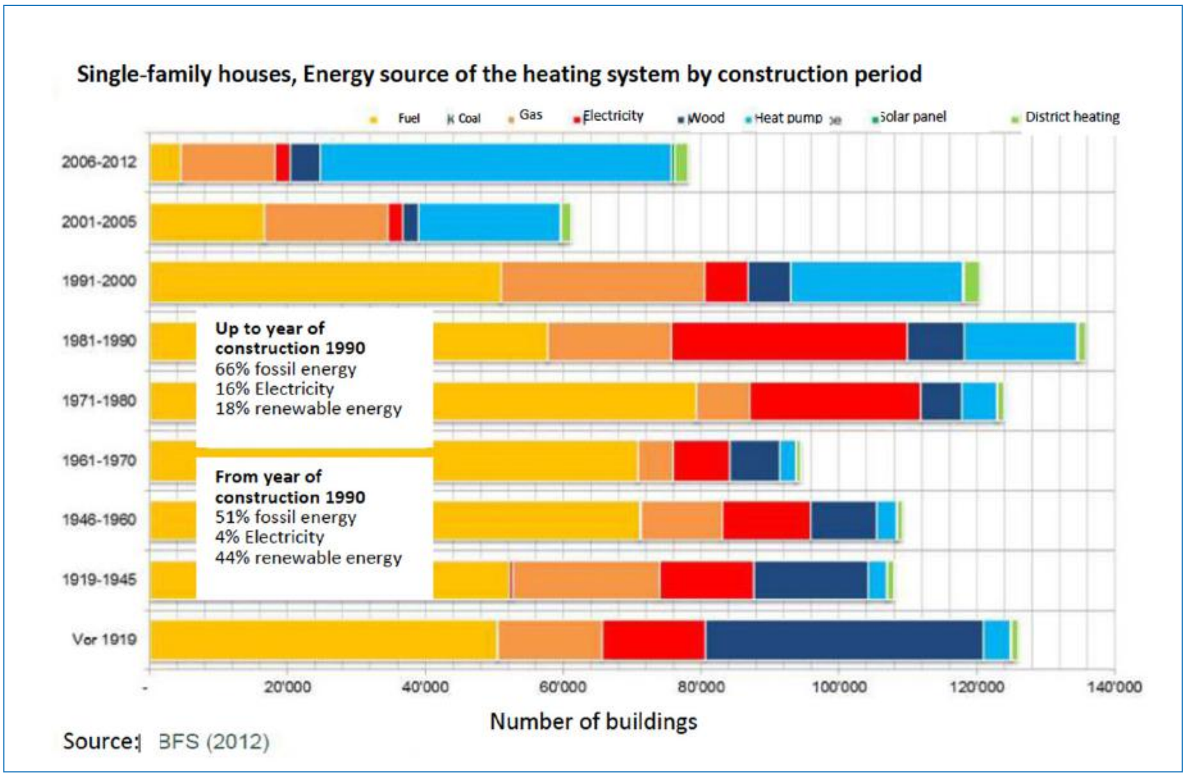

Fig. 8. One-family houses: energy type for space heating by construction period (translated from German). CC BY-NC

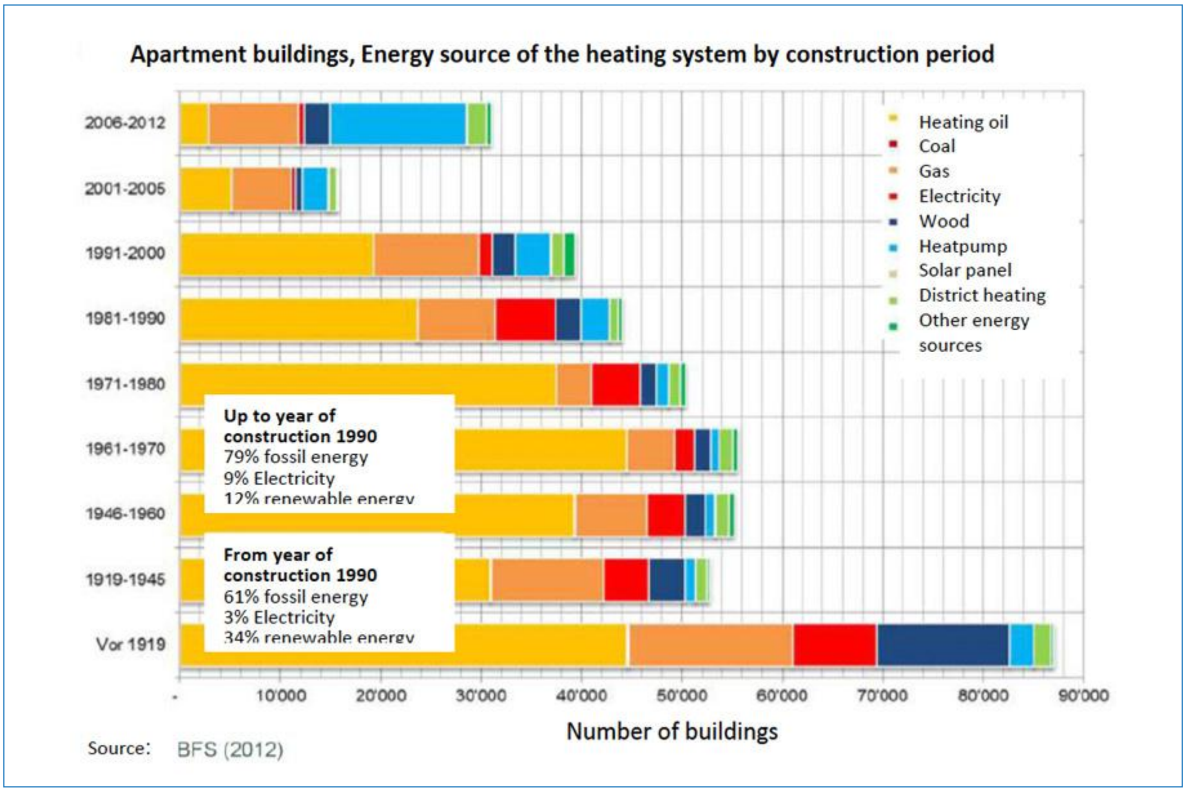

Fig. 9. Buildings for several families: energy type for space heating by construction period (translated from German). CC BY-NC

- Heat networks (hot water, steam). In this case, which energy sources are used? What is the CO_2 content per MWh th?

Local systems are dominant, but about 1 000 thermal networks exist in Switzerland, mostly in urban areas. They supply 6 TWh to 8 TWh heat per year (according to different sources).

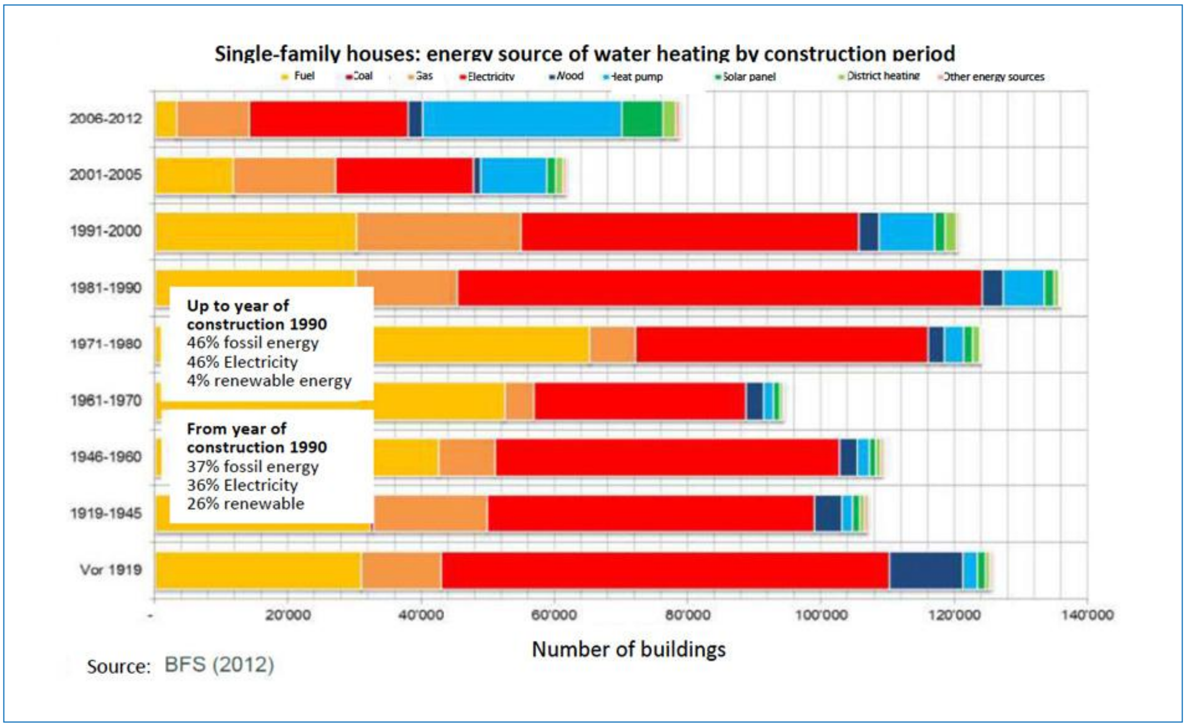

Fig. 10. One-family houses: energy type for hot water by construction period (translated from German). CC BY-NC

What are the main choices of the national policy – if there is one – to reduce the emissions from the existing stock of buildings? To make this reduction affordable?

The national energy strategy contains measures for increasing energy efficiency in buildings. These consist of a building programme that subsidises both the costs of the energy-saving renovation of buildings and the tax incentives for building renovation. The building programme supports insulation, the replacement of heating systems, as well as energy-efficient new buildings to replace older ones. The national strategy is implemented by the cantons, each of which has its own programme.

- From a technological point of view? (Insulation, heat pumps, low CO_2 district network, geothermal systems, local PV production, etc.).

All of this except deep geothermal, which has not been successful in Switzerland, generating concerns around earthquakes. Depending on the region, low-depth geothermal (around 150 m) is widespread, though.

- From a regulatory point of view? Through land ownership regulations?

Building policies are not national but cantonal. Each canton has different programmes to renew the building sector and also restrictions on new buildings. Several cantons have banned fossil fuel heating systems in new houses or even do not allow to renew existing furnaces. Other cantons require certain percentages of renewable energy for all public buildings.

- Through subsidies, different financial mechanisms? Which are the priorities: reducing CO_2 or energy; Better inclusivity.

Subsidies in the form of rebates or tax credits are the most common financial incentives. Direct subsidies are sometimes given to change the heating system or install PV.

The focus is on the reduction of CO_2.

[Energie sparen und Fördergelder erhalten | Das Gebäudeprogramm (dasgebaeudeprogramm.ch)](https://www.dasgebaeudeprogramm.ch)

- Replacing parts of the existing stock of buildings?

- Is there a specific roadmap for this subject?

Most cities have set up sustainability strategies and / or targets to reach net-zero in their own responsibility. The national Sustainable Development Strategy 2030[4] is the general framework.

Are there some case studies or best practices you would like to share?

There are numerous interesting projects related to sustainability and energy – e.g. the winners of the Watt d'Or awards[5].

3.2. New buildings

Does your country have a national policy regarding new buildings? If yes, what are the priorities? (For housing and for office buildings)

The federal government only plays a subsidiary role in the regulation of energy use in buildings. The Federal Constitution stipulates that the cantons have prime responsibility for implementing measures to regulate energy consumption in buildings. Therefore, this question cannot be answered in a general manner – various implementations exist among regions and cities.

Switzerland has a rather ambitious building code for new buildings and renovations.

Requirements for the building heat insulation are provided below in comparison to other countries.

	UK(3)	RO	DE	SK	CH(2)	DK	CZ	AT	PL	LT	EE	SE(4)	NO	FI
HDD	3 115	3 129	3 239	3 453	3 482	3 503	3 571	3 573	3 616	4 094	4 444	5 444	5 646	5 850
Roof	0.2	0.2	0.24	0.19	0.17 or 0.2	0.2	0.24	0.2	0.25	0.16	0.15-0.2	0.4-0.6	0.18	0.09
Walls	0.3	0.56	0.24	0.32	0.17 or 0.2	0.3	0.3	0.35	0.3	0.2	0.2-0.25		0.22	0.17
Floor	0.25	0.35	0.3		0.17 or 0.2	0.2	0.45	0.4	0.45	0.25	0.15-0.2		0.18	0.16
Window/ Door	2	1.3		1.7	1.3	1.8	1.7	1.4	1.7	1.6	0.7-1.4		1.6	1.0

Quelle: Buildings Performance Institute Europe (2011)

Table 8. Requirements for heat insulation for new buildings – comparison between Switzerland and other European countries (HDD = Number of heating degree days in the year)
Source: Building Performance Institute Europe (2011). Reproduced with permission

Are some technologies prioritised? At the building level? At the infrastructure level? (Development of district networks, prohibiting connection to the gas network…)

Not on a federal level. However, on a cantonal level, oil and gas heating are to be phased out or banned in certain areas. District heat networks are promoted, and so are heat pumps.

4 https://www.are.admin.ch/are/en/home/sustainable-development/strategy/sds.html
5 https://www.bfe.admin.ch/bfe/en/home/swiss-federal-office-of-energy/watt-d-or/winners-of-the-watt-dor-awards/winners-of-the-2021-watt-d-or-awards.html

How are they supported? Through regulations? Subsidies?

Both, depending on the area. Mainly subsidies, though.

Are there some case studies or best practices you would like to share?

- Steel industry (including mining): basically not existing in Switzerland.
- Cement industry: we will comment.
- Oil industry (refinery): basically not existing in Switzerland.
- Chemical industry (in particular petrochemicals: ammonia, ethylene, plastic…): only fine chemical industry in Switzerland.
- Information and telecommunication.
- Food and agriculture (from farm to fork).

4. Industry and Agriculture

4.1. Cement industry

Data are based on the website of CEMsuisse[6], not on government data.

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

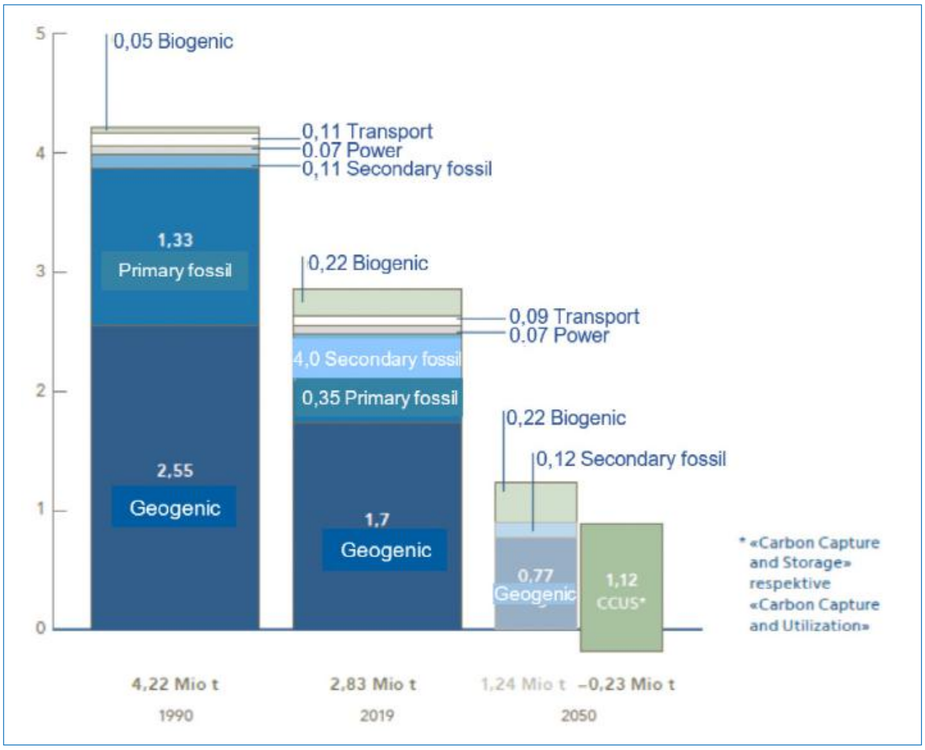

Fig. 11. Evolution of energy sources for cement production 1990, 2019, 2050 (translated from German).
Source: CEMsuise, CC BY-NC

6 Verband der Schweizerischen Cementindustrie - cemsuisse

Are the best available low carbon technologies used/considered?
If not, is it an economic problem? A matter of regulation? Or some social issues?

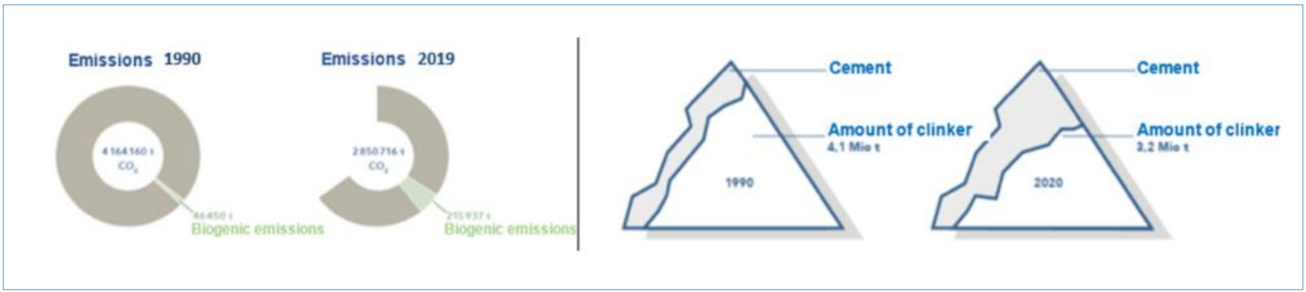

Fig. 12. Evolution of CO_2 emissions 1990 – 2019 and Cement/Clinker share 1990, 2020, (translated from German)
Source: CEMsuisse, CC BY-NC

Low carbon technologies are considered. The greatest reduction has been achieved by using lower carbon emission cement types[7].

The other approach is to use new building architecture with less cement and radically new supporting structures[8].

EMPA, the Swiss federal material research institute runs a large prototype building (NEST) to investigate low carbon building[9].

Is there a roadmap to decrease GHG emissions for 2030 - 2050
If yes, what are the intermediary steps?

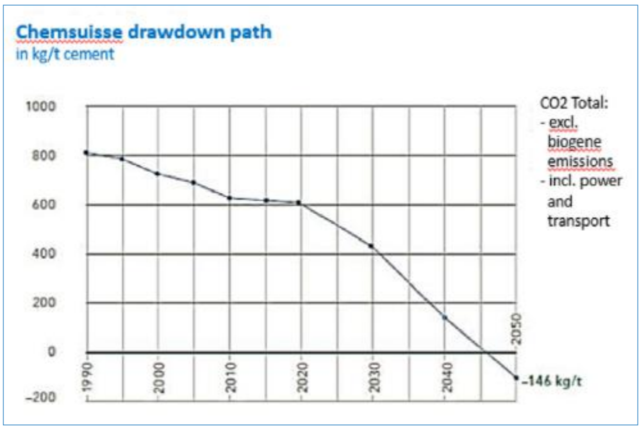

Fig. 13. Evolution of CO_2 emissions from cement manufacturing 1990 – 2050
Source: CEMsuisse, CC BY-NC

Is the implementation of low-carbon technologies helped by the government? For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

Since 2008, Switzerland has a CO_2 levy[10], which has increased from 12 CHF/tonne in 2008 to nearly CHF 100 now. Operators of greenhouse gas-intensive installations can be exempted from the CO_2 levy if they commit to reducing their emissions. Industries with high energy consumption have consistently invested in CO_2 reduction. There are no direct or other subsidies.

7 See Holcim's Climate responsibility: https://holcim.com/sustainability/net-zero

8 Center for Augmented Computational Design in Architecture, Engineering and Construction | ETH Zurich: https://designplusplus.ethz.ch/

9 Empa - NEST - STEP2

10 https://www.bafu.admin.ch/bafu/en/home/topics/climate/info-specialists/reduction-measures/co2-levy.html

Are there incentives for carbon capture, utilisation, and storage? How?

There are no direct incentives on how to reduce CO_2 emission. Carbon capture, storage and compensation are all measures considered by the cement industry to reach the reduction goal. The general understanding is that carbon capture technology now and probably up to 2050 cannot fully compensate the emissions. Other options such as emission trading by foundations such as KliK[11] (Foundation for Climate Protection and Carbon Offset) will need to be implemented.

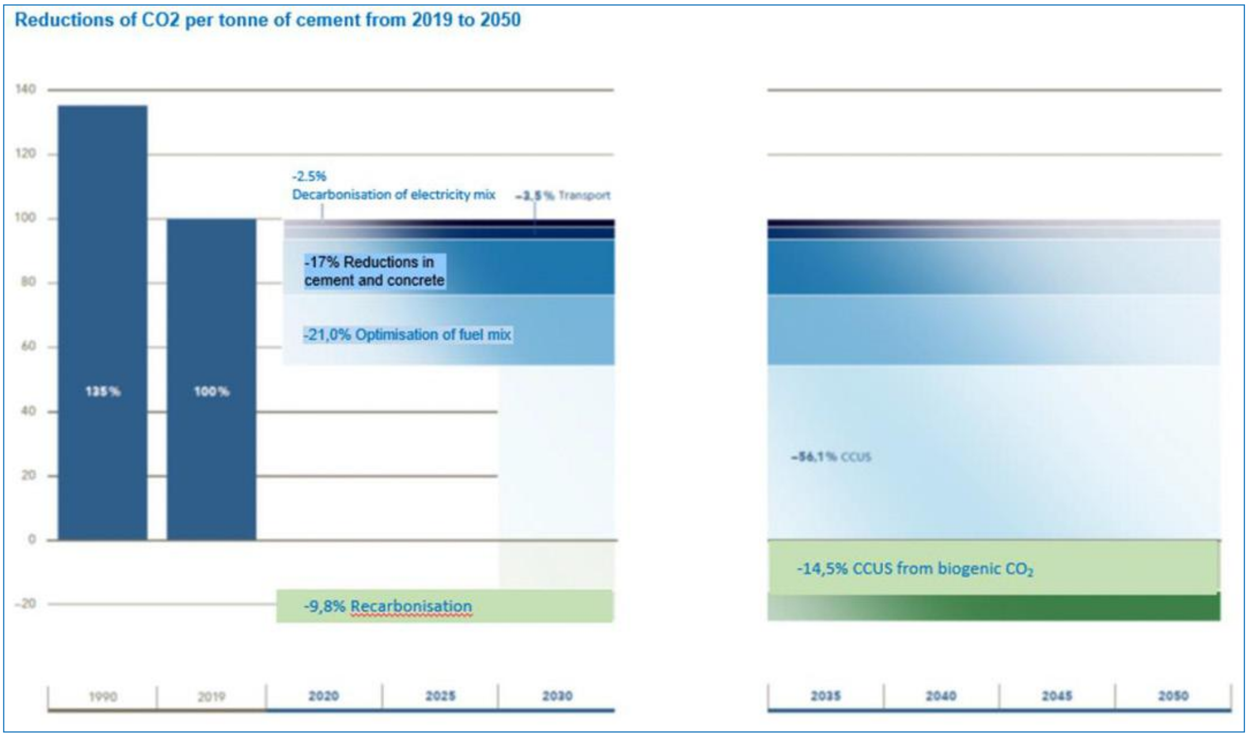

Fig. 14. Evolution of CO_2 emissions from cement manufacturing 1990 – 2030 via reduction of cement and concrete production (-17%) and fuel optimisation (-21%) and from 2035 to 2050 via CCUS (-56.1%) and CCUS of biogenic CO_2 (-14.5%) (translated from German)
Source: CEMsuisse, CC BY-NC

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

There is no government programme for recycling in the industry; this is left to each individual company.

Since 2015, the use of CEM III/B (cement containing slag ashes with a reduced carbon impact by -25% of gCO_2) is preferred, wherever possible. One of the major Swiss certification systems for ecological buildings (Minergie-ECO) now requires the use of recycled concrete.

Switzerland gets going with the recycling of construction waste (admin.ch)

The production of concrete in Switzerland today requires around 33 million tonnes of gravel annually – 2 million of this comes from recycling and the rest involves primary consumption. The main driver for this area is publicly funded constructions which require a certain amount of recycled material.

Are there some case studies or best practices you would like to share?

Some communities (e.g. Berne) require a certain percentage of recycled building materials (concrete) for new constructions.

[11] See www.klik.ch/news

4.2. Chemical Industry

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

Scienceindustries[12], the association of the Swiss Chemical, Pharma and Life Science industries, states the following mix for the energy consumption of their member industries (data from 2019):

- 35% natural gas,
- 33% electricity,
- 20% waste processing (fossil sources),
- 7% renewable energies (incl. biogenic wastes),
- 4% other fossil fuels,
- 1.4% fuel oil,
- 0.7% district heating,
- 0.4% unspecified.

We are not aware of a specific study on the energy source mix of electricity used in the Swiss chemical industry. Therefore, we assume the average Swiss mix stated below. However, the electricity market in Switzerland is liberalised for large consumers (over 100 000 kWh annual consumption) and these consumers (including part of the chemical industry) might purchase electricity with a different source mix.

Source mix for electricity consumed in Switzerland 2019:

- 75% renewable, mostly (66%) hydropower
- 21% non-renewable, mostly (21%) nuclear energy
- 4% not specified sources, 'grey energy'

The monitoring reports on the Swiss energy strategy[13] state that the CO_2 emissions of the entire industry have been slightly decreasing since 2000; however, we cannot comment on how this compares to other countries and for the chemical industry in particular. It is a minor part of industrial emissions.

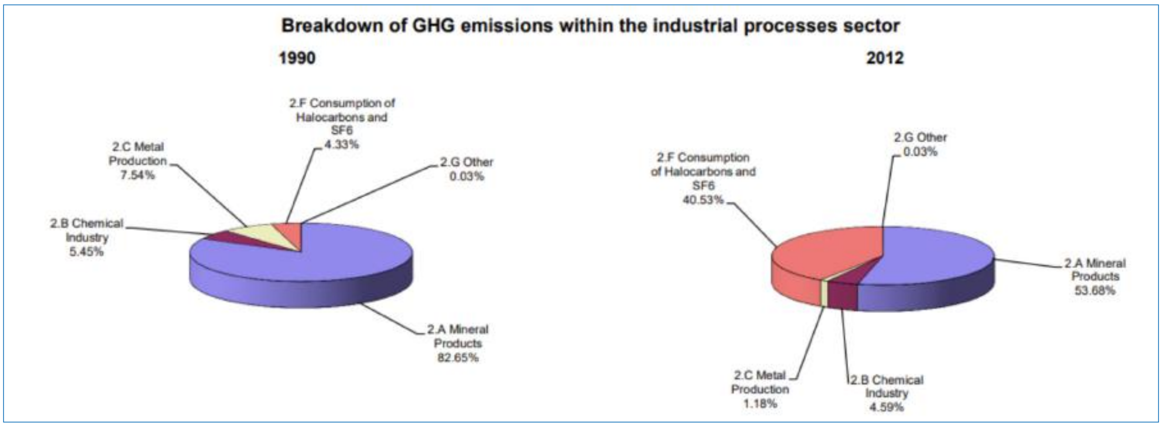

Fig. 15. Greenhouse gas emissions from industrial process sector
Source: UNFCCC GHG Data Interface, United Nations Climate Change Secretariat, "Summary of GHG Emissions for Switzerland": https://unfccc.int/sites/default/files/che_ghg_profile.pdf Copyright with UNFCCC. Reproduced with permission.

Switzerland has the lowest carbon intensity among IEA countries, owing to a carbon-free electricity sector dominated by nuclear and hydro generation.

12 https://www.scienceindustries.ch/en/home

13 https://www.bfe.admin.ch/bfe/en/home/supply/statistics-and-geodata/monitoring-energy-strategy-2050.html

Are the best available low carbon technologies used/considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

Low carbon technologies are considered to reduce the CO_2 levy mentioned above[14]. A major driver would be importing low carbon feedstocks, and building the chemical industry on renewable carbon sources. However, this is only possible in a European context (see in the German Chemical Industry the renewable Carbon Initiative[15]).

> The chemical industry in Switzerland is not engaged in the production of primary chemicals but rather imports plastics and the required chemicals *e.g.* for synthesis of fine and specialty chemicals. According to data published by the Swiss customs, in 2019 the net-import (*i.e.* the import minus the export) of chemicals and plastics amounted to 1.6 Mt. Based on the carbon content of the products, we estimated that this corresponds approximately to 1.5 Mt (65 PJ) of oil (see Supplementary Information for details). Furthermore, the Swiss energy statistic reported the consumption of 0.4 Mt of oil (17 PJ) for non-energetic purposes, for example as lubricants for machines and vehicles or as bitumen for road construction. Overall, the non-energetic use of oil in Switzerland amounts to 1.9 Mt, which corresponds to 20% of the total energetic oil consumption (9.5 Mt, 407 PJ) and to 9% of the total final energy demand (Fig. 1c).

Taken from doi:9.2533/chimia.2021.788, Open Access, CC BY 4.0

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

Scienceindustries states in a position paper its support to the Swiss strategy to reach net zero in 2050. Four fields of measures are prioritised:

- the application of innovative technologies,
- target agreements with the authorities that are linked to reductions in CO_2 taxes,
- compensation of greenhouse gas emissions,
- Emission trading.

Is the implementation of low-carbon technologies helped by the government? For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

See *Section 4.2* (CO_2 levy). In addition, very strict regulations on the emission of Volatile Organic Compounds (VOC) are enforced, requiring the chemical industry to mainly work with aqueous and not solvent systems.

Are there incentives for carbon capture, utilisation, and storage? How?

There are now official guidelines on how to reduce CO_2 emission.

14 CO_2 levy : admin.ch

15 www.renewable-carbon-initiative.com

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

Every year, around 1 million tonnes of plastics are used in Switzerland – this corresponds to 125 kg per capita (reference year 2010). Around 250 000 tonnes are made into durable products (e.g. plastic window frames) and remain in use for a fairly long period. Every year, around 780 000 tonnes of plastic waste is generated, more than 80% of which (around 650 000 tonnes) is used for energy recovery in incinerators and over 6% in cement factories. About 80 000 tonnes are recycled.

See Plastics (admin.ch).

Are there some case studies or best practices you would like to share?

Nothing in particular

4.3. ICT

Microsoft Word - 2017_Study_Digitalization_Climate_Protection_KORRIGIERT.docx (wwf.ch)

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

The Swiss electricity mix is used.

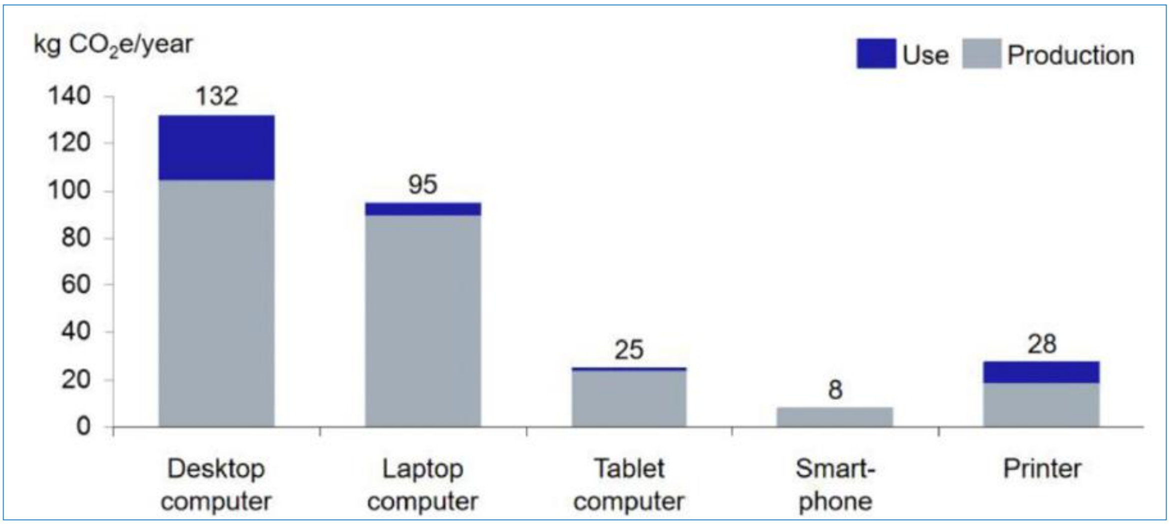

Fig. 16. Average annual greenhouse gas emissions per end-user device during production and use by device type. The annual values of production emissions (grey) are based on current average useful lives of the devices.
Source: University of Zurich, Opportunities and Risks of Digitalization for Climate Protection in Switzerland. Hilty, Lorenz; Bieser, Jan. Open Access. https://www.zora.uzh.ch/id/eprint/141128/10/Study_Digitalization_Climate_Protection_Summary_Oct2017.pdf

Are the best available low carbon technologies used / considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

No, the ICT sector is expected to grow.

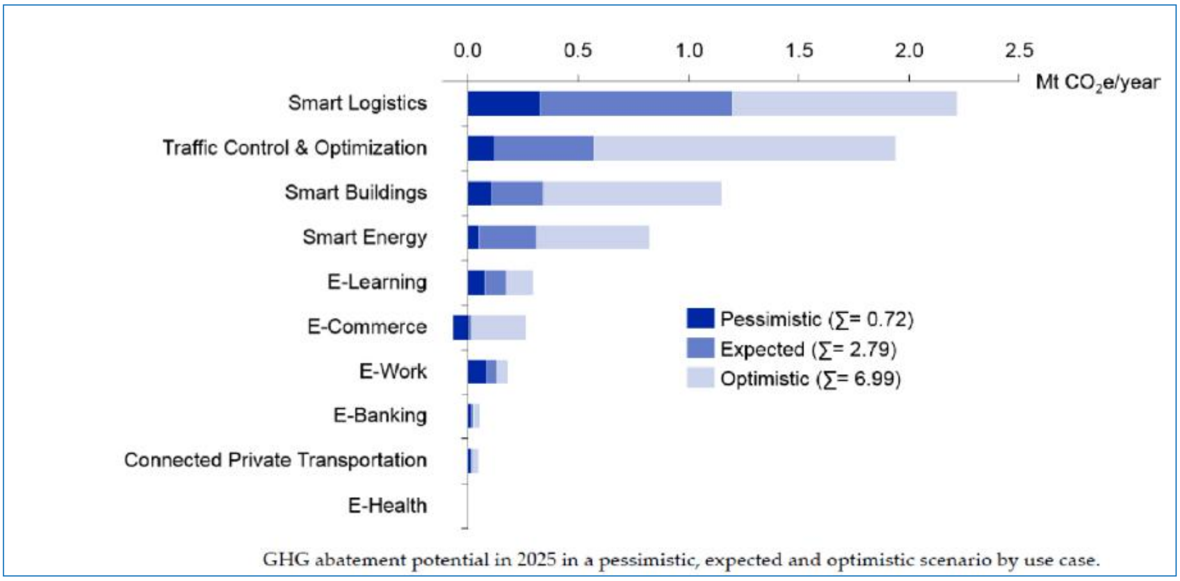

Fig. 17. Abatement potential for GHG emissions in 2025: Pessimistic, expected, and optimistic scenarios by use case
Source: University of Zurich, Opportunities and Risks of Digitalization for Climate Protection in Switzerland. Hilty, Lorenz; Bieser, Jan. Open Access.
https://www.zora.uzh.ch/id/eprint/141128/10/Study_Digitalization_Climate_Protection_Summary_Oct2017.pdf

4.4. Agriculture

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

From CHE_ghg_profile.pdf (unfccc.int)[16]

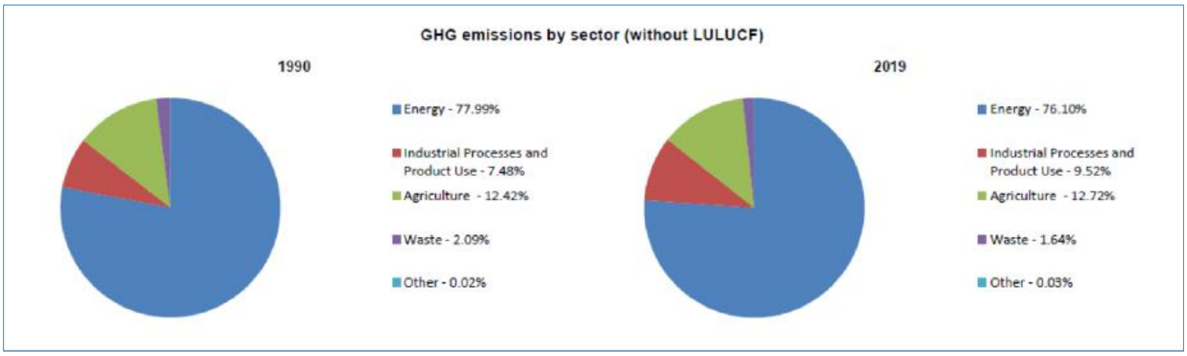

Fig. 18. GHG emissions by sector (without LULUCF), 1990 and 2019
Source: UNFCCC GHG Data Interface, CHE_ghg_profile.pdf (unfccc.int) 17 Copyright with UNFCCC. Reproduced with permission.

16 https://di.unfccc.int/ghg_profiles/annexOne/CHE/CHE_ghg_profile.pdf

Is there a roadmap to decrease GHG emissions for 2030 - 2050
If yes, what are the intermediary steps?

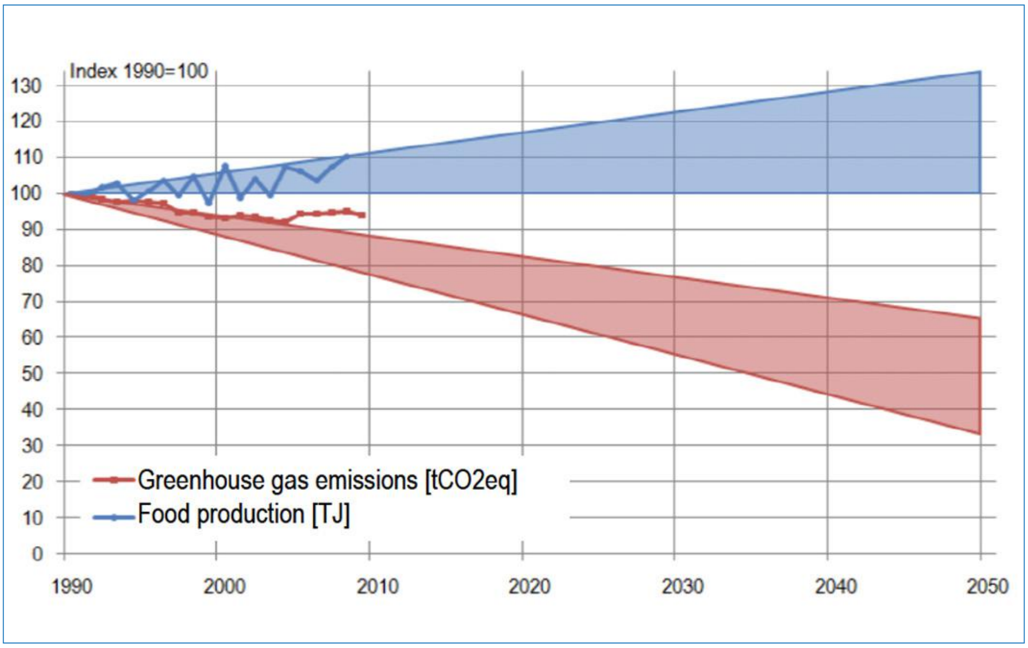

Fig. 19. Target paths in terms of food production (blue area), greenhouse gas emissions (red area) and development to date
Source: Microsoft Word - [Klimastrategie Landwirtschaft d (admin.ch)]
Open Source

There is a road map but not many important measures to ensure it will be implemented.

Are there incentives for carbon capture, utilisation, and storage? How?

The GHG reduction plans for agriculture are not very well implemented.

UNITED KINGDOM

Table of Contents

Introcuction

1. This UK response has been drafted by the following contributors:
   - Mr Andrew Haslett – Fellow of the Royal Academy of Engineering and Fellow of the Institution of Chemical Engineers.
   - Dr Julie Godefroy – Head of Sustainability at the Chartered Institution of Building Services Engineers (CIBSE), and member of the NEPC Decarbonisation Working Group.
   - Dr Chris Melvin – Member of the Institute of Materials, Minerals and Mining.
2. The draft has also been reviewed by the National Engineering Policy Centre (NEPC) Decarbonisation Working Group, which guides the NEPC's net zero policy project. The NEPC is a partnership hosted by the Royal Academy of Engineering that represents 43 different UK engineering organisations, which in turn represent 450 000 engineers. The NEPC exists to give policymakers a route to advice from across the whole engineering profession, and to give the engineering profession a unified voice on shared challenges.
3. The industry sectors considered in part three of this response are chemicals and steel.
4. Headings in the text align with the top-level questions of the questionnaire.

1. National Energy Profile

For consistency with other national inputs, this section uses IEA country data. The data are shown on a territorial basis – for England, Scotland, Wales and Northern Ireland.

Key data for 2019 are:

- Population 66.8 M
- Total energy consumption 1 646 TWh
- Electricity consumption 317.3 TWh
- Total CO_2 emissions 342 Mt
- Energy consumption per capita 24.6 MWh
- Electricity consumption per capita 4.8 MWh
- CO_2 per capita 5.1 t

The UK economy has a higher share of services and a lower share of manufacturing than many other developed economies. Energy supply to transport and buildings are themajor end-uses. Oil and gas products are used in chemicals production, but to a lesser extent than many other European economies.

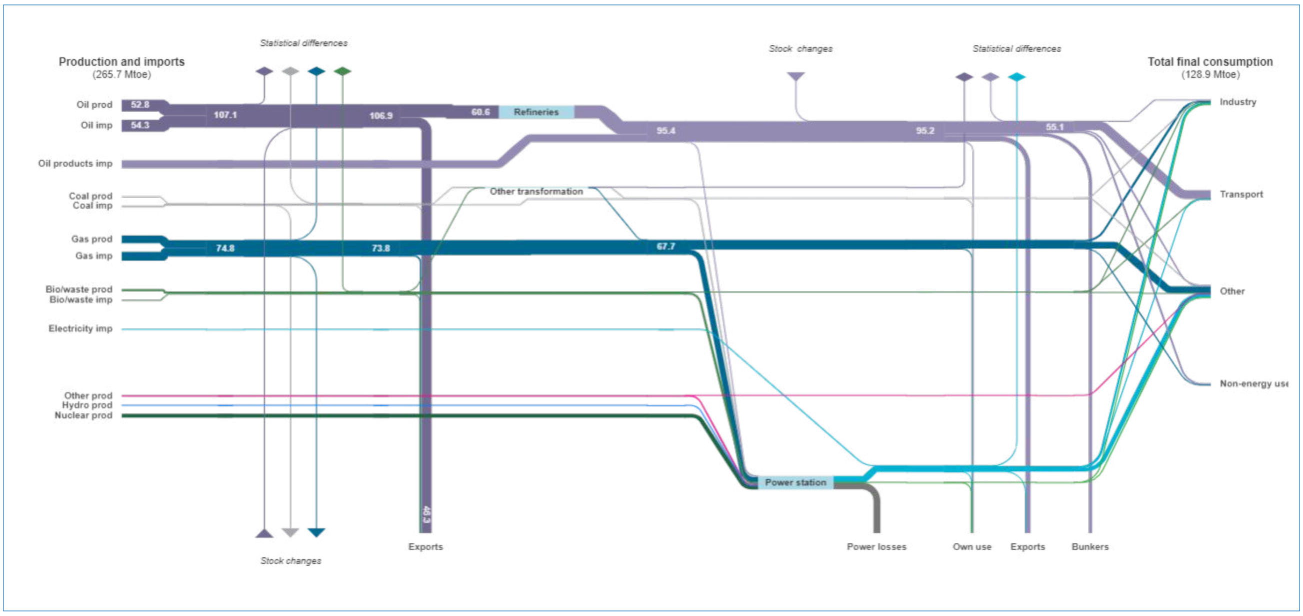

Fig. 1. IEA UK 2018 Energy Sankey Diagram, **IEA**
Source: IEA https://www.iea.org/sankey/#?c=United%20Kingdom&s=Balance, Reproduced with permission

The UK is also notable in that natural gas boilers dominate in the supply of space heating and hot water supply; cooking is split between electricity and gas. Electricity and oil are the next most significant heating sources (in areas outside of the gas network). Until recently, the UK was the world's largest market for fossil fuel boilers.

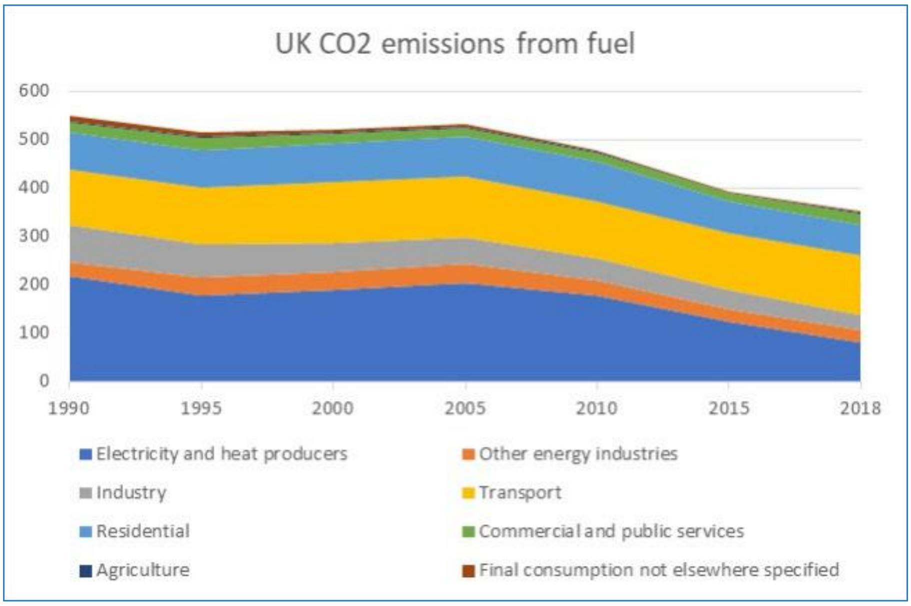

Fig. 2. UK CO_2 emissions from combustion by source, based on IEA data Units: Million tonnes CO_2.

UK combustion emissions are consistent with this pattern of energy supply and use. Progress since 1990 has been largely in electricity generation, with efficiency gains in transport and buildings offset by increased demand. Industry has improved efficiency, but the largest gains have come from switching to less energy intense economic activities.

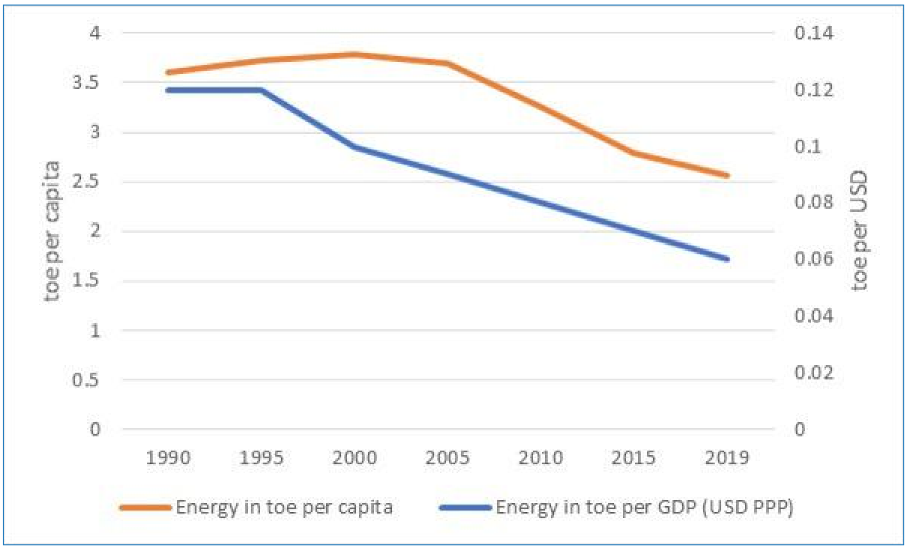

Fig. 3. Energy Intensity, based on IEA data.

The UK is notable for:

- A very diverse and relatively inefficient stock of residential, commercial and institutional buildings.
- A short but relatively intense heating season, for which boilers are an ideal solution, but so far limited penetration of air conditioning.
- Excellent offshore wind resource but a northerly location with low winter sunlight and frequent cloud cover.
- Good potential for economic offshore secure geological CO_2 storage.
- Existing brine-mined salt cavern hydrogen storage with potential for major expansion.

- High average population density in combination with large areas of much lower population density and a diverse set of requirements for the movement of people and goods.
- A service-oriented economy with increasing business and private use of information and communications technologies.
- Potential for increased economic value from land, including afforestation and peatland rewetting.
- Potential for significant health improvements through dietary changes (including switching to more plant fats and proteins and less animal fats and proteins) and through improved air quality, active travel, and more comfortable and energy efficient homes.

Primary data sources for the UK are the Digest of UK Energy Statistics[1] and the National Atmospheric Emissions Inventory[2].

2. Energy Perspective 2030 - 2050

The existence of anthropomorphic climate change, the potential local and global damaging effects of climate change and the need to achieve Net Zero are widely understood and supported in the UK. Net Zero targets for England, Scotland and Wales were set by three different political parties from across the spectrum. Other political parties are if anything even more supportive of Net Zero. The Northern Ireland Assembly is currently consulting on its Energy Strategy.

Following the publication of an Energy Strategy in 2003 which committed the UK to significant reductions in greenhouse gas emissions, the Climate Change Act of 2008 established a target of 80% reduction compared to 1990 levels (effectively 85% for energy related emissions) and a governance mechanism in which an independent statutory body (the Climate Change Committee or CCC) proposes a series of 5-year Carbon Budgets. Once accepted by Parliament, the CCC then reports on progress against budgets and gaps in policy to deliver future budgets. The CCC has staff and resources to commission research and analysis.

Given the urgency of moving beyond electricity to the greater challenges of buildings, transport and industry, the role of the CCC in assessing and critiquing the development and deployment of policy and plans will assume greater importance. How fundamental differences between the CCC and different levels of government will be resolved, and interact with the processes of democracy and the legal system, is untested.

In June 2019, the UK became the first major economy to set a legally binding Net Zero greenhouse gas emissions target (for 2050). The Sixth Carbon Budget covers the period from 2033 to 2037 and was adopted by Parliament in April 2021. This commits the UK to reduce emissions by 78% (from 1990) by 2035, explicitly including a UK share of international aviation and shipping (IAS) emissions in the legal target for the first time. “Consumption” emissions, those of products made abroad but used in the UK, are increasingly discussed in CCC reports but not yet included in formal targets.

1 https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes

2 https://naei.beis.gov.uk/overview/ghg-overview

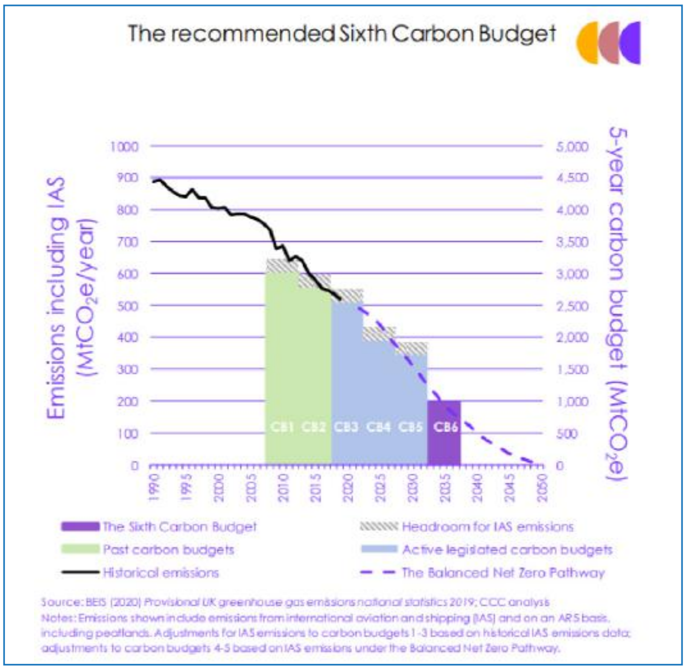

Fig. 4. Committee on Climate Change (2020). The Sixth Carbon Budget: The UK's path to Net Zero The CCC's 'Balanced Net Zero pathway', a model for how the UK could reach net zero emissions, would see the next few carbon budgets being met. Notes: CB 1 to 6: Carbon Budgets 1 to 6. ***Source:*** Energy&Climate Intelligence Unit: https://eciu.net/analysis/briefings/uk-energy-policies-and-prices/how-is-the-uk-tackling-climate-change, Climate Change Committee (CCC): https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf, Reproduced with Permission.

Carbon Budgets include all territorial greenhouse gas emissions (as CO_{2e}) plus IAS. The legally binding target is total emissions over each 5-year period, but the CCC recommendation is backed by ~1,000 pages of analysis which shows how the budgets might be economically and feasibly delivered, the scientific and political context and the policy mechanisms that might be appropriate.

As the chart shows, the period 2025 to 2035 is critical in moving the pathway beyond decarbonising electricity to decarbonising transport, buildings and industry and laying the foundations for a zero-carbon economy by 2050. A major expansion of electricity supply will be required to support this, along with establishing a functioning low-carbon hydrogen economy, bioenergy with CCS and at least one Direct Air Capture plant of 1MTe per year (or more) capture rate.

Over time the CCC has established itself as the shop window for a broad community of academic and industrial interests involved in climate change analysis, planning and implementation.

The UK Energy Transition involves all aspects of social, industrial and infrastructure planning. The lead actors in this are:

- UK Parliament, Scottish Parliament, Welsh Senedd and Northern Ireland Assembly,
- the CCC,
- the Electricity/Energy System Operator for Great Britain (GB ESO),
- the Office of Gas & Electricity Markets (Ofgem).

For example – establishing a successful UK offshore wind industry and driving down the cost from around £140 per MWh to £70 per MWh between 2010 and 2020, involved support for ports, technology and supply chain support, electricity market mechanisms, offshore and onshore regulated assets for transmission, skills and training development etc. Many public and private sector organisations were involved in this. The CCC central scenario foresees major further technology and deployment challenges for offshore wind.

Ofgem has a number of key roles in this:

- understanding and protecting the interests of energy customers,
- agreeing financial settlements for regulated asset base companies, principally networks,

- funding and structuring innovation support for infrastructure assets and technologies,
- setting direction for market and regulatory changes and sponsoring individual projects.

The Department for Business Energy and Industrial Strategy (BEIS) is currently considering a proposal from Ofgem to strengthen and expand the role of the GB ESO to include both operations and strategic planning. The scope of this role may be as narrow as the electricity system or encompass the whole energy system, for example including heat distribution. The island of Ireland has its own integrated electricity system.

There is increasing focus on the planning responsibilities of local and regional authorities for buildings and transport and how local plans for building refurbishment, electric vehicle charging, public transport and local energy networks can be established in partnership with network companies, Ofgem and a strengthened ESO.

At a UK level, there are three key sources for energy planning:

- the CCC Carbon Budget reports[3] and supporting information,
- the GB ESO Future Energy Scenarios[4],
- policy documents from the UK, Scottish, Welsh and Northern Ireland governments.

Examples of policy documents include the UK Prime Minister's 10-point plan[5], the recent Transport strategy[6] and Hydrogen Strategy[7], and the expected Heat & Buildings Strategy and significant updates to the Smart Energy strategies.

These strategies share certain characteristics:

- A limited portfolio of options to be developed, tested and deployed in combination as a whole system but significant uncertainty about citizen engagement (for example on diet) and on the overall energy mix, notably in terms of the size and shape of the hydrogen economy and the mix of solutions for building energy efficiency and heating.
- An expectation that commercial forces will discover and deploy the best solutions within an overall framework set by government.
- Short-term targets up to 2030-35 within a set of broader possibilities by 2050.
- Discussion of supply chain, regulatory and planning capacity building, along with debate about citizen engagement and overall social capacity and change (see for example the first part of the CCC Policy report[8])
- Greater or lesser integration into wider strategies for example for industry, housing, healthcare, skills development and employment and the social and physical infrastructure required to address regional inequalities in opportunity and outcomes.

The core of UK strategy is electrification by offshore wind, supported by onshore wind, solar PV, nuclear, bioenergy with CCS, and hydrogen. In addition, there will be power balancing from natural gas with CCS and stored hydrogen. Debate is ongoing on the role of hydrogen in industry, transport and heating and competition between different production routes for low-carbon hydrogen[9].

A smart energy system will be required, to manage vehicle charging and heating to match renewable energy supply and network capacity. This will require technical, market structure and behavioural changes. An expected increase in EVs on the road from 0.5M in 2021 to over 10M in 2030 means that progress with managed charging is now a priority[10]. The UK Smart Meter programme is an important enabler for this[11].

3 https://www.theccc.org.uk/publication/sixth-carbon-budget/

4 https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021

5 https://www.gov.uk/government/news/pm-outlines-his-ten-point-plan-for-a-green-industrial-revolution-for-250000-jobs

6 https://www.gov.uk/government/publications/transport-decarbonisation-plan 7 https://www.gov.uk/government/publications/uk-hydrogen-strategy

7 https://www.gov.uk/government/publications/uk-hydrogen-strategy

8 https://www.theccc.org.uk/wp-content/uploads/2020/12/Policies-for-the-Sixth-Carbon-Budget-and-Net-Zero.pdf

9 See for example - https://www.autocar.co.uk/car-news/industry-news-government-and-legislation/government-pledges-%C2%A33m-create-uk%E2%80%99s-first-hydrogen, https://h21.green/projects/h21-north-of-england/, https://www.hy4heat.info/, https://www.energylivenews.com/2021/03/17/uks-first-carbon-capture-project-given-72m-funding/, https://www.storegga.earth/projects/ and https://www.upstreamonline.com energy-transitionearly-engineering-starts-on-major-direct-air-capture-facility-in-uk/2-1-1030184

10 https://www.zemo.org.uk/work-with-us/energy-infrastructure/projects/EVP20-1-EV-Energy-Taskforce.htm

11 See for example - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/937296/future-coordinated-consumer-engagement-govt-response.pdf

There are two kinds of shorter-term markers:

- Specific legislative and regulatory actions - for example to ban the sale of fossil fuel vehicles by 2030, mandate low-carbon heating for new housing by 2025 and switch the electricity market to settling supplier costs based on individual half-hourly metering
- Innovation support activities by Ofgem[12] (regulated asset companies), Innovate UK[13] (industry) and the Business Department[14] (policy support)

3. Buildings

3.1. Existing Buildings

Buildings have a significant part to play in reaching UK Net Zero: in 2018, energy use in buildings accounted for the following (IEA Global Status, 2019):

- 30% of global final energy use, of which 22% from residential and 8% from non-residential buildings
- 28% of energy-related* carbon-equivalent emissions, of which 17% from residential and 11% from non-residential buildings.

Buildings are responsible for a significant part of heating energy use, with homes alone responsible for 60% of UK heat energy use. Residential buildings are acknowledged to be a significant area for policy action, due to their contribution to total emissions, relative inefficiency, and high numbers of households in fuel poverty.

UK reliance on gas for heating is one of the highest among OECD countries, at around 80%. A large majority of homes (around 85%) are heated with gas boilers. The non-domestic sector is also heavily reliant on gas for heating, even though electric heating (including heat pumps) is more prevalent than in the domestic sector[15]. Heat networks have seen two decades of expansion (starting from a rather low base) and a large majority are gas-fed, often with combined heat and power. Data on their carbon content has often not been reported, but many networks are understood to operate with high distribution losses.

The current state of UK residential buildings and possible pathways to decarbonisation are discussed in a report prepared for the CCC[16]. The Net Zero scenarios from the CCC and from National Grid ESO all assume a contribution from improving the energy efficiency of the existing stock, and it is generally acknowledged that this is required to allow heat pumps to operate more efficiently, reduce demand and support demand management, and reduce energy costs for consumers.

There is still significant debate about the right level of energy efficiency improvement which should be targeted. Policy in this area is patchy and is often focused on individual measures rather than whole-building approaches and deep retrofit. There are few incentives for retrofit – often only for individual measures or stop-start policies that affect trust among consumers and supply chains. The rate of installation of insulation measures has dropped in the past few years[17].

Retrofit works are mostly subject to 20% VAT (sales tax), while new build construction is zero-VAT rated. One significant area of policy progress, however, is the expected introduction of operational ratings for non-domestic buildings (starting with commercial offices), which would rate buildings for their actual measured performance rather than theoretical asset ratings.

Examples of low-energy retrofits tend not to be available in a single resource, but some can be found from the Passivhaus Trust (Enerphit standard) andthe AECB, both mostly for homes. The Better Buildings Partnership has examples for the commercial office sector, often focusing on energy management rather than deep retrofit but still demonstrating thepotential for energy savings in that sector.

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12 https://www.ofgem.gov.uk/publications/riio-2-strategic-innovation-fund-possible-innovation-challenges-round-1
13 https://www.gov.uk/government/organisations/innovate-uk
14 https://www.gov.uk/guidance/energy-innovation
15 BEIS, Clean Growth – Transforming Heating, December 2018
16 https://www.theccc.org.uk/publication/development-of-trajectories-for-residential-heat-decarbonisation-to-inform-the-sixth-carbon-budget-element-energy/
17 CCC 2021 Progress Report to Parliament, Figure 3.5

3.2. New Buildings

A draft Bill[18] is being developed to enact a step change in the quality and safety of buildings, especially high-rise residential buildings and other high-risk buildings.

There is a shortage of housing in the UK, especially of more affordable housing in areas of higher employment. This has been the subject of repeated policy developments over the last twenty years. Housing is largely a devolved issue within the UK[19] and detailed planning is a regional and local matter.

Within England, new housing will have to achieve low-carbon efficiency and emissions standards by 2025[20], which effectively bans the use of new gas boilers and mandates the use of heat-pumps, electric heating or other low-carbon heating systems. This will have a major effect on housing development. Proposals are similar for non-domestic buildings, though will probably be phased over a longer period with flexibility for a wider range of heating and hot water systems.

Through combination of a significant increase in renewables generation by 2030, charging of suppliers by the half-hourly usage of their customers, and the development of new technologies to test the as-built performance of buildings (e.g., low-pressure air testing, heat transfer coefficient estimates through smart meters), policies aim to transform both the supply chain and the user experience. Recent policies have been proposed to address the carbon content of new and expanding networks; as starting point, this could mean that financial support would only be available for networks which are as low-carbon (or lower) than a local air source heat pump system[21].

Case studies of recent low-energy buildings were produced by the Green Construction Board in 2019[22], in response to a (now dropped) government ambition to halve energy use in new buildings. This covers schools, offices, and homes.

4. Industry

4.1. Chemicals

The UK Chemicals Industry (including pharmaceuticals) is the largest industrial energy user, accounting for ~15% of industrial energy use[23].

11% of direct emissions in chemicals are from the process and the rest from combustion to provide heat. Natural gas is the dominant fuel. 25% of direct emissions are from olefins production, 13% from ammonia and the rest are split across a wide variety of basic organic (for example acrylonitrile or acetic acid) and inorganic chemicals (for example soda ash or titanium dioxide). Indirect emissions from electricity use arejust under 40% of total attributable emissions. The most immediate opportunity for decarbonisation after efficiency gains and further electrification is the capture of CO_2 from ammonia production, as part of one or more industrial CCS clusters.

The global chemical industry has multiple inputs to enabling a low-carbon economy, for example in production of insulating materials or technologies for producing low-carbon ammonia as a potential fuel for shipping. Requirements for chemicals will change – adapting to the future global economy is not just about reducing emissions from existing operations[24]. The industry has agreed an action plan[25] with the Department for Business, Energy and Industrial Strategy – building on its Industrial Decarbonisation and Energy Efficiency Roadmap[26].

Decarbonisation in the chemical industry is entangled with national strategies for industrial clusters, low-carbon hydrogen production, and progress with decarbonising electricity and ensuring consistent baseload electricity

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18 https://www.gov.uk/government/news/explained-the-draft-building-safety-bill

19 https://www.gov.uk/government/publications/homes-england-strategic-plan-201819-to-202223, https://www.gov.scot/publications/housing-2040-2/, https://www.birmingham.gov.uk/info/20054/local_plan_documents/78/birmingham_development_plan,...

20 https://www.gov.uk/government/consultations/the-future-homes-standard-changes-to-part-l-and-part-f-of-the-building-regulations-for-new-dwellings

21 BEIS Green Heat Network fund. The details are still to be confirmed and the calculation may use marginal carbon factors.

22 Green Construction Board, Buildings Mission Background Report, 2019 https://www.constructionleadershipcouncil.co.uk/wp-content/uploads/2019/05/GCB-Energy-Mission-Report-300419-FINAL.pdf

23 https://www.cia.org.uk/Portals/0/Documents/Publications/20150217%20CIA%20facts%20and%20figures%202 015.pdf?ver=2017-01-09-143806-033

24 https://www.cia.org.uk/Portals/0/Documents/Publications/Low%20carbon%20brochure_2015_MR.PDF?ver=20 17-01-09-143808-563

25 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/651230/chemi cals-decarbonisation-action-plan.pdf

26 https://www.gov.uk/government/publications/industrial-decarbonisation-and-energy-efficiency-roadmaps-to-2050

supply at competitive prices. International discussions about cross-border embedded carbon accounting are important to progress, given the significance of trade to the production and use of chemicals in the UK.

4.2. Steel

The UK Steel Industry is responsible for 2% of the entire UK greenhouse gas emissions (13.5% of entire UK manufacturing GHG output). Over the past 50 years the production of steel in the UK has decreased from c. 30MT/pa to under 10MT/pa. The majority of this is via the more carbon intensive BF/BOS processes however significant improvements have been made over that period to reduce the carbon intensity of the steel manufacturing process.

Steel is 100% recyclable either via the Basic Oxygen or Electric Arc Steelmaking route, however some of the key decarbonisation issues facing the industry at present come from the grades of steel being produced and the scrap sources available, alongside energy intensity concerns for decarbonisation pathways. The different types of scrap can have an impact on both the overall process and subsequent product quality. Product quality concerns tend to be driven by the scrap residuals such as copper and tin, whereas some of the dusts generated can impact the environmental performance of the plant.

UK finished steel consumption is stable at approximately 10MT/pa. It must be noted that not all of the grades consumed can be produced within the UK thus there is a trade deficit within our current asset configuration. Alongside this, currently a significant volume of steel scrap is exported from the country every year.

Current market conditions drive producers to maximise scrap consumption where possible, leading to a reduction in the carbon intensity of primary production, as less Liquid Iron is required per ton of finished steel. This market position will further evolve as steel grades are developed which are acceptable to customers with a higher residual content and the global steelmaking market decarbonises with major global iron ore suppliers decarbonising their production processes and changing their products being offered.

A technology development pathway towards net zero carbon emissions for steel has been proposed by Primetals shown in the figure below. This transition requires a stepwise increase in the electricity consumption within the regions that these industrial areas are located; thus, a holistic review of energy generation and co-industrial location needs to be developed. Such a pathway would however enable companies to transition towards lower carbon intensive technologies in a managed manner.

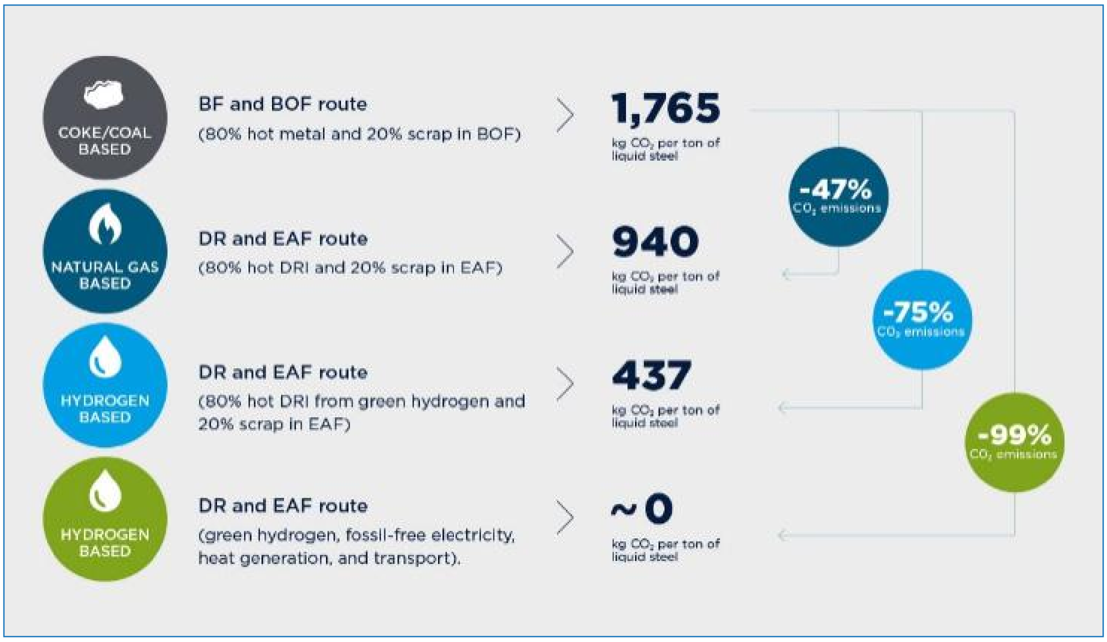

Fig. 5. Comparing CO_2 emissions of different process routes for liquid steel.
Calculations are based on emissions from electricity production on European OECD level
Source: Primetals Technologies, Metals Magazine,
https://magazine.primetals.com/app/uploads/2021/02/Metals-Magazine9-1-2020.pdf,
Reproduced with Permission.

The graphic is based on a presentation for the "Enhanced Energy Efficient Steel Production – E3-SteP" Project October 2019 by Norbert Rein, Slide 5: https://nachhaltigwirtschaften.at/resources/nw_pdf/events/20191009_highlights/spreitzer-rein-eisl_e3-step.pdf?m=1570609448& at the Technical University in Vienna: Highlights der Energieforschung 2019 – Dekarbonisierung in der Industrie - Nachhaltig Wirtschaften

Significant investment support had been made available by the government for decarbonisation-based projects for the steel industry (£250m Clean Steel Fund) and a number of other funding streams have been made available from the UK government for industrial clusters centred in steelmaking regions[27, 28]. Whilst these large-scale funds are very welcome, the full cost of decarbonisation for the UK steel industry is expected to be an order of magnitude higher; thus, long term capital support mechanisms are also required.

The UK government published a Hydrogen Roadmap[29] in August 2021 covering further support for maturing Hydrogen generation and Carbon Capture technologies which are critical to support business decision making onwhich technology to progress towards. A UK industrial decarbonisation policy is expected to be published within Q4 2021 which further enables the UK steel industry a basis to refine the UK decarbonisation roadmap which is being developed by the UK Steel Council.

27 https://www.zerocarbonhumber.co.uk/the-vision/

28 https://www.swic.cymru/

29 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

UNITED STATES

Please, note that in tables
D=Withheld to avoid disclosing data for individual establishments.
Q=Withheld because Relative Standard Error (RSE) is greater than 50 percent

Table of Contents

1. National energy profile 2019

US Total yearly consumption: final energy, electricity (TWh)

Year	Energy Consumption (TWh)	Electricity Consumption (TWh)	Elec/Energy (%)
1990	15 043.82	2 923.92	19.4
1995	16 023.04	3 370.98	21.0
2000	17 983.19	3 857.46	21.5
2005	18 178.41	4 049.93	22.3
2010	17 595.85	4 143.41	23.5
2015	17 568.83	4 128.51	23.5
2019	18 473.97	4 055.51	22.0

Table 1. US Total yearly consumption: final energy, electricity (TWh)
Source: Based on and/or calculated from the following data: International Energy Agency - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region IEA (2021) Emission Factors

During this period, the population steadily increased from 250 million to 329 million (+30%). Energy consumption also rose steadily through 2005 (+20.8%), then fell and remained lower for about a decade. The 2008 financial crisis and ensuing recession played some role in the decreased energy use during this time period. The recession also precipitated the American Recovery and Reinvestment Act of 2009 (ARRA), which provided USD 70-80 billion in tax credits and direct spending on clean energy and clean transport. The result is a 22.8% increase in final energy consumption from 1990 to 2019, but 2019 final energy consumption is 1.6% higher than 2005 levels.

Electricity use increased 38.7% from 1990 to 2019, yet slightly decreasing from 2010 to 2019 (by 2.1%). 2010 and 2015 had both the highest electricity consumption and lowest energy consumption levels.

Electricity consumption as a proportion of final energy consumption grew from 1990 to 2019, but not as dramatically as some other OECD countries, and with slight decrease from 2015 to 2019.

Per capita yearly final energy and electricity consumptions (MWh)

Year	Energy (MWh/capita)	Electricity (MWh/capita)
1990	60.27	11.69
1995	60.17	12.64
2000	63.73	13.66
2005	61.51	13.68
2010	56.89	13.38
2015	54.79	12.86
2019	56.28	12.28

Table 2. Per capita yearly final energy and electricity consumptions (MWh)
Source: Based on and/or calculated from the following data: International Energy Agency - Data and statistics https://www.iea.org/data-and-statistics
Explore energy data by category, indicator, country or region IEA (2021) Emission Factors
Population data from: https://data.worldbank.org/indicator/SP.POP.TOTL?name_desc=false&locations=US

Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)

Year	Total CO_2 Emissions ($MtCO_2$)	CO_2 Emissions from electricity ($MtCO_2$)	CO_2 emissions per capita
1990	4 803.00	1 901 (1825)	19.20
1995	5 073.84	2 167 (1957)	19.03
2000	5 729.82	2 542 (2306)	20.29
2005	5 703.15	2 523 (2411)	19.27
2010	5 352.05	2 346 (2270)	17.28
2015	4 928.61	1 985 (1911)	15.36
2019	4 744.50	1 699 (1617)	14.40

Table 3. Total CO_2 emissions, CO_2 emissions from electricity production ($MtCO_2$), total CO_2 emissions per capita (tCO_2)
Sources: Data for total CO_2 emissions: https://www.iea.org/data-and-statistics/data-browser/?country=USA&fuel=CO2%20emissions&indicator=TotCO2 Data for CO_2 emissions from electricity: IEA Greenhouse Gas Emissions from Energy. https://www.iea.org/data-and-statistics/data-product/greenhouse-gas-emissions-from-energy Parenthetical numbers are U.S. EIA-reported CO_2 emissions from electricity sector, as IEA binds electricity and heat producers together, thus producing some inconsistency. EIA Source is Table 11.6 from February 2022 Monthly Energy Review. Data for CO_2 emissions per capita: https://www.iea.org/countries/united-states

CO_2 emissions by fossil energy source ($MtCO_2$)

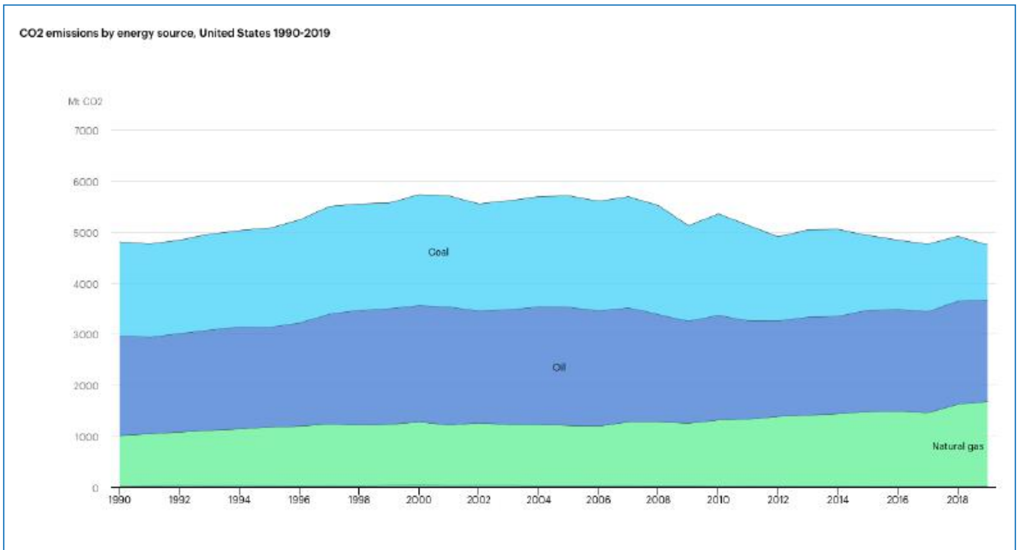

Fig. 1. CO_2 emissions by fossil energy source ($MtCO_2$) **IEA**
https://www.iea.org/countries/united-states

US energy-related CO_2 emissions peaked in 2007, according to the U.S. EIA. US energy-related CO_2 emissions from coal have significantly reduced; the U.S. EIA reports a decline of more than 50% from 2007 to 2019, which is more than a billion metric tonnes. This is largely due to coal no longer being the most economic choice in many regions. US energy-related CO_2 emissions from oil have been slightly decreasing. The U.S. EIA indeed reports a decline of 8.5% from 2007 to 2019. US energy-related CO_2 emissions from natural gas have been increasing, which is mainly due to increased supply and therefore competitive natural gas prices; the U.S. EIA reports 35.6% increase from 2007 to 2019. EIA (U.S. Energy Information Administration). 2020. "U.S. Energy-Related Carbon Dioxide Emissions, 2019." Washington, DC: U.S. Energy Information Administration https://www.eia.gov/environment/emissions/carbon/archive/2019/

CO_2 emissions by sector ($MtCO_2$)

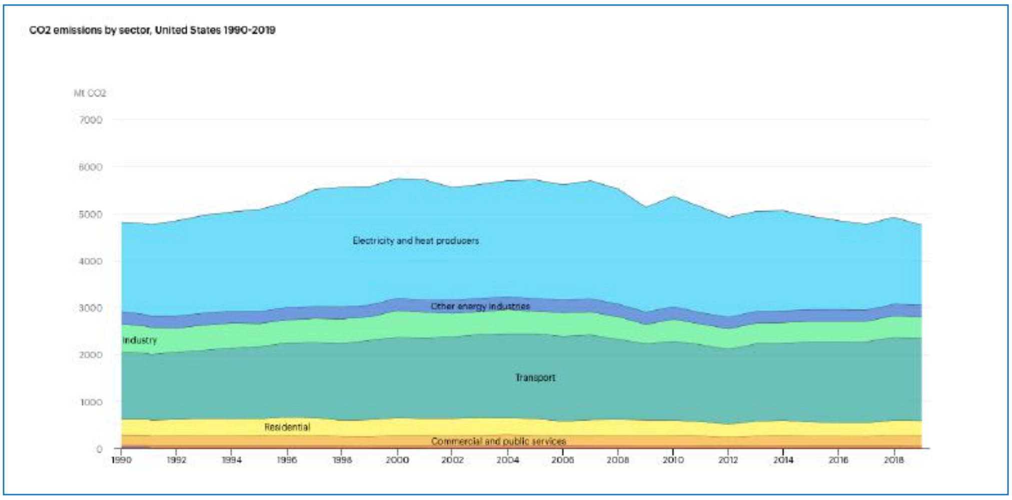

Fig. 2. CO_2 emissions by sector ($MtCO_2$), **IEA**
https://www.iea.org/countries/united-states

Final energy carbon intensity: gCO_2/MJ and gCO_2/kWh (1 Megajoule = 0.27778 Kilowatt hours)

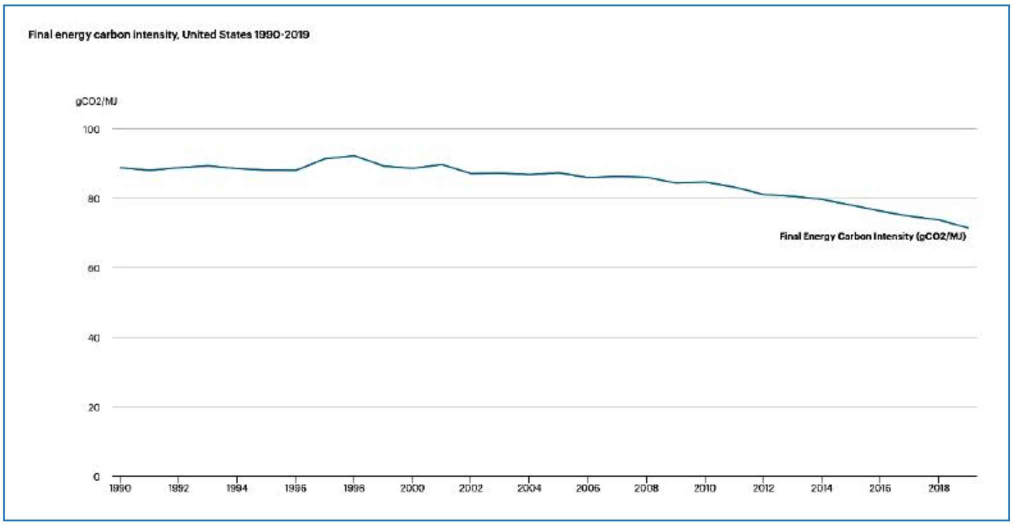

Fig. 3. Final energy carbon intensity, United States, 1990-2019, gCO_2/MJ, **IEA**
https://www.iea.org/countries/united-states

Year	Final Energy Carbon Intensity (gCO_2/MJ)	Final Energy Carbon Intensity (gCO_2/KWh)
1990	88.69	319.2814
1995	87.96	316.6535
2000	88.51	318.6335
2005	87.15	313.7375
2010	84.49	304.1616
2015	77.93	280.5458
2019	71.34	256.8219

Table 4. Final energy carbon intensity, United States, 1990-2019, both in gCO_2/MJ and gCO_2/KWh

The falling carbon intensity of energy in the United States has largely come from decreases in the consumption of fuels with high carbon contents. Part of this change comes from the continuing trend of natural gas and renewables displacing coal for electric power generation, both of which have lower or zero carbon content.

Electricity Carbon intensity: gCO_2/kWh

Year	Carbon intensity of electricit production (gCO_2/kwh)
1990	
1991	
1992	606.832
1993	601.2016
1994	599.9504
1995	598.0736
1996	603.0784
1997	663.7616
1998	656.2544
1999	640.6144
2000	625.6
2001	661.0
2002	588.6
2003	591.4
2004	589.2
2005	586.2
2006	562.8
2007	571.6
2008	554.4
2009	525.9
2010	530.5
2011	510.8
2012	487.6
2013	489.4
2014	485.7
2015	455.7
2016	433.2
2017	421.1
2018	411.1
2019	383.2

Table 5. Electricity carbon intensity: gCO_2/KWh
Sources: 1992-2000 data back-calculated using carbon intensity of power indexed data from https://www.iea.org/data-and-statistics/data-browser?country=USA&fuel=CO2%20emissions&indicator=CO2IntensityPower and "Year 2000" data from IEA, *Development of CO_2 emission intensity of electricity generation in selected countries, 2000-2020*, IEA, Paris[1].
2000-2019 data from: IEA, *Development of CO_2 emission intensity of electricity generation in selected countries, 2000-2020*, IEA, Paris https://www.iea.org/data-and-statistics/charts/development-of-co2-emission-intensity-of-electricity-generation-in-selected-countries-2000-2020

1 https://www.iea.org/data-and-statistics/charts/development-of-co2-emission-intensity-of-electricity-generation-in-selected-countries-2000-2020

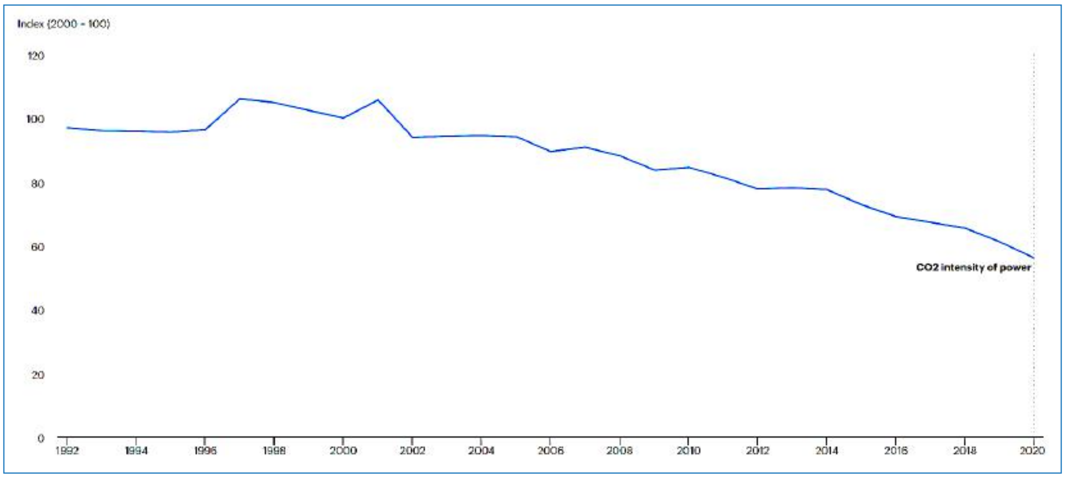

Fig. 4. Carbon intensity of the power sector, **IEA**
https://www.iea.org/countries/united-states

As displayed in the above graph from IEA, the carbon intensity of the power sector has been steadily decreasing since the early 2000s.

The U.S. Energy Information Administration (EIA) reports the 2020 carbon intensity of electricity generation in the United States to be 0,386 kg of CO_2 emissions per KWh, which equates to about 385.55 gCO_2/KWh.

2. Energy perspectives 2030 - 2050

If possible, give the national perspectives for 2030 and 2050 or the roadmap to 2030 and 2050 if they exist.

National roadmaps regarding energy production and GHG

The United States does not have a national roadmap for either energy production or GHG emissions. In September 2020, the U.S. Department of Energy published a Fossil Energy Roadmap, pursuant to a congressional request in the explanatory statement accompanying the Consolidated Appropriations Act, 2018. However, this Roadmap is a collection of research and development objectives for fossil energy, not a pathway to decreasing emissions.

The U.S. Energy Information Administration (EIA) 2021 Annual Energy Outlook projects energy production through to 2050. 2020, 2030, and 2050 values are presented below.

Production	2020	2030	2050	Average annual increase (+) or decrease (-) in per-cent 2020-2050
(quadrillion Btu)				
Crude oil and lease condensate	23.87	28.57	26.64	+0.4%
Natural gas plant liquids	6.58	7.90	8.05	+0.7%
Dry natural gas	35.14	39.28	44.58	+0.8%
Coal	10.80	10.14	9.08	-0.6%
Nuclear / Uranium	8.21	6.59	6.21	-0.9%
Conventional hydroelectric power	2.53	2.43	2.29	-0.3%
Biomass	4.47	4.89	5.39	+0.6%
Other Renewable energy	4.43	9.52	14.11	+3.9%
Other	0.69	0.65	0.71	+0.1%
Total	96.72	109.97	117.08	+0.6%

Table 6. Projected annual energy production through to 2050 (1 Btu = 0,293071 Wh)
Source: Table 1 of EIA Annual Energy Outlook 2021, Open access. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=1-AEO2021&region=0-0&cases=ref2021&start=2019&end=2050&f=A&linechart=ref2021-d113020a.3-1-AEO2021~ref2021-d113020a.4-1-AEO2021~ref2021-d113020a.5-1-AEO2021~ref2021-d113020a.6-1-AEO2021~ref2021-d113020a

The EIA 2021 Annual Energy Outlook projects GHG emissions through 2050. 2020, 2030, and 2050 values below:

CO_2 Emissions	2020	2030	2050	Average annual increase (+) or decrease (-) in percent 2020-2050
(million metric tonnes carbon dioxide)	4 562.5	4 583.5	4 806.9	+ 0.2%

Table 7. Projected annual GHG emissions through to 2050
Source: Table 18 of EIA Annual Energy Outlook 2021, Open access. https://www.eia.gov/outlooks/aeo/data/browser/#/?id=17-AEO2021&region=1-0&cases=ref2021&start=2019&end=2050&f=A&linechart=~ref2021-d113020a.40-17-AEO2021.1-0&map=ref2021-d113020a.4-17-AEO2021.1-0&ctype=linechart&sourcekey=0

Roadmap for the energy mix

The United States does not have a national roadmap for the energy mix. In November 2016, the Obama administration put forth its United States Mid-Century Strategy for Deep Decarbonization; this strategy was not continued by the following administration. The U.S. National Academies published a decarbonization report in 2021 focusing on actions necessary in the 2020s to put the United States on the path to net-zero energy system, Accelerating Decarbonization of the U.S. Energy System.

The US Energy Information Administration (EIA) 2021 Annual Energy Outlook projects the energy mix through to 2050 as below:

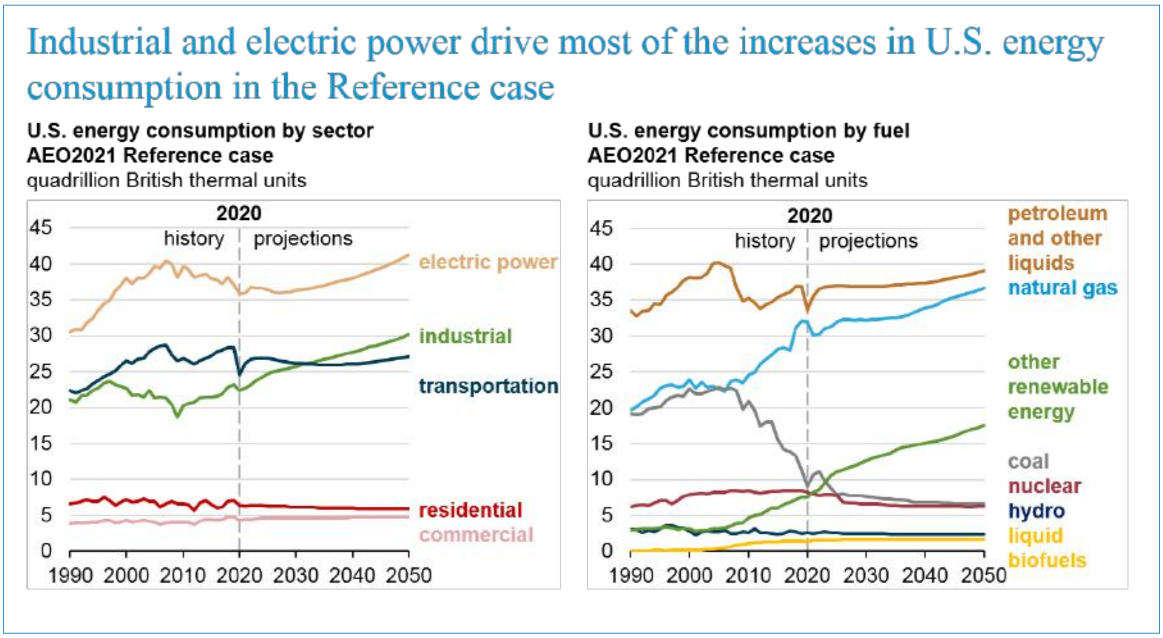

Fig. 5. Past and projected energy consumption through to 2050 by sector (left) and by fuel type (right)
Source: U.S. Energy Information Administration Annual Energy Outlook 2021 (AEO2021) www.eia.gov/aeo
Open access

Roadmap for the GHG emissions (country, per capita)

There is no national GHG emissions roadmap administered or enforced by the U.S. federal government. However, many states have established emissions targets and roadmaps to reach those goals, often with legally binding elements. Several states have also joined into the Regional Greenhouse Gas Initiative (RGGI), a mandatory, market-based greenhouse gas pollution reduction programme.

The EIA 2021 Annual Energy Outlook projects energy related GHG emissions per sector and per capita:

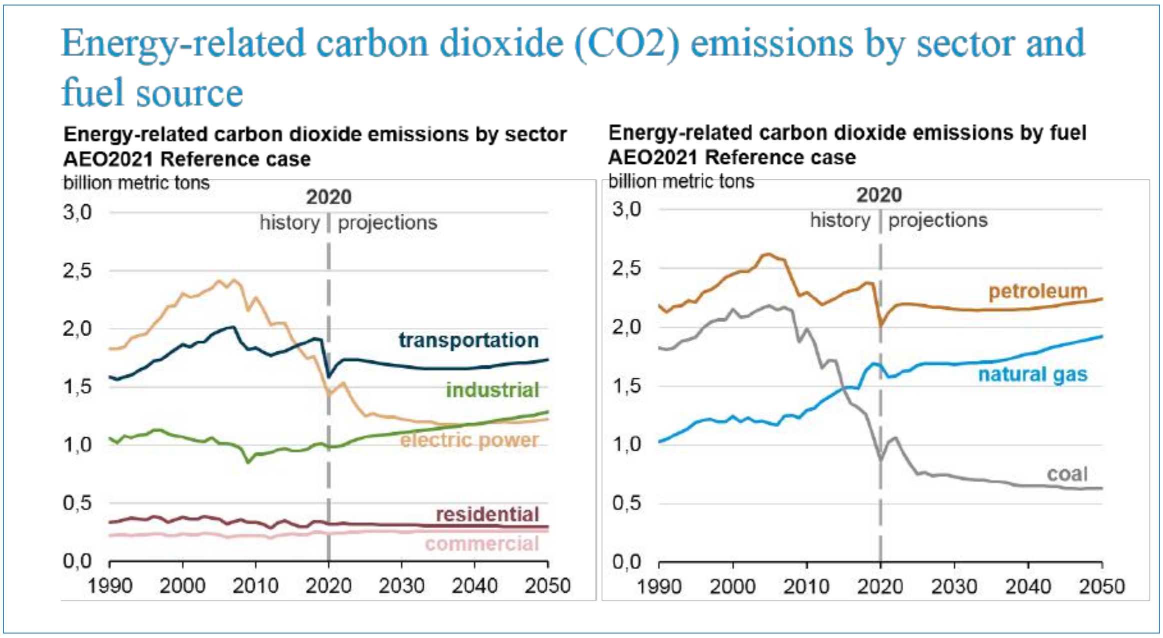

Fig. 6. Past and projected CO_2 emissions through to 2050 by sector (left) and by fuel type (right)
Source: U.S. Energy Information Administration Annual Energy Outlook 2021 (AEO2021) www.eia.gov/aeo
Open access

	2020	2030	2050	
CO_2 Emissions Per Capita (tonnes CO_2 per person)	13.8	13.0	12.4	-0.3%/yr

Table 8. CO_2 emissions per capita

Roadmap for the electricity mix

There is no national roadmap for the electricity mix administered or enforced by the U.S. federal government. However, many states have established renewable portfolio standards or carbon-free electricity targets and roadmaps to reach those goals, often with legally binding elements (see figure below from the NC Clean Energy Technology Centre and the Database of State Incentives for Renewables & Efficiency – DSIRE, which shows the aimed-for share of renewable energies by a given year (Example: New Mexico: 80% by 2040 and 100% by 2045). In April 2021, the Biden administration set a goal for 100% carbon-free electricity generation by 2035. In September 2021, the Biden administration set a goal to produce 50% of US electricity via solar power by 2050. Neither of these has legal enforcement capability and both must wait for legislation from Congress or regulation from authorised entities.

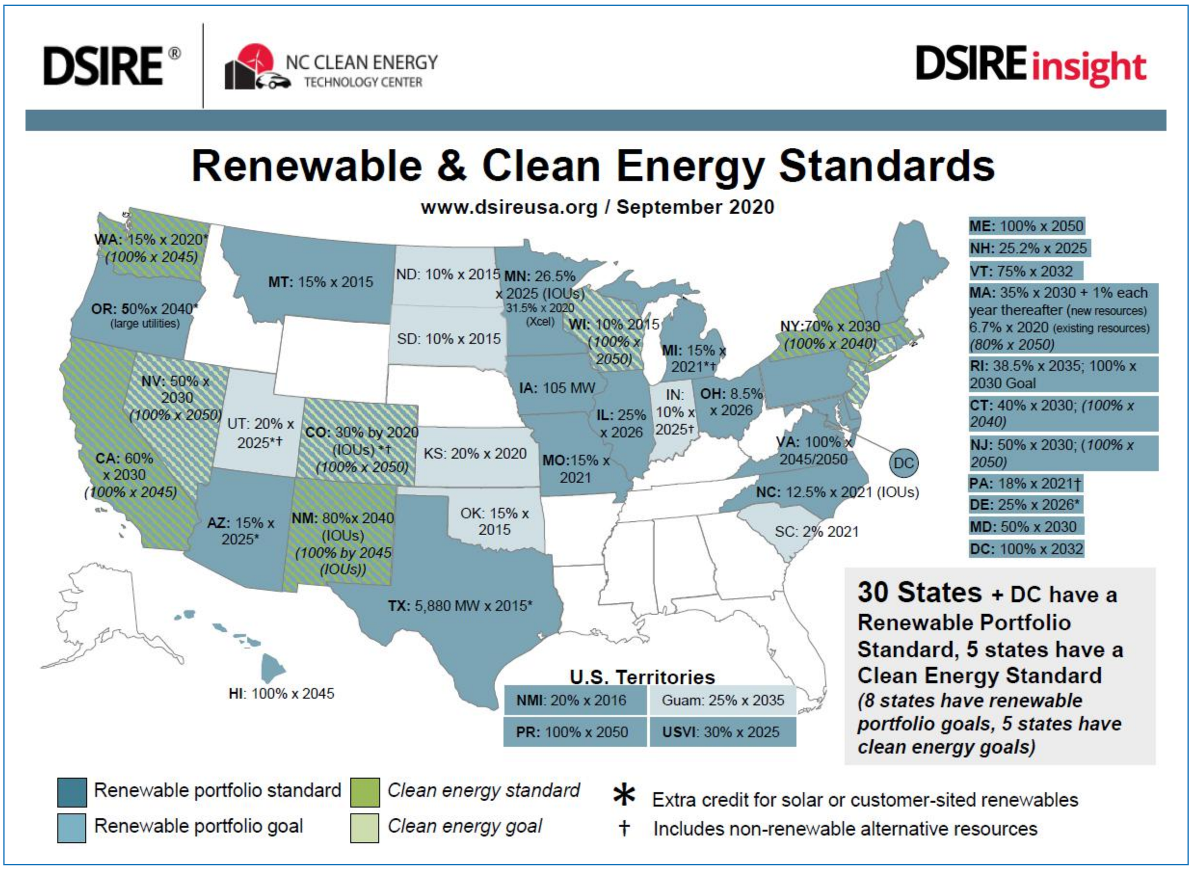

Fig. 7. Renewable & Clean Energy Standards in the 30 States + DC by type and percentage
Source: http://ncsolarcen-prod.s3.amazonaws.com/wp-content/uploads/2020/09/RPS-CES-Sept2020.pdf
Courtesy of the North Carolina Department of Natural and Cultural Resources, CC-BY-SA

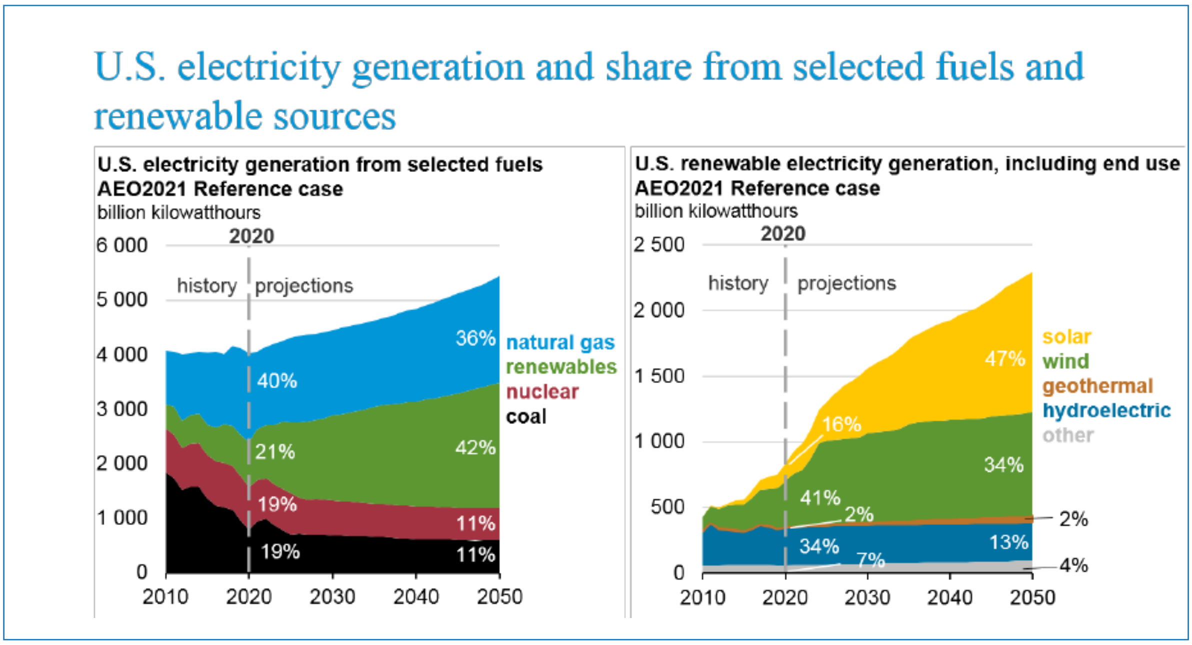

Fig. 8. Past and projected electricity generation through to 2050 by fuel type (left) and by renewable source (right)
Source: U.S. Energy Information Administration Annual Energy Outlook 2021 (AEO2021) www.eia.gov/aeo
Open access

CO_2 emissions from electricity production

The Biden Administration has set a goal for 100% carbon-free electricity by 2035. This does not have legal enforcement capability and must wait for legislation from Congress or regulation from authorised entities.

The EIA 2021 Annual Energy Outlook projects emissions from electricity production to change in the following ways over the next 30 years:

Electric Power	2020	2030	2050	Average annual increase (+) or decrease (-) in percent 2020-2050
million metric tonnes CO_2				
Petroleum	12	6	4	-3.3%
Natural gas	643	560	665	+0.1%
Coal	767	648	545	-1.1%
Other	10	11	11	+0.3%
Total electric power	1 432	1 224	1 226	-0.5%

Table 9. EIA 2021 projected evolution of CO_2 emissions from various fuel types through to 2050
Source: Table 18 of EIA Annual Energy Outlook 2021: https://www.eia.gov/outlooks/aeo/data/browser/#/?id=17-AEO2021&region=1-0&cases=ref2021&start=2019&end=2050&f=A&linechart=~~ref2021-d113020a.29-17-AEO2021.1-0~ref2021-d113020a.30-17-AEO2021.1-0~ref2021-d113020a.31-17-AEO2021.1-0~ref2021-d113020a.32-17-AEO2021.1-0~ref2021-d113020a.33-17-AEO2021.1-0&map=ref2021-d113020a.4-17-AEO2021.1-0&ctype=linechart&sourcekey=0.
Open access

Energy balance (energy sources to end-uses)

There is no national energy balance roadmap administered or enforced by the U.S. federal government. Lawrence Livermore National Laboratory produces an annual Sankey diagram of current energy balances (see below):

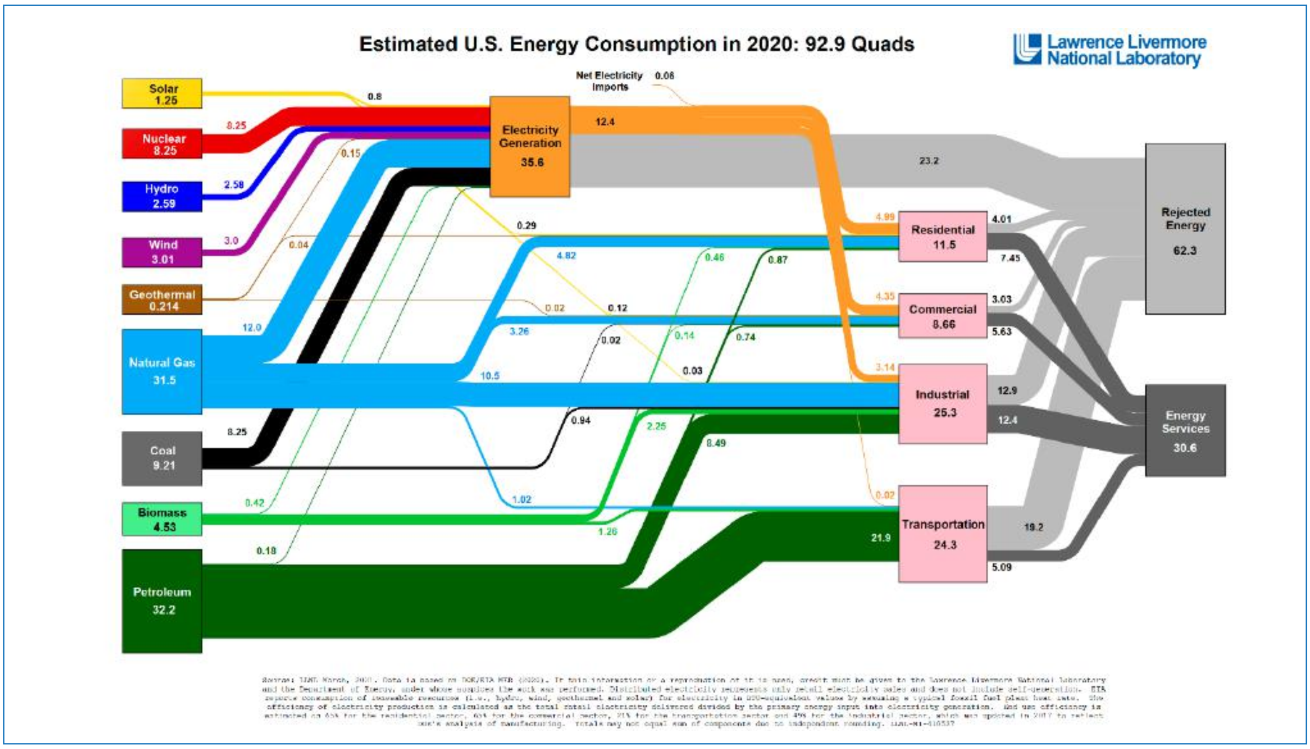

Fig. 9. Sankey diagram on Energy balance – energy sources to end-uses (1 quad = 293 TWh)
Source: Lawrence Livermore National Laboratory.
Open access

The EIA 2021 Annual Energy Outlook projects energy production and energy consumption out to 2050. A graphical representation for consumption up to 2050 for the residential, commercial, industrial, and transport sectors is provided below:

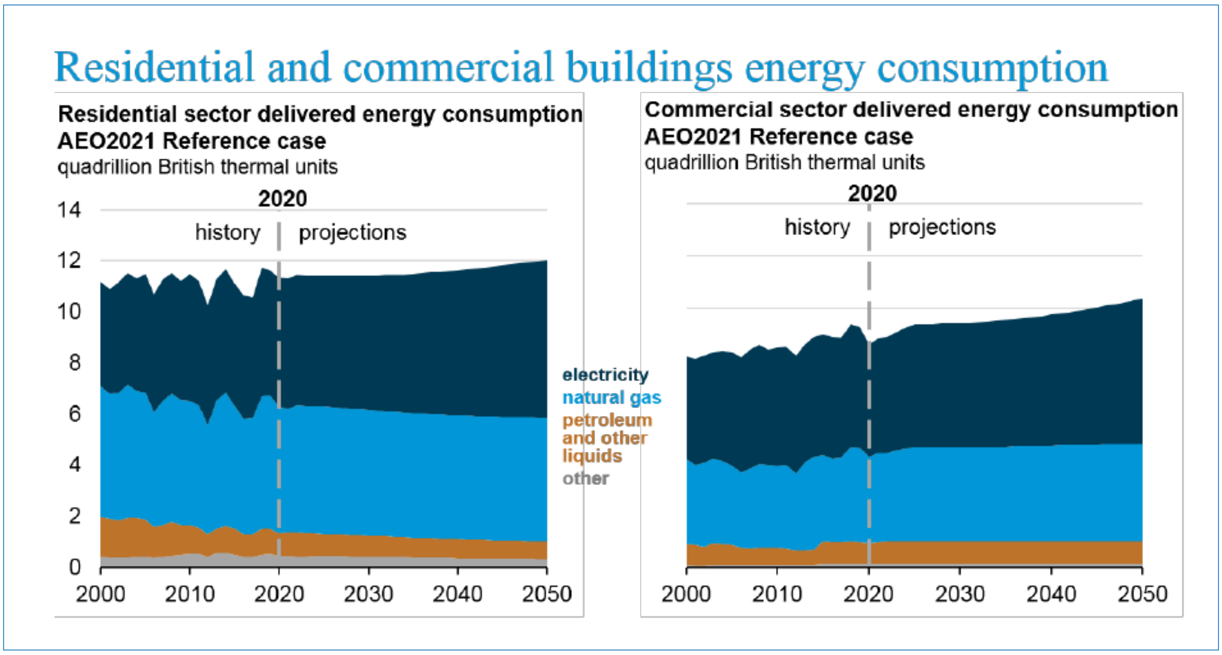

Fig. 10. Past and projected energy consumption through to 2050 by type of source for the residential sector (left) and the commercial sector (right)
Source: U.S. Energy Information Administration Annual Energy Outlook 2021 (AEO2021) www.eia.gov/aeo, CC BY-NC

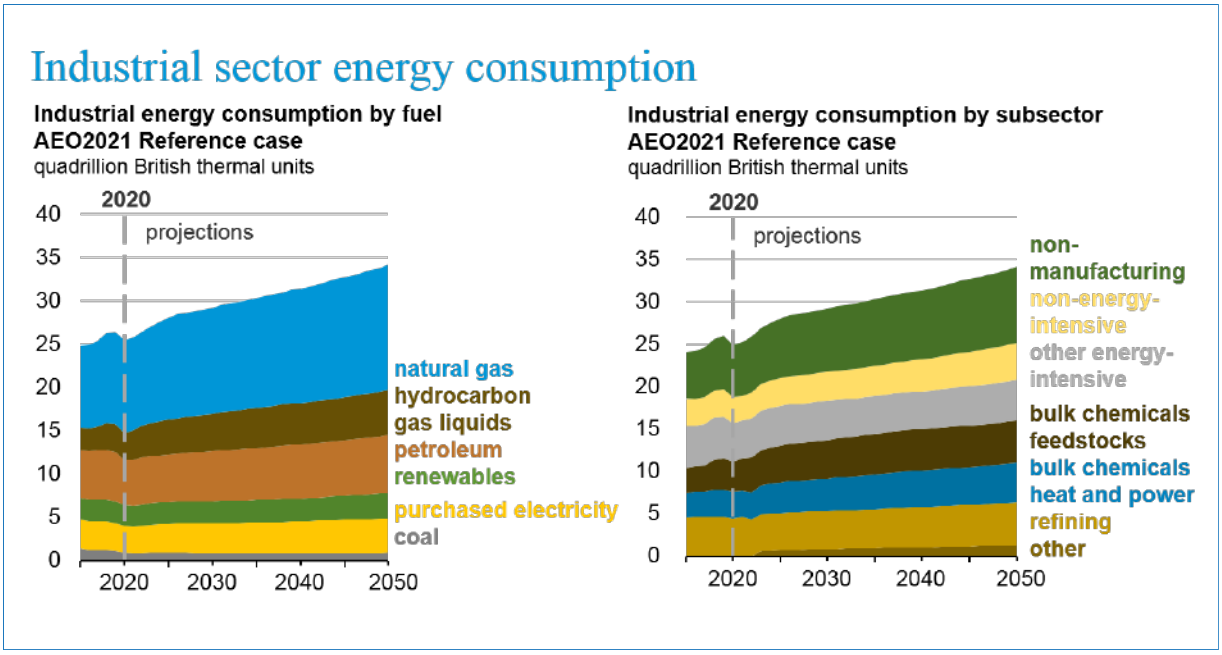

Fig. 11. Past and projected industrial sector energy consumption through to 2050 by fuel type (left) and by industrial sub-sector (right)
Source: U.S. Energy Information Administration Annual Energy Outlook 2021 (AEO2021) www.eia.gov/aeo, CC BY-NC

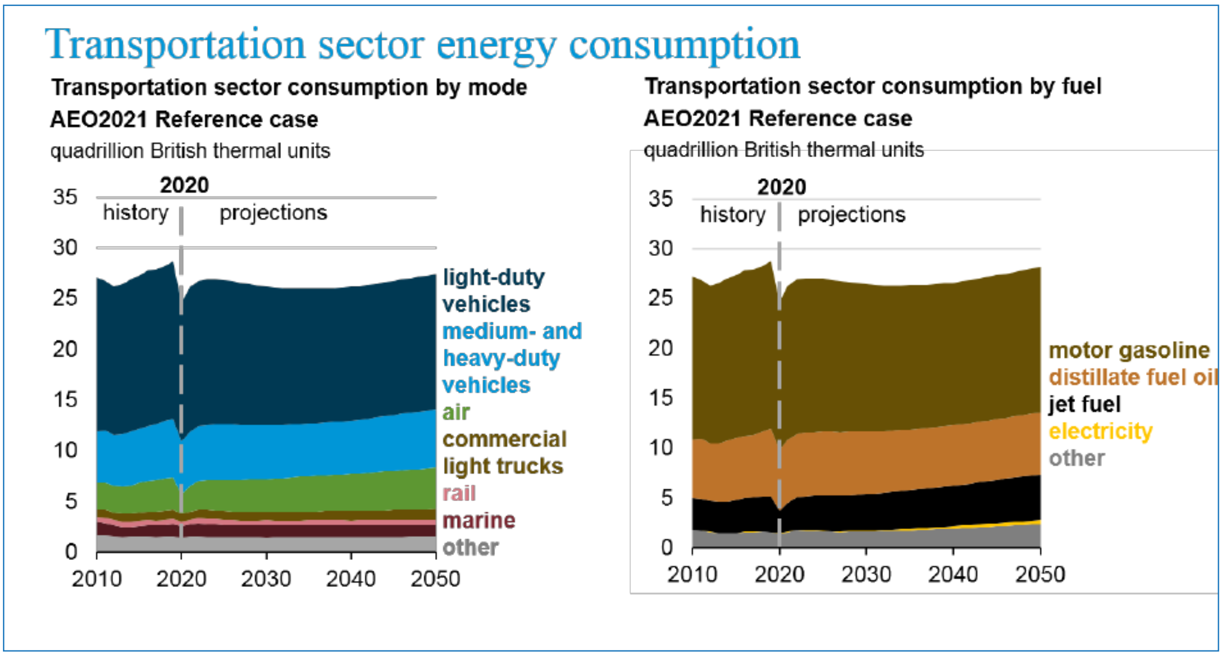

Fig. 12. Past and projected transport sector energy consumption through to 2050 by transport mode (left) and fuel type (right)
Source: U.S. Energy Information Administration Annual Energy Outlook 2021 (AEO2021) www.eia.gov/aeo, CC BY-NC

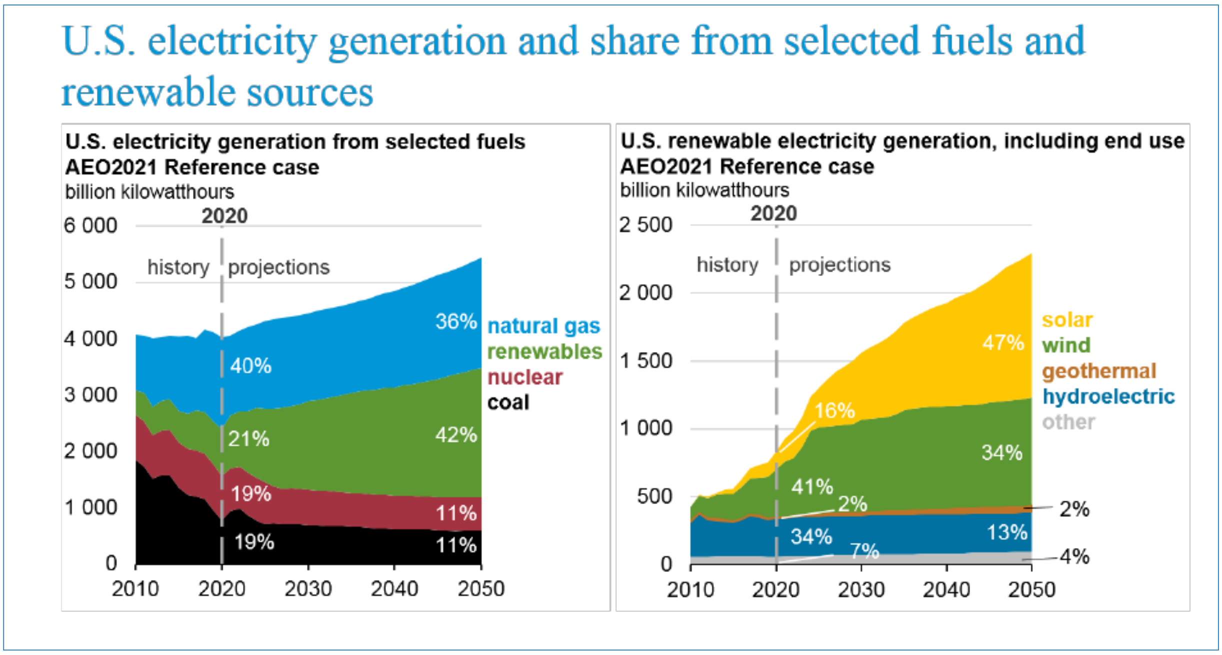

Fig. 13. Past and projected electricity generation through to 2050 by fuel type (left) and by renewable source (right) [same as *Fig. 8*]
Source: U.S. Energy Information Administration Annual Energy Outlook 2021 (AEO2021) www.eia.gov/aeo, CC BY-NC

3. Building sector

3.1. Existing buildings

Energy balance 2019 (energy sources to end-uses)

The U.S. EIA conducted its last Residential Energy Consumption Survey (RECS) in 2015. According to the EIA's website, data for the 2021 RECS was collected in 2020-21, and results are to be released in late 2021 / 2022.

The U.S. EIA did its last Commercial Building Energy Consumption Survey (CBECS) in 2012. Preliminary building characteristics for the 2018 CBECS are available now. According to the EIA website, microdata will be available in November 2021, and consumption and expenditures information will be available starting in spring 2022.

Energy partition between single houses, apartments buildings and office buildings

The 2015 RECS found that the average single family detached home used 94.6 million Btu per year, single family attached home used 70, apartment with 2-4 units used 53.5, apartment with 5+ units used 34.2, and mobile homes used 59.8. See *Table CE3.1* "Annual household site end-use consumption in the U.S.—totals and averages, 2015" below:

Table CE3.1 Annual household site end-use consumption in the USA —totals and averages, 2015

		Total site energy consumption (trillion Btu)						Average site energy consumption (million Btu per household using the end use)					
Housing unit type	Total housing units (million)	Total	Space heating	Water heating	Air con-ditioning	Refrigerators	Other	Total	Space hea-ting	Wa-ter hea-ting	Air con-ditio-ning	Refri-gera-tors	Other
Single-family detached	73.9	6 991	3 201	1 185	586	221	1 798	94.6	44.9	16.1	8.9	3.0	24.3
Single-family attached	7.0	491	228	95	33	16	119	70.0	34.1	13.5	5.4	2.3	17.0
Apartments in buildings with 2–4 units	9.4	503	197	136	25	17	129	53.5	22.2	14.5	3.3	1.8	13.7
Apartments in buildings with 5 or more units	21.1	724	183	234	51	35	220	34.2	9.7	11.1	2.9	1.7	10.4
Mobile homes	6.8	406	136	96	36	14	124	59.8	22.1	14.1	6.2	2.2	18.3

Table 10. Total and average energy consumption by housing type and by type of use
Source: EIA, Table CE3.1 (CC BY-NC): https://www.eia.gov/consumption/residential/data/2015/index.php?view=consumption

The 2012 CBECS found the average office building is responsible for 1,226 million Btu per year of energy use, with major fuel energy intensity of 77.8 thousand Btu/square foot. See "Table PBA3. Sum of major fuel consumption totals and gross energy intensities by building activity subcategories, 2012" below:

Sum of major fuel consumption totals and gross energy intensities by building activity subcategories:

				Sum of major fuel consumption					
	All buildings						Distribution of building-level intensities (thousand Btu/square foot)		
	Number of buildings (thousand)	Total floor-space (million square feet)	Floor-space per building (thousand square feet)	Total (trillion Btu)	per building (million Btu)	per square foot (thousand Btu)	25th per-centile	Median	75th per-centile
All buildings	5 557	87 093	15.7	6 963	1 253	80.0	18.9	45.9	89.0
Office	1 012	15 952	15.8	1 241	1 226	77.8	32.6	52.7	80.2

Table 11. Buildings – Total and average Floor spaces and energy consumption - total, per surface area, and distribution – all buildings and Office space
Source: EIA, https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/pba3.php, CC BY-NC

Which systems are mostly used for heating? Local systems (Furnaces, electric heating, heat pumps, solar thermal panels, geothermal systems, etc.)?

Local systems service 88% of residential buildings – mostly central warm-air furnaces and heat pumps (exact numbers in *Table HC6.1, 2015 RECS*, below).

Main heating equipment (including all fuels) [EIA 2015 RECS Table HC6.1]	Number of housing units, millions
Total	118.2
Central warm-air furnace	70.1
Heat pump	13.4
Steam or hot water system	9.1
Built-in electric units	9.2
Built-in oil or gas room heater	3.1
Portable electric heaters	3.0
Heating stove burning wood	2.7
Built-in pipeless furnace	1.1
Fireplace	0.8
Some other equipment	0.6
Do not use heating equipment	5.1

Table 12. Main heating equipment in residential buildings
Source: EIA, https://www.eia.gov/consumption/commercial/data/2012/c&e/cfm/pba3.php, CC BY-NC

Local systems service 99.1% of commercial buildings – mostly packaged heating units and space heaters, followed by furnaces, heat pumps, and boilers (*Table B26, 2012 CBECS*, below).

Heating equipment (more than one may apply [EIA 2012 CBECS Table B26]	Number of housing units, millions
Total	5 557
Heat pumps	628
Furnaces	755
Individual space heaters	1 247
District heat	48
Boilers	544
Packaged heating units	2 802
Other	62

Table 13. Main heating equipment in commercial buildings
Source: EIA, https://www.eia.gov/consumption/commercial/data/2012/bc/cfm/b26.php. CC BY-NC

- **Heat networks (hot water, steam). In this case, which energy sources are used? What is the CO_2 content per MWh_{th}?**

  7.7% of residential buildings use steam or hot water system heat (RECS 2015). As seen in the excerpt of *Table HC6.1* below, natural gas powers these systems in 6.6 million homes and fuel oil/kerosene in 1.7 million homes.

Main heating fuel and equipment [EIA 2015 RECS Table HC6.1]	Million housing units
Natural gas	**57.7**
Central warm-air furnace	46.5
Steam or hot water system	6.6
Built-in room heater	2.2
Some other equipment	2.4
Electricity	40.9
Central warm-air furnace	16.1
Heat pump	11.8
Built-in electric units	9.2
Portable electric heaters	3.0
Some other equipment	0.8
Fuel oil/kerosene	**5.8**
Central warm-air furnace	3.5
Steam or hot water system	1.7
Some other equipment	0.7
Propane	5.0
Central warm-air furnace	3.8
Some other equipment	1.2
Wood	3.5
Heating stove	2.7
Some other equipment	0.8
Some other fuel	Q
Do not use heating equipment	5.1

Table 14. Steam or hot water systems powered by natural gas or fuel oil/kerosene
Source: EIA, https://www.eia.gov/consumption/residential/data/2015/hc/php/hc6.1.php. CC BY-NC

- **0.86% of commercial buildings use district heat (CBECS 2012). *Table B28, 2012 CBECS* below, shows what energy sources are used for heat networks.**

Number of buildings (thousand)							
	All buildings	Buildings with space heating	Primary space-heating energy source used				
			Electricity	Natural gas	Fuel oil	District heat
All buildings	5 557	4 722	1 819	2 322	205	47
Heating equipment (more than one may apply)						
Heat pumps	628	628	484	117	Q	2
Furnaces	755	755	191	485	Q	Q
Individual space heaters	1 247	1 247	392	622	81	8
District heat	48	48	Q	Q	Q	47
Boilers	544	544	83	355	71	Q
Packaged heating units	2 802	2 802	1 057	1 506	85	3
Other	62	62	14	27	Q	Q

Table 15. District heating used in 0.86% of commercial buildings
Source: EIA, https://www.eia.gov/consumption/commercial/data/2012/bc/cfm/b28.php. CC BY-NC

What are the main choices of the national policy – if there is one – to reduce the emissions from the existing stock of buildings? To make this reduction affordable?

There is no national policy on the reduction of emissions by buildings.

- **From a technological point of view? (Insulation, heat pumps, low CO_2 district network, geothermal systems, local PV production, etc.).**

  There is primarily an "all of this" approach.

- **From a regulatory point of view? Through land ownership regulations?**

  The United States does not have a national building code in place. Building codes are monitored and enforced at a state or municipal level and are either codes developed by private organisations (American Society of Heating, Refrigerating and Air-Conditioning Engineers and the International Code Council) or state governments.

  More than half of US states currently have mandatory or voluntary energy efficiency resource standards (EERSs) in place for their electric or natural gas utilities (or both). No such standard has been adopted at the federal level.

  The federal government has appliance standards in place in 60 use categories. The US Department of Energy is required to revisit the standards every six years to make updates if necessary.

- **Through subsidies, different financial mechanisms? Which are the priorities: reducing CO_2 or energy; Better inclusivity.**

  Subsidies in the form of rebates or tax credits are the most common financial incentives.

  The federal government offerings are tax credits of up to $500 on certain appliances, and subsidies for low-income households to weatherise homes. Rebate programs also exist through state and local governments as well as utilities.

- **Replacing parts of the existing stock of buildings?**

  The U.S. Green Buildings Council created and administers *Leadership in Energy and Environmental Design* (LEED) Certifications for all building types and all building phases including new construction, interior outfits, operations and maintenance and core and shell. LEED O+M (Building Operations and Maintenance) and LEED Zero (projects with net zero carbon and/or resource goals) applies to existing buildings.

- **Is there a specific roadmap for this subject?**

  There is no specific roadmap for decarbonising existing buildings. The DOE Building Technologies Office (BTO) deals with most of the emission reduction efforts of buildings, including research and development at national laboratories. Incentives and requirements for buildings and their components vary by state, locality, and utility provider.

Are there some case studies or best practices you would like to share?

In 2016, the National Academies hosted a workshop on *Electricity Use in Rural and Islanded Communities* as part of the Quadrennial Energy Review. Curtis Wynn, Roanoke Electric Cooperative, describes therein his co-op's experience using the Rural Utilities Service (RUS) Energy Efficiency and Conservation Loan Program (RUS-EECLP) to reach their members in a more inclusive way, and how their approach benefits both members and the cooperative providing the energy. American Council for an Energy-Efficient Economy (ACEEE) covers many of the best practices for *building policies* that are currently or could be applied in the Unites States, as does *Resources for the Future* (RFF).

3.2. New buildings

Does your country have a national policy regarding new buildings?
If yes, what are the priorities? (For housing and for office buildings)

There is no specific national policy for decarbonising new buildings. Building energy codes require that a certain standard be met when building new or renovating existing buildings. However, the United States does not have a national building code in place. The existing codes are monitored and enforced at a state or municipal level, and are developed either by private organisations (American Society of Heating, Refrigerating and Air-Conditioning Engineers and the International Code Council) or state governments.

The U.S. Green Buildings Council created and administers LEED Certifications for all building types and all building phases including new construction, interior outfits, operations and maintenance and core and shell. LEED BD+C (building design and construction), ID+C (interior design and construction), ND (neighbourhood development), and Homes programs apply to new construction.

Are some technologies prioritised? At the building level? At the infrastructure level?
(Development of district networks, prohibiting connection to the gas network…)

No. The DOE Building Technologies Office (BTO) deals with most of the technology development aspects of emissions reductions in buildings. They primarily follow an "all of this" approach.

How are they supported? Through regulations? Subsidies?

The U.S. Department of Energy (DOE) announced on August 13, 2021 the granting of nearly $83 million in funding to 44 projects that will lower Americans' energy bills by investing in new energy-efficient building technologies, construction practices, and the US buildings-sector workforce. All but one of these 44 projects is directly relevant to new buildings.

There are no federal regulations or incentives supporting the purchase or utilisation of lower-emitting building technologies. However, some States have such regulations (NY, CA?)

Are there some case studies or best practices you would like to share?

DOE has established a goal of tripling energy efficiency and demand flexibility in residential and commercial buildings by 2030, relative to 2020 levels. In May 2021, Lawrence Berkeley National Laboratory published a National Roadmap for Grid-Interactive Efficient Buildings in support of this goal.

The United States Climate Alliance, a coalition of governors committed to the Paris Climate Agreement, commissioned a Building Decarbonization Roadmap by Rocky Mountain Institute published June 2021, designed to summarise the highest-impact actions that states can take to decarbonise buildings. American Council for an Energy-Efficient Economy (ACEEE) covers many of the best practices for *building policies* that are currently or could be applied in the Unites States, as does *Resources for the Futur*e (RFF).

4. Industry

Please choose three or four industries that are important for your country:

- Steel industry (including mining),
- Cement industry,
- Chemical industry (ammonia, ethylene, plastic…).

For each of these industries:

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

The U.S. EIA did its last Manufacturing Energy Consumption Survey (MECS) in 2018. Data was released across 2021, and as of August 27 is fully available. See "*Table 1.2 First Use of Energy for All Purposes (Fuel and Nonfuel), 2018*" for more details

Steel: 1225 trillion Btu (359 TWh) of energy were used in 2018 on Iron and Steel Mills and Ferroalloys and steel products from purchased steel, 479 (140) from natural gas, 272 (80) from coal, 238 (70) from coke and breeze, 214 (63) from electricity, 4 (1.2) from distillate fuel oil, and 18 (5) from other sources (EIA 2018 MECS). Steel is responsible for ~100 million tonnes CO_2 emissions (Feldmann and Kennedy, 2021). As of 2018, the carbon intensity of iron and steel production (a $39 billion dollar industry) was 3.2 kg CO_2 emission per dollar value added (Broekhoff et al., 2021). As of 2020, U.S. Steel reports its North American operations' GHG intensity to be 2.39 metric tonnes) of CO_2 emissions per metric tonne of raw steel produced (with 8.49 Mt raw steel produced in 2020).

Cement: 296 trillion Btu (87 TWh) of energy were used in 2018 on cements, 58 (17) from natural gas, 106 (31) from coal, 2 (0.6) from coke and breeze, 39 (11) from electricity, 1 (0.3) from distillate fuel oil, and 90 (26) from other sources (EIA 2018 MECS). In 2015, over 800 kg of CO_2 were emitted per metric tonne of cement produced (Hasanbeigi and Springer 2019). As of 2015, the carbon intensity of cement production (a $5 billion dollar industry) is 15.1 kg CO_2 emissions per dollar value added (Broekhoff et al., 2021).

Chemical: 7724 trillion Btu (2263 TWh) of energy were used in 2018 on chemicals (subcategories in below table). 3234 trillion Btu (948 TWh) were from natural gas, 2839 (832) from Hydrocarbon Gas Liquids (HGL), 130 (38) from coal, 2 (0.6) from coke and breeze, 501 (147) from electricity, 9 (2.6) from distillate fuel oil, 45 (13) from residual fuel oil, and 965 (283) from other sources (EIA 2018 MECS). As of 2018, the carbon intensity of cement production (a $256 billion dollar industry) is 1 kg CO_2e per dollar value added (Broekhoff et al., 2021).

See https://www.epa.gov/ghgreporting/ghgrp-chemicals for 2019 data on chemical emissions.

Sub-sector and Industry	Total (b)	Net Electricity (c)	Residual Fuel Oil	Distillate Fuel Oil (d)	Natural Gas (e)	HGL (excluding natural gasoline) (f)	Coal	Coke and Breeze	Other (g)	Shipments of Energy Sources Produced Onsite(h)
Chemicals	7 141	501	45	9	3 234	2 839	130	2	965	583
Petrochemicals	1 461	24	0	1	307	1 204	0	0	347	422
Industrial Gases	291	74	0	*	243	*	0	0	4	30
Other Basic Inorganic Chemicals	555	101	44	*	264	55	33	2	57	0
Ethyl Alcohol	453	37	0	*	360	*	44	0	12	0
Cyclic Crudes, Intermediate and Gum and Wood Chemicals	233	11	0	*	120	78	3	0	30	9
Other Basic Organic Chemicals	1 366	65	*	Q	597	412	42	0	333	88
Plastics Materials and Resins	1 675	58	0	D	458	D	D	0	D	34
Synthetic Rubber	38	5	0	*	19	3	2	0	9	0
Artificial and Synthetic Fibres and Filaments	33	9	0	*	23	*	*	0	*	0
Nitrogenous Fertilisers	614	18	0	*	D	*	0	0	D	0
Phosphatic Fertilisers	37	D	*	D	29	*	D	0	*	0

Table 16. Energy consumption in the chemical industry by product and by fuel type in trillion Btu (1 trillion Btu = 0,293 TWh)
Source: Unites States Environmental Protection Agency (EPA), CC BY-NC https://www.epa.gov/ghgreporting/ghgrp-chemicals

Are the best available low carbon technologies used/considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

Steel: In many cases, yes. 70% of American steel is produced by recycling steel scrap to produce new steel using electric arc furnace (EAF). Steel produced by blast furnace and basic oxygen furnace (BF/BOF) technology in the United States has the lowest CO_2 intensity of steel produced via BF/BOF in the seven largest steel producing countries. BF/BOF steel production is fed almost entirely by domestically sourced iron ore pellets, resulting in lower emissions of CO_2, as well as NOx, SO_2 and particulate matter (Mourao et al., 2020). The steel industry is also pursuing R&D in increased use of renewable energy in steel production, and advancements in domestic production using direct reduced iron (DRI) and hot briquetted iron (HBI) in place of pig iron in both integrated and EAF steelmaking. HBI and DRI use natural gas as a reductant which will further increase blast furnace and electric arc furnace productivity and reduce CO_2 emissions. The American steel industry uses a higher percentage of low-emitting natural gas than most other countries. Boston Metal process emissions.

Cement: In most cases, no. US cement production has, on average, the highest electricity intensity, fuel intensity, and carbon intensity (15.1 kg/$ value added [Broekhoff et al., 2021]) in the world. This is in part due to the high clinker-to-cement ratios used in US cement plants, partially because blending with Supplementary cementing materials (SCMs) typically occurs at concrete mixing plants after the cement is produced, but also due to plant ages, types of cement produced, and fineness of clinker grinding.

Chemical: Low carbon technologies are used in some chemical production, not often for their lower emissions but rather for economic reasons, where they intersect with increased production volumes or greater production efficiencies.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

No, there is no national roadmap for industrial emissions. The Portland **Cement** Association and U.S. **Steel** have both published roadmaps to carbon neutrality by 2050.

Is the implementation of low-carbon technologies helped by the government? For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through bench-marking? Audits?

Low-carbon industrial technologies are mainly supported by the federal government through the funding of RD&D, mostly through ARPA-E and DOE.

Steel: The U.S. Department of Energy has provided significant funding to support Boston Metal's MOE process (see *section 3.7* for more detail on this steelmaking process).

Are there incentives for carbon capture, utilisation, and storage? How?

The U.S. Department of Energy is actively researching and investing in carbon capture, utilisation, and storage technologies, with most research conducted at the National Energy Technology Laboratory (NETL). The National Academies have released multiple reports on this topic in recent years, including *Negative Emissions Technologies and Reliable Sequestration* and *Gaseous Carbon Waste Streams Utilization*. In December 2019, U.S. House and Senate appropriators provided $60 million, the first dedicated funding for carbon removal technology development.

For existing CCUS technologies, the Code Section 45Q tax credit is the main incentive, enacted in February 2018, industrial manufacturers that capture carbon from their operations can earn $50 per metric tonne of CO_2 stored permanently or $35 if the CO_2 is put to use, such as for enhanced oil recovery (EOR). There are no specific incentives for the **steel**, **cement**, and **chemical industries** in the United States to pursue CCUS technologies.

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

Steel: There are typically 60 to 80 million tonnes of steel scrap recycled per year into new steel products. Steel is the most recycled product in the US, and 100% of the co-products of the steel production process can be beneficially used.

Cement: The Construction Materials Recycling Association estimates that about 140 million tonnes of concrete are recycled each year in the United States. Concrete products can be crushed and used as aggregate for new Portland cement concrete products, usually mixed with virgin aggregate or used in sub-base layers. This saves energy in mining, processing, and transporting new aggregates, as well as landfill avoidance, which is important due to the high volume of concrete removed from demolition sites.

Are there some case studies or best practices you would like to share?

Steel: Boston Metal is pursuing an alternative steel production method called molten oxide electrolysis (MOE), which requires inputs of iron ore and electricity. This process is more energy efficient, using 4 MWh of electricity to produce one tonne of crude steel, rather than 5.5 MWh of coal in traditional steel production. This results in significantly lower emissions, as long as there is sufficient low-carbon electricity.

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5. Case study

Localizing Climate Solutions: Case Study of Drawdown Georgia, *reproduced with permission from the author.*

Dr. Marilyn A. Brown (mbrown9@gatech.edu)

Professor of Sustainable Systems, School of Public Policy, Georgia Institute of Technology

Avoiding costly climate change necessitates actions at every political scale and across all sectors of the economy. Drawdown Georgia illustrates how robust place-specific plans for climate action can be derived from foundational global and national work and by embedding that research into the context of socio-ecological-technological systems. Its replicable methodology advances the science of carbon abatement by incorporating solution interdependencies, by spanning both carbon sources and sinks, and by emphasizing beyond-carbon societal costs and benefits including their distributional impacts. By focusing on the 2030 timeframe, Drawdown Georgia highlights pathways for immediate action that can help put sub-national jurisdictions onto a path toward net-zero emissions by mid-century. However, it recognizes that post-2030, additional solutions will likely be cost-effective and necessary for deeper reductions.

Down-Selection of 20 Solutions

Engaging universities and stakeholders across the state, 20 high-impact solutions for Georgia were identified, spanning five sectors. They address a combination of traditional sources of carbon emissions from electricity generation, transportation, and the energy consumption of buildings. In addition, they tackle emissions from agriculture and food systems, and they focus on the carbon absorbed in trees and soils. These solutions are diverse, and many of them depend on the actions of consumers—such as rooftop solar, electric vehicles, recycling, plant-rich diets, and composting organic waste. Others depend on the actions of businesses and industry, such as refrigerant management, conservation agriculture, increasing forest cover, and generating electricity from landfill methane. Some depend on significant public funding, such as mass transit, and they all would benefit from private investments and supportive public policies.

Approximately 100 climate solutions were examined by applying a sequence of filters covering applicability to Georgia, technology readiness, magnitude of impact, cost-effectiveness and beyond-carbon attributes. *Figure 14* presents the carbon abatement cost curve that aligns costs and benefits with megatons of carbon reduction for the final set of 20 high-impact climate solutions. Per megaton of abatement, the solutions range from net savings of \$336 to net costs of \$144. The estimated total financial impact of achieving a 35% reduction of CO_2-e in 2030 ranges from net benefits of \$1.3 billion to net costs of \$148 million.

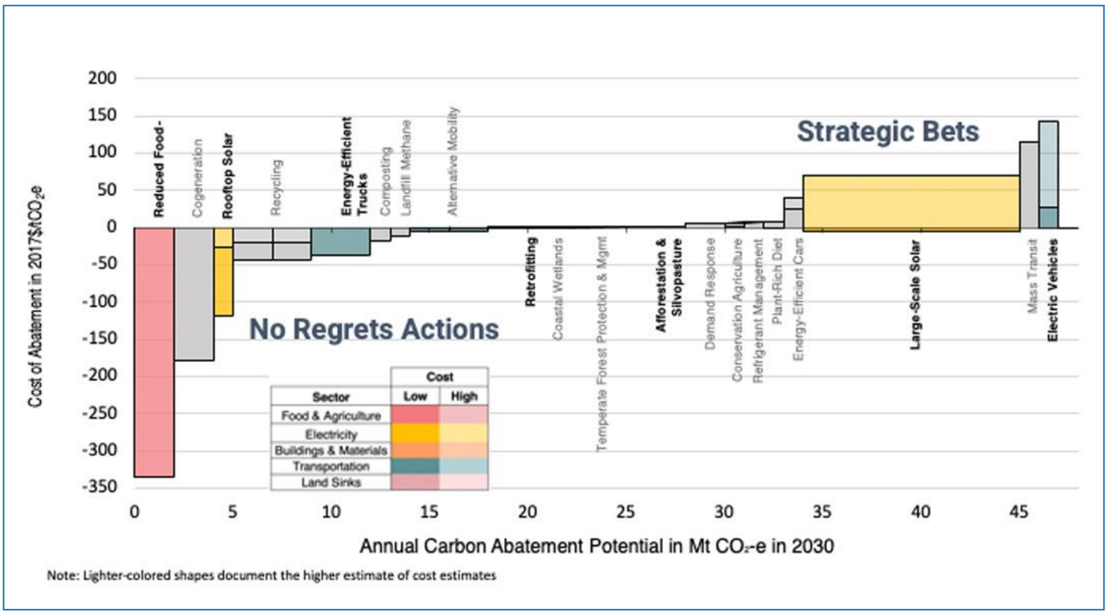

Fig. 14. Carbon Cost Abatement Curve. Reproduced with permission from the author.
(Note: Abatement costs and potentials have ranges for some solution, that are highlighted by dividing boxes vertically and horizontally.)

On the left side of the abatement cost curve are the solutions that deliver the largest net benefits (reduced food waste, rooftop solar, and cogeneration). Consumers and businesses can make money by investing in them. For example, companies in many industries can cut their energy bills by buying their own generation equipment and running it primarily on waste heat. On the right side are the solutions that deliver the highest net costs (electric vehicles and mass transit, in particular). Mass transit requires significant public investments, but based on the array of key benefits, the expenditures are justifiable.

Figure 15 aligns these 20 solutions with a multi-criteria assessment of societal attributes to acknowledge the hard-to-monetize costs and benefits of each solution and to consider equity as it relates to their distribution.

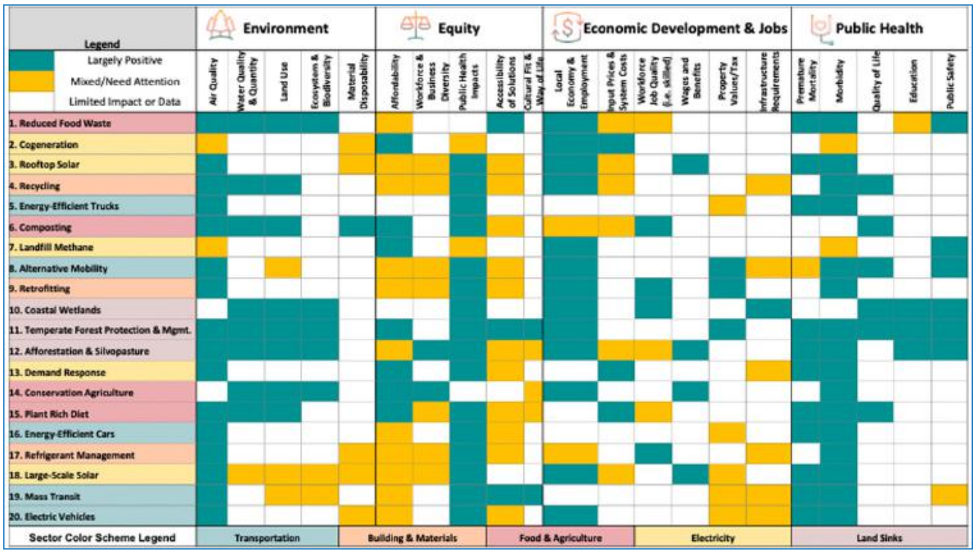

Fig. 15. Multi-Criteria Assessment of Selected Attributes
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By comparing the baseline forecast and achievable scenarios for each of the 20 high-impact solutions, we estimated their potential to contribute to carbon abatement in 2030. Summing the results over the decade produces the “wedge” diagrams shown in *Figure 16*. The grey band across the top shows carbon sinks at about 46 megatons, Georgia’s current carbon footprint of about 122 megatons, which is also the baseline forecast for 2030. The colored wedges below the gray band represent the carbon abatement associated with each of the 20 solutions, showing how much each solution could contribute over the next decade, by year from left to right. For example, the largest wedge represents utility-scale solar that increases from 3.9 megatons in 2021 to 11.2 megatons in 2030. The wedge for energy-efficient trucks grows from 0.5 megatons in 2021 to 3.3 megatons in 2030. When all 20 abatement estimates are included and two major interactions are taken into account, the projected total GHG emissions in 2030 would fall from the forecast of 122 megatons to 79 megatons, a 35% reduction. Relative to Georgia’s 156.5 megatons of net emissions in 2005, this would be a 50% reduction, which is consistent with the 2015 Paris Climate Agreement.

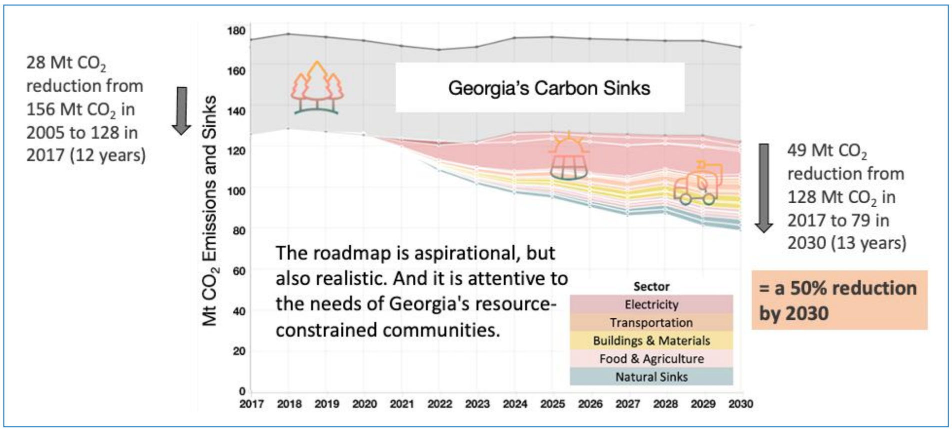
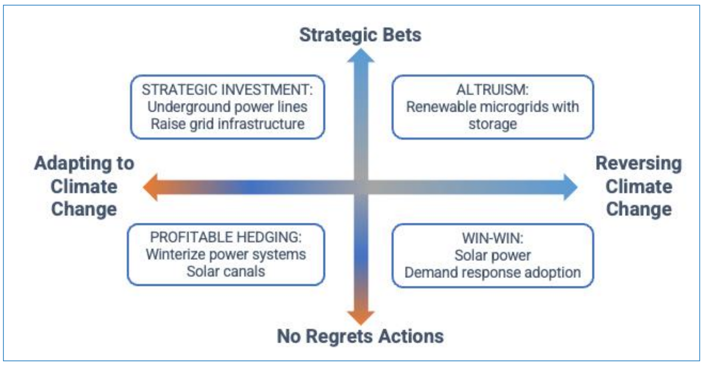


Fig. 16. The Achievable Abatement Potential of 20 High-Impact Solutions for Georgia
Reproduced with permission from the author

In sum, putting all the parts together, we show that this scenario of 20 solutions could reduce Georgia's carbon footprint at no net financial cost. However, implementing some solutions will require public support through information/outreach and technical assistance programs, while others will require direct financial outlays from private individuals/firms or public institutions. This conclusion is independent of the co-costs (such as the handling of hazardous waste streams) and co-benefits (such as improved public health and coastal land storm protection) that can result from implementing these solutions.



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Next steps for Drawdown Georgia include the creation of a dashboard to monitor monthly GHG emissions by county and metro area in the state of Georgia. In addition, nearly 20 Georgia companies operating in Georgia have signed the Georgia Climate Compact and the Drawdown Georgia team will be working with them to build a community-of-interest. Finally, we have created a Climate Solutions Game and we are in the process of evaluating the results of a public survey to ascertain the attitudes of state residents to climate solutions and policies, which will provide key inputs to climate action planning across Georgia.

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Learn more about the Drawdown Georgia Project at these two websites:
Drawdownga.org
https://cepl.gatech.edu/projects/Drawdown-Georgia

SECTOR ANALYSIS QUESTIONNAIRES

FOOD AND AGRICULTURE ANALYSIS

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Nigeria

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

Nigeria is endowed with abundant natural energy resources including fossil and renewable reserves. The country is energy-rich and ranks as the 11th largest global producer of oil[1] (about 2 million barrels/day) and the 9th biggest gas producer accounting for 3% of the world's total natural gas reserves (6 923 trillion cubic feet)[2]. Fossil energy (oil, gas and coal) was about 97% of the total production (5.93 quads - 1738 TWh) in 2018 with renewables (hydro-power, wind, solar and biofuels) accounting for the balance[3]. Indeed, oil and gas contribute about 86% of the nation's total export earnings. Nigeria's strong reliance on fossil fuels to power its economy is also reflected in the energy consumption[4] history during the last three decades as shown in *Fig. 1*. The rapid rise in natural gas consumption reflects the preponderance of gas-powered plants for electricity generation, especially since the turn of the 21st century. Through its Natural Gas Expansion Programme (NGEP), the government is implementing gas utilisation and expansion activities. However, despite the diversity of renewable energy resources[5], its relatively flat profile is indicative of weak government efforts at promoting national uptake in this energy category. Crucially, the agricultural sector in Nigeria has access to less than 1% of the total energy supply in the country[6]. This is worrisome, given that the country consumed about 1.655 quads (485 TWh), for example, in 2018 and is presently driving a strong agricultural mechanisation and processing agenda.

Greenhouse gases (GHGs) released during energy-related activities typically contribute to global warming. The emissions intensity (release rate of the emitted gases relative to a specific activity or an industrial production process such as the quantity of energy produced or the GDP) may therefore be used as an environmental impact metric. GHGs include CO_2, CH_4, N_2O, SF_6, PFCs, HFCs and others as listed comprehensively in the IPCC Report[7]. *Fig. 2* illustrates the CO_2 intensity profiles for representative nations from Europe, the Americas, Asia, Africa and Oceania. CO_2 was used as a proxy for total GHGs data as obtained from the World Bank[8]. The CO_2 intensity for Nigeria appears to have generally decreased from 1.19 to 0.67 (kg CO_2 released/kg oil equivalent energy use) over the past three decades. Whilst this is a desirable trend from an environmental perspective, the underlying interplay of factors may, however, be more complex than appears on the surface of these data. Even so, South Africa, the largest economy on the African continent seemed to be in a poorer position with a CO_2 intensity exhibiting a general rise from 2.55 to 3.05 within the same period – an unenviable trajectory. Nigeria is, in fact, second to South Africa as the largest GHG emitter on the continent but 17th on the global ladder. More detailed analyses and in-depth comparisons with other nations are beyond the scope of this feedback.

1 https://www.investopedia.com/articles/investing/101515/biggest-oil-producers-africa.asp

2 https://www.worldometers.info/gas/nigeria-natural-gas/#:~:text=Gas%20Reserves%20in%20Nigeria&text=Nigeria%20holds%20187%20trillion%20cubic,306.3%20times%20its%20annual%20consumption.

3 https://www.eia.gov/international/data/country/NGA/

4 World Energy Statistics | Enerdata

5 https://www.iea.org/policies/4974-nigeria-renewable-energy-master-plan

6 Onyema M-A. C., (2016), International Food Policy Research Institute: Nigeria Strategy Support Program, Policy Note No. 24.

7 https://www.ipcc.ch/report/ar6/wg1/

8 https://data.worldbank.org/conc

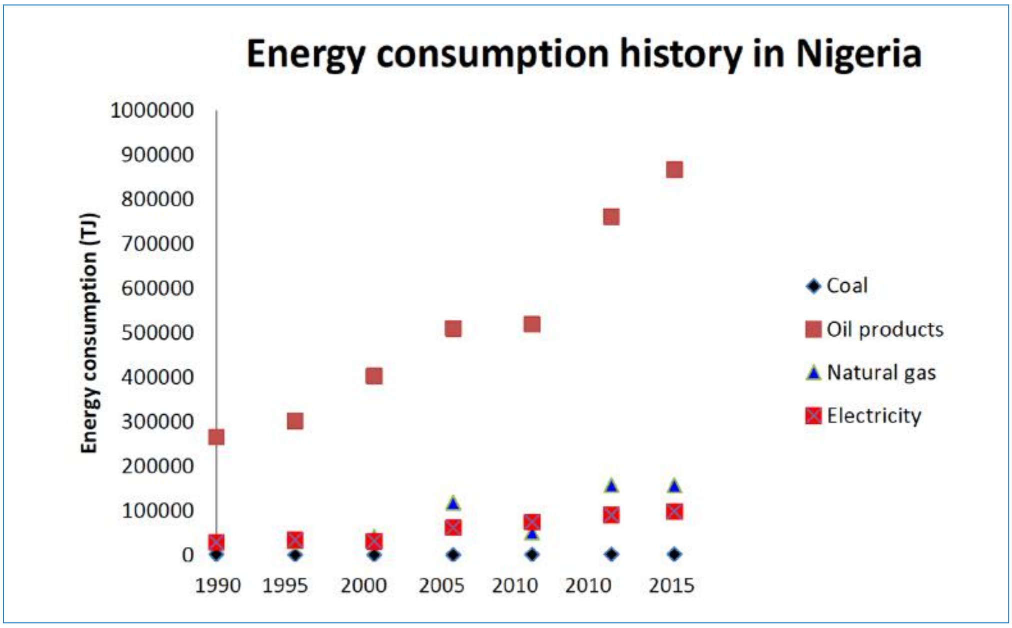

Fig. 1. Nigeria's energy consumption profile between 1990-2020.
Source: IEA World Energy Balances https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances.
Reproduced with Permission

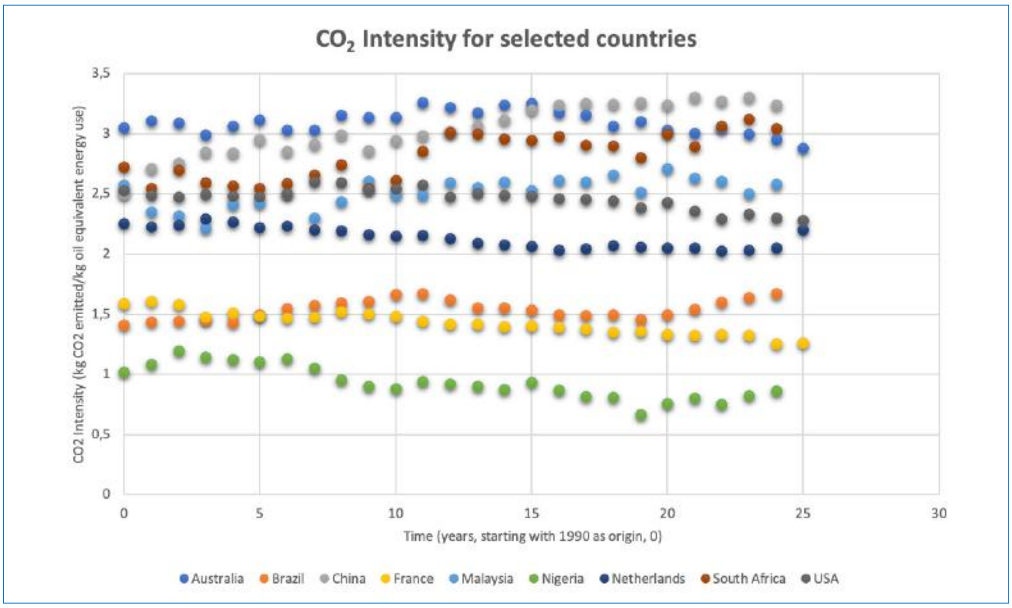

Fig. 2. CO_2 intensity history over the last three decades
Open data, https://data.worldbank.org
Source: https://data.worldbank.org/indicator/EN.ATM.CO2E.EG.ZS

Are the best available low-carbon technologies used/considered?

If not, is it an economic problem? A matter of regulation? Or some other social issues?

The Federal Government of Nigeria (FGN) produced a Vision 2020 document which identified Agriculture & Land as one of the four areas (i.e. agriculture & land use; oil & gas; power; transport) where the application of low-carbon technologies may help in realising the vision to become the 20th largest global economy. However, an examination of the publicly accessible documents on the website of the Federal Ministry of Agriculture and Rural Development[9] (FMARD) revealed that there seems to be no policy framework to stimulate economic

[9] https://fmard.gov.ng/green-alternative/

growth in key carbon-emitting sectors that can lead to a reduced carbon footprint. This means that GHG emissions would increase over the next decade or at best, be maintained at their present value (ca. 0.67 tonnes CO_2 per capita). Additionally, the unavailability of low-carbon technologies may be attributed to poor political commitment as evidenced by the absence of an appropriate regulatory agency. Nonetheless, there is a consistent growth within the private sector, of investment activities in renewable energy (solar-powered farms, water supply, etc.) and carbon reduction (gas-powered automobile/transportation) technologies.

Is there a roadmap to decrease GHG emissions for 2030 or 2050? If yes, what are the intermediary steps?

The Nigerian government has committed to reducing its GHG emissions by 20% by 2030 when compared to the "business-as-usual" practice but has opened the window for a possibility of a reduction by up to 45% if it has international support[10]. It is estimated that Nigeria's nationally-determined contribution (NDC)[11, 12] to GHG emissions by 2030 will be about 453 million tonnes of CO_2 equivalent – a 31% increase from its 2018 level – if there is no mitigation effort. The country is especially vulnerable to climate change impact because of its tropical location and the dependency of the agricultural sector on a reliable rain-fed pattern. The government's National Climate Change Policy (2021-2030)[13, 14] is a new roadmap for the reduction of emissions en route to 2030. The country is also benefitting from the $10.6 billion UN initiative on Reducing Emissions from Deforestation and Forest Degradation programme (REDD+) via the new national REDD+ Strategy (2021)[15, 16] on land use and forestry, to the tune of $7.6 million.

The Agricultural Promotion Policy (APP) of the present FMARD has led to the "Green Alternative" document[17]. Although the new policy highlights eleven national priorities, only one of them, "Factoring climate change and environmental sustainability" carries the explicit notion that the policy instrument may engage low-carbon technologies to mitigate GHG emissions as well as land, soil and natural ecosystems for improved agricultural sector productivity. In fact, in 2018, the Agriculture, Forestry and Other Land Use (AFOLU) sector contributed the country's 2nd largest (25%) GHG emissions[11] (with the energy sector being the 1st with 60% contribution i.e. 209 million tonnes of CO_2 equivalent). However, under Business-as-Usual conditions, the energy and agricultural sectors will contribute 51% and 33% respectively by 2030 to the national GHG emissions. Interestingly, existing renewable energy sources for agricultural production and processing activities, especially in rural areas, are being harnessed (and necessitate promotion) as Sambo[18] has summarised (cf. *Table 1.*).

Energy Source	Reserves	Energy Capacity
Crop residue	83 million tons/year	5.3×10^{11} MJ (147.2 TWh)
Animal waste	227.5 tons per day	2.2×10^{9} MJ (0.611 TWh)
Saw dust	1.8 millions/year	31.43×10^{6} MJ (0.009 TWh)
Fuel wood	80 million m³/year	6.0×10^{9} MJ (1,667 TWh)
Biogas	6.8 million m³/day	199.24 TJ (0.055 TWh)
Solar	6.25 hours/day	6.25-7.0 kWh/m² daily
Wind	2-4 m/s at 10 m height	5 MW
Small hydropower	0.143 billion tons (of water)	734.2 MW

Table 1. Potential sources of energy for rural agricultural production and processing in Nigeria
Source: IFPRI-Abuja, International Food Policy Research Institute, "Alternative Energy Sources for Agricultural Production and Processing in Nigeria", Page 2, Table 2 https://www.researchgate.net/profile/Mac-Anthony-Onyema/publication/286372661_Alternative_energy_sources_for_agricultural_production_and_processing_in_Nigeria/links/

10 Party (unfccc.int); UNFCCC
11 https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Nigeria%20First/NDC%20INTERIM%20REPORT%20SUBMISSION%20-%20NIGERIA.pdf
12 https://www.ndcs.undp.org/content/ndc-support-programme/en/home/our-work/geographic/africa/Nigeria.html
13 https://climatechange.gov.ng/wp-content/uploads/2020/09/national-climate-change-policy-1-1.pdf
14 https://climate-laws.org/geographies/nigeria/policies/national-policy-on-climate-change-67399bf5-f1f8-4102-9a15-5fa7e597a551
15 https://www.un-redd.org/post/2018/06/21/community-based-redd-programme-in-nigeria-a-success-story
16 https://republic.com.ng/april-may-2020/redd-in-nigerias-last-rainforests/
17 https://agra.org/wp-content/uploads/2017/12/agra-nigeria-final.pdf
18 Sambo, A. S. (2005). "Renewable energy for rural development. The Nigerian perspective". *UNESCO: Science and Technology Vision 1: 12-22.*

Is the implementation of low-carbon technologies helped by the government?

For refurbishing or replacing equipment? How are public authorities pushing this transformation? Through benchmarking? Audits?

As a signatory to the Paris Agreement, Nigeria's pledge to roll out solar power technologies and end gas flaring seems to be working (a reduction in gas flaring by 70% between 2000 to 2019), albeit slowly. Developments in agricultural mechanisation are being spear-headed by nearly 40 government agencies involved with various food and agricultural technologies such as National Agency for Science & Engineering Infrastructure (NASENI) and National Centre for Agricultural Mechanisation (NCAM). For example, NASENI, through collaboration with state governments, deploys agricultural innovations promoting decarbonisation[19]. While government efforts in the implementation of the Agricultural Transformation Agenda (ATA) have been largely fruitful, international benchmarking activities are somewhat diffuse. It is evident that public authorities and recent policies are lethargic in pushing low carbon economic transformation. This could be seen in the Petroleum Industry Act (PIA 2021) which places emphasis on increased prospecting of fossil fuels rather than on renewable energy investments in frontier locations and on the lack of targeted emphasis in the Economic Recovery & Growth Plan (2017-2020)[20].

Are there incentives for carbon capture, utilisation and storage? How?

The importance of carbon capture, storage and utilisation (CCSU) technologies in the decarbonisation of the Nigerian economy has been discussed in several papers[21, 22, 23]. These studies placed a premium on the realisation of the FGN's Vision 2020, especially regarding the 6-fold improvement in domestic agricultural production while offering a basis (through different scenario analyses) for government policy formulation and implementation. The absence of incentives for adopting CCS technologies (even in the more recent APP) by small-scale farmers and government-owned agricultural plantations is rather bewildering.

If relevant, what about recycling?

The recycling programme is under the auspices of the Federal Ministry of Environment, embedded in the department's Clean & Green Initiative. In practice, however, solid waste management (collection, processing and recycling) is often a state affair (there are 36 states in Nigeria). Lagos State, where Africa's largest city, Lagos, is located, runs an enviable recycling programme under the agency of the Lagos State Waste Management Authority. The programme has become a model for other big cities such as Ibadan, Abuja, Kano and Port-Harcourt. The LAWMA recycle programme is decentralised to the 57 local government areas (LGAs) in the state where private recycling companies handle the waste collection, processing and materials recovery. Over 40 million tonnes of waste are produced annually in Nigeria with about 30% of this as recyclable plastics, electronic wastes and other PVC materials. The recycling business is principally organised by the informal sector through social participation (waste pickers subcontracted by private companies). Thus, the absence of a central policy on solid waste management has led to a proliferation of private recycling companies operating with little or no regulation[24]. Despite the central government's relative apathy towards recycling, private Nigerians have developed a niché market for waste-to-wealth technologies as exemplified by young entrepreneurs like Victor Boyle-Komolafe whose company, GIVO, is processing plastic bottles into plastic face shields[25]. By the same token, a partnership between Nigeria's National Environmental Standards & Regulation Enforcement Agency, the UN Environment Programme, and a private company, Global Environment Facility, has led to Nigeria's first e-waste processing facility[26]. Other developments are found in public institutions where recycling and waste valorisation activities provide a parallel revenue stream in the overall waste management arm. With its

19 https://naseni.org/

20 https://www.cbn.gov.ng/Out/2017/CCD/Financial%20Inclusion%20Newsletter_%20MAY%202017_Volume%202%20Issue%202-final%20-%20Review%20%20%20.pdf

21 Cervigini R., Dvorak I. & Rogers J.A. (2013), "Assessing low-carbon development in Nigeria: An analysis of four sectors." World Bank Series. https://openknowledge.worldbank.org/handle/10986/15797

22 Galadima A. & Garba Z. (2008), "Carbon capture and storage (CCS) in Nigeria: Fundamental science and potential implementation risks." Sci. World J. 3(2), 95-99.

23 Ugwuishiwu B.O., Nwakaire J.N. & Ohagwu C.J. (2019), "Cost analysis of carbon capture and storage for current gas-fired power plants in Nigeria." Greenhouse Gases: Science and Technology, 9(2), 370-386.

24 Nzeadibi T.C. & Adama O. (2013), "Improved recycling performance: Policy options for Nigerian cities", The Nordic Africa Institute, Policy Note 2.

25 https://www.government.nl/latest/news/2021/04/08/%E2%80%98over-the-next-five-years-we%E2%80%99re-going-to-recycle-150-million-plastic-bottles%E2%80%99

26 https://www.unep.org/news-and-stories/press-release/nigeria-turns-tide-electronic-waste

burgeoning population, continuing advocacy with the Federal government on a robust policy for education on recycling is essential to avoid a degenerative or even chaotic market environment.

Are there some case studies or best practices you would like to share?

In terms of smart technology embrace, development and business practices, the Lagos State Waste Management Authority provides inspiration for the future of sustainable resource harnessing in Nigeria. LAWMA[27] has received both national and international awards for its adventures.

27 https://www.lawma.gov.ng/index.html

BUILDINGS AND SMART CITIES ANALYSIS

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China

Existing and new buildings

Energy balance 2019 (energy sources to end-uses)
Based on our long-term research on the energy consumption of civil building operations, considering the difference in the heating method in winter, the difference in lifestyle and types of buildings of urban and rural areas and the difference in activities and devices that consume energy in Northern China and Southern China, building energy use could be divided into four categories: **northern urban heating (NUH)**, public and P&C buildings (excluding NUH), urban residential buildings (excluding NUH) and rural residential buildings as described below.

Systems used for heating

Energy use for NUH
Refers to the energy use of various provinces, autonomous regions and municipalities such as all urban areas in Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia autonomous regions, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang autonomous region and part of Sichuan province that use district heating methods in winter. Heating is also needed for the cold winter in the Tibetan autonomous region, Western Sichuan and part of Guizhou provinces. However, the situations in Tibet, Western Sichuan and Guizhou are quite unique and thus should be treated independently. The reason for taking NUH energy use as an independent category is that district heating has been the main heating method in northern urban areas. This is the area where we would see many heat-supply networks in cities and communities. Different from other types of energy use in buildings, where the calculation is based on the consumption of single buildings or single households, the energy use for NUH depends mainly on the structure and the operation mode of the heating system, and the calculation of the energy used for heating in northern urban areas is based on the heating system as a whole, which is why we regard the energy use of this area as an independent category. Based on heat sources and the scale of heating, centralised heating methods include large- and mid-scale combined heat and power generation (CHP), small-scale CHP, district coal-fired boilers, district gas-fired boilers, community-level coal-fired boilers, community-level gas-fired boilers, and centralised heat pumps. Decentralised heating methods include household gas furnaces, household coal furnaces, air conditioners and direct electrical heating. The energy use considered in this report includes the primary energy consumption at the heat source and the power use of various related equipment (fan, water pump). Energy consumption can also be divided into transitional heat loss from heat sources and heating stations, heat loss from pipelines and transmission processes, and heat gain for buildings.

Urban residential building energy use (excluding NUH)
This refers to residential building energy use in urban areas excluding NUH. It includes energy use for household appliances, air conditioners, lighting, cooking, domestic hot water (DHW), and winter heating of the hot summer and cold winter (HSCW) climate zone. The energy types mainly include electricity, coal, natural gas, liquefied petroleum gas, etc. The main winter heating method in HSCW areas was decentralised, and the heat source included an air source heat pump, direct electrical heating, and local heating methods such as coal-fired stoves, electrical heating blankets, and electrical hand warmers.

Public and commercial building energy use (excluding NUH)
Refers to buildings for public and commercial purposes, including offices, commercial buildings, tourism buildings, buildings for educational purposes, buildings for communication and buildings for transportation in urban and rural areas. Apart from NUH energy use, the energy use of P&C buildings includes air conditioning, lighting, electricity sockets, elevators, cooking, and winter heating in the HSCW zone. Electricity, natural gas, oil and coal are the main energy sources for P&C buildings.

Rural residential buildings' energy use
This refers to the energy consumed by rural households, including cooking, heating, cooling, lighting, domestic hot water, household appliances, etc. Electricity, coal, LPG, natural gas and biomass energy (straw burning, firewood) are the major energy sources. Biomass was not included in national energy statistics, but it will be an independent category in this report.

The data of this report came from the China Building Energy Model (CBEM) from BERC, Tsinghua University, which delineated the status quo of China's building energy consumption and its transformation between 2001 and 2019. From 2001 to 2019, the sum total building energy use increased dramatically, as shown in *Figure 1*. In 2019, the total commercial energy use during the building operation stage amounted to 1.02 Gtce (8 304 TWh), accounting for 22% of the national energy consumption. The energy use of all building-related products and biomass was 1.11 Gtce (9 036 TWh) (0.09 Gtce (733 TWh) of biomass), and detailed information is presented in *Table 1*.

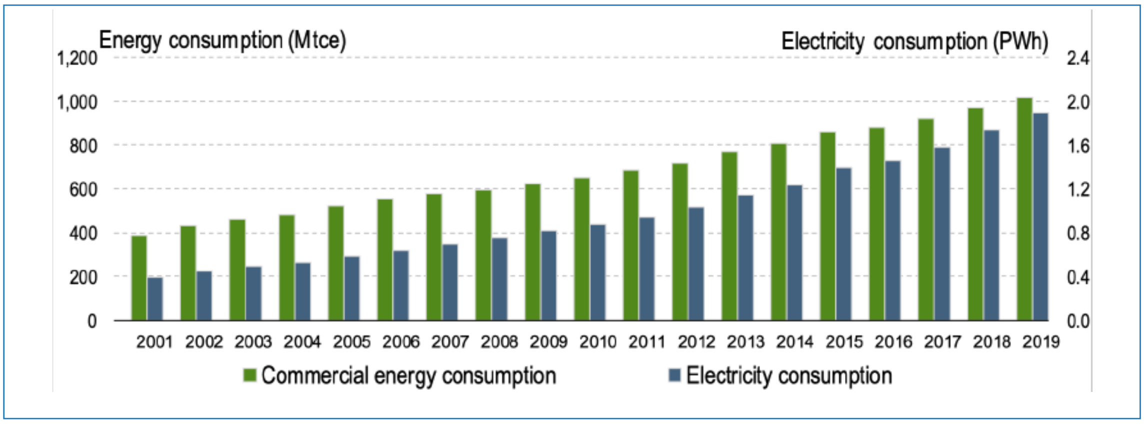

Fig. 1. Primary energy consumption and total electricity use for building operation in China (2001~2019) – 1Mtce = 8,14 TWh
Source: Hu S, Jiang Y, Yan D. China building energy use and carbon emission yearbook 2021: A Roadmap to Carbon Neutrality by 2060[M]. Springer Nature, 2022. License N° 5493941056473, Feb. 21.2023
https://www.researchgate.net/publication/360590746_China_Building_Energy_Use_and_Carbon_Emission_Yearbook_2021_A_Roadmap_to_Carbon_Neutrality_by_2060, page 41

Types of energy	Activity data (Floor space or number of households)	Electricity (TWh)	Commercial energy (Mtce)	Primary energy use intensity
NUH	15.2b m²	61.1	213	14.1kgce/m² (115 kWh/m²)
UR buildings (Excluding NUH)	28.2b m²	537.4	242	792kgce/h (6 447 kWh/hh) h
P&C buildings (Excluding NUH)	13.4b m²	993.2	342	25.6kgce/m² (208 kWh/m²)
RR buildings	22.8b m²	305.4	222	1 527kgce/hh (12 431 kWh/hh)
Total	1.4b people 64.4b m²	1 897.2	1 020	

Table 1. China energy use in buildings (2019) – b = billion, hh = household, ce = coal equivalent
Source: Hu S, Jiang Y, Yan D. China building energy use and carbon emission yearbook 2021: A Roadmap to Carbon Neutrality by 2060[M]. Springer Nature, 2022. License N° 5493941056473, Feb. 21.2023 https://www.researchgate.net/publication/360590746_China_Building_Energy_Use_and_Carbon_Emission_Yearbook_2021_A_Roadmap_to_Carbon_Neutrality_by_2060, page 42

The sum of the energy consumption and intensity of the four building types can be found in *Figure 2*, in which the building floor area is represented by the horizontal axis and the energy intensity per square meter is represented by the vertical axis. The size of the square refers to the total energy use of the building. From the aspect of building stock, urban residential and rural residential were the biggest, and building stock within the NUH accounted for one-fourth of the total, and P&C building one-fifth of the total. Regarding energy intensity, P&C buildings and NUH occupied a higher percentage of the total. Therefore, it is fair to conclude that each category of building type occupied approximately one-fourth of the total energy use. Since the building stock and energy intensity of P&C buildings have increased rapidly in recent years, P&C buildings have become the largest building energy consumer group in the Chinese building sector.

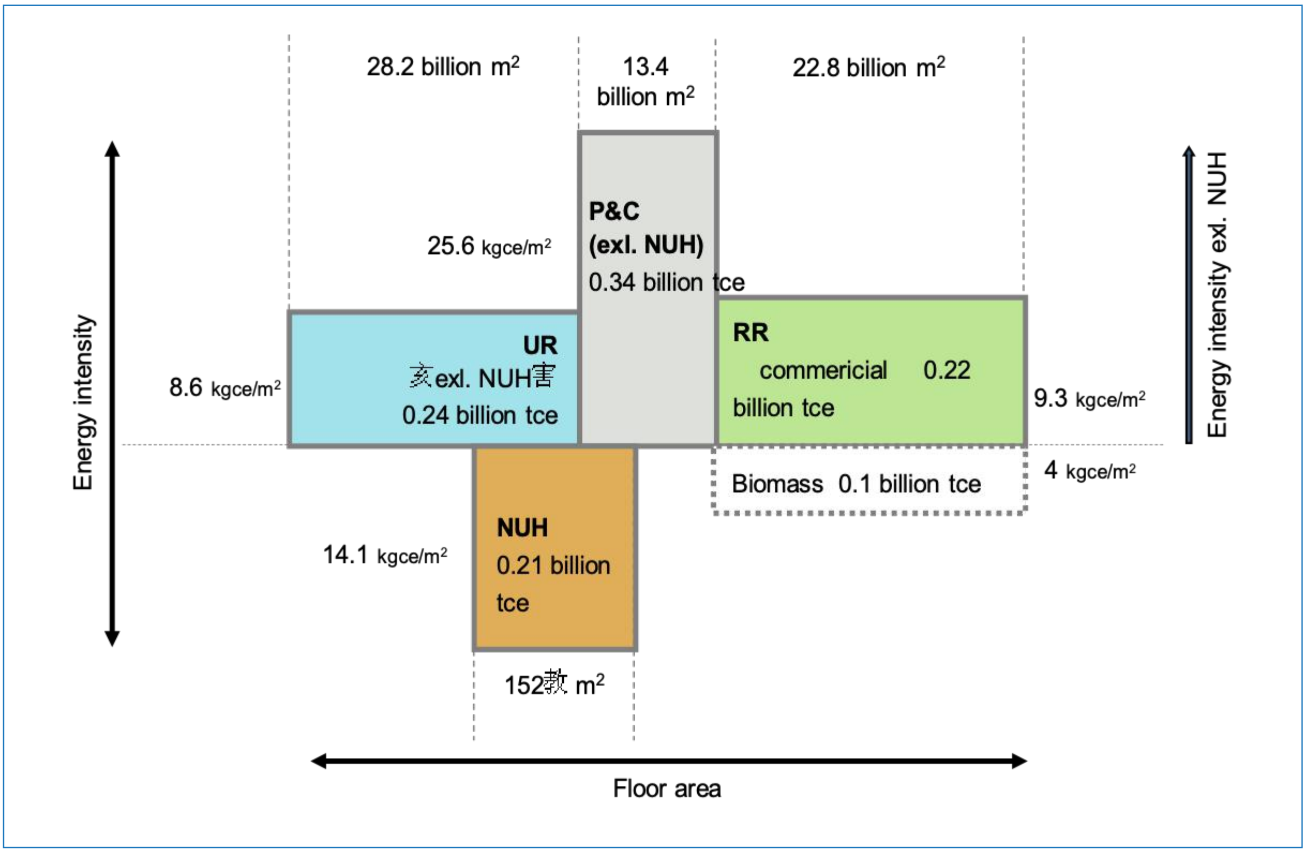

Fig. 2. Energy use of building operation in China (2019)
Source: https://www.researchgate.net/publication/360590746_China_Building_Energy_Use_and_Carbon_Emission_Yearbook_2021_A_Roadmap_to_Carbon_Neutrality_by_2060, page 43

The shift in total energy use and energy intensity between 2008 and 2019 can be characterised as follows. While biomass energy use in rural areas decreased, energy use for all types of buildings increased significantly. The characteristics of the energy intensity of each type of building are described below:

- Although the energy intensity of NUH is relatively large, it has been decreasing in recent years, which was the result of energy efficiency improvement.
- Energy intensity continued to increase for P&C buildings. The increasing energy demand of different kinds of end users (air conditioners, devices, lighting, etc.) was the major cause of the increase in building energy intensity. In recent years, many large-scale P&C buildings have been constructed, with much higher energy intensity than other P&C buildings.
- The energy intensity of urban residential buildings increased continuously because there was more demand for domestic hot water, air conditioners, and household appliances, which led to more energy consumption. There was also a debate about heating methods in the HSCW zone. There was not too much increase in the energy use of lighting in residential buildings because of the adoption of energy-efficient illumination devices. The cooking energy intensity also remained basically unchanged.

Commercial energy intensity for rural residential buildings also increased. As the number of rural households and rural populations slowly decreased, commercial energy use in rural areas basically remained stable. However, as household appliances became more popular and the policy of “switching from coal to electricity” in rural areas, the power consumption intensity has increased dramatically in recent years. Meanwhile, the use of biomass has dropped continuously, and the total energy use for rural residential buildings has declined slightly in recent years.

National policies

During the "12th Five-Year Plan" period, China has made significant progress in the energy efficiency of buildings and green buildings, improving energy efficiency standards, leapfrogging the development of green buildings, fully implementing energy-saving renovation of existing residential buildings in cold areas, further strengthening the supervision of energy-saving public buildings, steadily promoting energy-saving renovation in key cities and schools, hospitals and other areas, and further expanding the scale of renewable energy building applications, and successfully completing the work targets and tasks set by the State Council.

Roadmap of building sector to achieve neutrality by 2060

There is currently no national roadmap for carbon neutrality in the building sector in China. But as one of the most important research centres in the energy and emission sector, the Building Energy Research Centre has conducted research on carbon neutrality roadmap planning. The research result is demonstrated below.

The dual carbon targets set forth by the central government are very clear and need to be achieved on time. Currently, the direct carbon emission of the building sector has already peaked, whereas the indirect one from electricity use and heating will peak by 2030. To achieve a carbon peak in the building sector at an early date, we recommend large-scale electrification transformation for building energy use and strengthening the energy efficiency of new buildings while retrofitting existing ones and promoting green living while practising frugality. To realise zero-carbon emissions in the building sector, we recommend building a new type of building energy system with distributed photovoltaic, distributed energy storage, low-voltage DC distribution network and flexible load control. Key technologies and related research on new rural energy systems based on distributed photovoltaic, combined with water and power generation based on recovered heat from nuclear and cross-seasonal heat storage need to be promoted and implemented at a faster pace.

Best practices

We will demonstrate best practices in the above-mentioned technologies, including PSDF building (Photovoltaic, Energy Storage, DC system and Flexible energy demand), low carbon district heating systems in northern China, and other energy efficiency technologies in public and commercial buildings (including passive and active measures).

Croatia

Existing buildings

Energy partition between single houses, apartment buildings and office buildings

The energy balance for buildings was derived from the 2019 energy statistics on a national level, developed by Energy Institute Hrvoje Požar, which is published every year and publicly available[1]. To define the distribution of fuels between different end-uses, the Odyssee-MURE database was used[2]. *Table 1* shows energy consumption in buildings per sector and per fuel. Total energy consumption is 3.05 Mtoe, where the residential sector represents 73% and the service sector 27%. The most used fuels are electricity (34%) biomass (33%) and natural gas (22%). It should be noticed that biomass is dominantly used in the residential sector, around 1.01 Mtoe, which is equal to 46% of residential sector energy consumption.

	Total [TWh]	Oil [TWh]	Natural gas [TWh]	Biomass [TWh]	District heating [TWh]	Electricity [TWh]	Other [TWh]
Residential	25.82	1.16	5.35	11.75	1.28	6.16	0.12
Service	9.54	0.47	2.44	0.12	0.47	6.05	0.12
Total	35.00	1.63	7.79	11.87	1.75	12.21	0.24
Share	100%	5%	22%	33%	5%	34%	1%

Table 1. Energy consumption in buildings per sector and fuel
Source: National Energy Report developed by EIHP „Energija u Hrvatskoj 2019" available here http://www.eihp.hr/wp-content/uploads/2020/12/1_Energija_u_Hrvatskoj_2019-compressed-1.pdf. Public source

Table 2 shows the energy consumption of the residential sector per use and per fuel. Unfortunately, such data is not available for the service sector. Space heating share is equal to 67% of total energy consumption, mostly covered by biomass and natural gas. Domestic hot water share is 10%, usually covered by electricity and natural gas. Electrical appliances, lighting and cooling together represent around 4% while cooking is 7%.

	Total [TWh]	Oil [TWh]	Natural gas [TWh]	Biomass [TWh]	District heating [TWh]	Electricity [TWh]	Other [TWh]	Share of residential sector [%]
Space Heating	17.33	0.70	3.84	11.16	1.16	0.35	0.12	67%
Domestic hot water	2.67	0.12	1.05	0.35	0.12	1.16	0.00	10%
Cooking	1.74	0.35	0.47	0.23	0.00	0.58	0.00	7%
Cooling	0.47	0.00	0.00	0.00	0.00	0.47	0.47	2%
Lighting	0.47	0.00	0.00	0.00	0.00	0.58	0.00	2%
Electrical appliances	3.02	0.00	0.00	0.00	0.00	0.00	3.02	12%

Table 2. Energy consumption per use and fuel for the residential sector
Source: Odyssee-MURE database available here https://www.odyssee-mure.eu/

Which systems are mostly used for heating?

- Local systems (Furnaces, electric heating, heat pumps, solar thermal panels, geothermal systems, etc.)?
- Heat networks (hot water, steam). In this case, which energy sources are used? What is the CO_2 content per MWh_{th}?

[1] National Energy Report developed by EIHP „Energija u Hrvatskoj 2019" available here http://www.eihp.hr/wp-content/uploads/2020/12/1_Energija_u_Hrvatskoj_2019-compressed-1.pdf

[2] Odyssee-MURE database available here https://www.odyssee-mure.eu/

As noticeable from *Table 2*, biomass is dominantly used for heating in the residential sector, especially in rural areas. Biomass is usually burned in furnaces or biomass boilers. In urban areas, natural gas boilers are dominantly used. District heating share is around 6%. It should be mentioned that around 80% of the use of district heating is in the capital, the City of Zagreb. District heating in Croatia is relatively old, with high-temperature regimes of the network (steam is also supplied to industrial customers). Larger district heating systems are based on natural gas cogeneration power plants, while smaller district heating networks use natural gas boilers. The carbon emission factor of natural gas boiler-based district heating systems is around 300 kg/MWh. The allocated carbon emission factor for natural gas CHP-based district heating systems is around 220 kg/MWh. Zagreb district heating network is currently being overhauled and a natural gas combined-cycle cogeneration plant is under construction.

Which systems are mostly used for cooling? (local systems, cooling networks…)

Cooling is mostly covered with air-air heat pumps, while district cooling does not exist in Croatia. However, there are examples of utilising different heat sinks combined with heat pumps such as the ground/soil, groundwater or seawater but they are not common. Cooling represents a relatively small share in the residential sector, around 2%. It is assumed that this share is much higher in the service sector.

What are the main choices of national policy?

Decarbonisation of the building sector is usually based on the energy-related refurbishment of existing buildings. The refurbishment rate is one of the lowest in the EU, around 0.7%, although national subsidies are usually granted both for the refurbishment of buildings and the integration of renewable energy sources, usually solar thermal and PV, for the residential as well as the service sector. Integration of heat pumps is not common but a plan for increasing their share is in place, according to the National Energy and Climate Plan. The most important issue is biomass, which is dominantly used in rural areas in inefficient stoves and furnaces.

Is there some roadmap for making existing cities more sustainable?

Croatia does not have an official roadmap for sustainable cities. However, such a roadmap is promoted in the National Energy and Climate Plan, including the Recovery and Resilience Facility Plan.

Are there some case studies or best practices you would like to share?

The overhaul of the Zagreb district heating network is a large infrastructural project. The goal is to refurbish around 60 km of the network, equal to 1/3 of the overall length. The project value is 100 million EUR, while 60% comes from EU subsidies. This is also one of the highest EU subsidies awarded to Croatia.

The city of Vukovar has one of the most prominent district heating systems in the country. It is the first DH network which has successfully integrated solar thermal, with a relatively small share of around 5%. The plan is to expand this further. Besides biomass boilers and solar PVs, the plan is to invest in the first large-scale heat pump system for district heating purposes in Croatia while using the ground or groundwater as a heat source.

The old historical city centre of Dubrovnik has implemented seawater heat pumps for cooling purposes in several public buildings. The plan is to expand the system and connect additional customers. Generally speaking, blue energy for heating and cooling, through heat pump utilisation is becoming more popular and other coastal cities are investigating these possibilities.

New buildings

Does your country have a national policy regarding new buildings?
Are some technologies prioritised?
How are they supported? Through regulations? Subsidies?

The plan for increasing the number of nearly-zero energy buildings exists. Heating systems in these buildings are based on solar thermal collectors and air or ground-sourced heat pumps. Due to the high primary energy consumption of district heating systems, they are usually not a feasible option. In Croatia, CHP-based DH systems consume more primary energy per building or household than individual natural gas boilers. Currently, systems with lower primary energy factors are under development which should tackle this issue. District heating networks are expanded, but mostly in the City of Zagreb. However, there are no subsidies for DH network connections. On the other hand, after the Zagreb earthquake, national subsidies for condensing natural gas boilers have been assigned.

Are there some recommendations and regulations for sustainable districts and cities?

Most of the largest cities in Croatia have district heating systems. However, there is no heat zoning in place which would define neighbourhoods that should be connected to the district heating network. An obvious recommendation is to propose heat zoning for urban areas which would allow the definition of densely populated zones eligible for district heating networks.

As already mentioned, the primary energy factors for cogeneration-based district heating systems are higher than for individual natural gas boilers. This is unsustainable, especially when considering newly developed nearly-zero energy buildings which have defined primary energy-related criteria. The recommendation is to update the criteria for CHP-based district heating which would enable future expansion of thermal networks in urban areas.

Although the utilisation of natural gas in CHP is better than using it in boilers, it still represents a fossil fuel, which should be phased out in the heating sector by 2050. For this reason, large-scale integration of renewable energy sources in existing district heating systems is needed. The recommendation is to use locally available renewable energy sources in combination with heat pumps to reach needed supply temperature regimes. In parallel, a reduction of temperature regimes in the network is needed. This is achievable with building renovation and the development of low-temperature districts which could be separated from the main network with the shunt valve connection.

Are there some case studies or best practices you would like to share?

The Zagreb earthquake in 2020 heavily damaged the historical city centre. Nevertheless, this presents an opportunity for the coordinated renovation of historical neighbourhoods, integration of renewable energy sources and expansion of the existing DH network. The City of Zagreb developed a case study of one damaged building block in the historical city centre which could be used as a lighthouse project for other neighbourhoods[3]. The project included connection to the district heating network, integration of heat pumps, solar PV and energy-related refurbishment of the buildings. However, at the time of writing this report, the project is still in the development stage.

3 https://www.zzpugz.hr/program-cjelovite-obnove-povijesne-jezgre-zagreba-izvjesce-i-plan/

Sweden

Existing buildings

Energy balance 2019 (energy sources to end-uses)

All figures and graphs are from Sweden Energy Agency – Energy Facts and figures 2021. energy-in-sweden-facts-and-figures-2021_210205-1.xlsx (live.com). CC BY-NC.

Biomass	Coal and coke	Oil products	Natural gas, gasworks gas	Other fuels	District heating	Electricity	Total
15	0	11	2	0	45	72	**144**

Table 1. Final energy use in the residential and services sector by energy carrier, 2019, 144 TWh

Construction	Agriculture	Fishing	Forestry	Public administration	Commercial	Households	Total
4	6	0	2	16	31	85	**144**

Table 2. Final energy use in the residential and services sector by subsector, 2019, TWh

Electric heating	Domestic electricity	Business electricity	Total
20,9	22,5	28,6	**72,0**

Table 3. Electricity use in the residential and services sector, 2019, TWh

See also *Figure 1.* below.

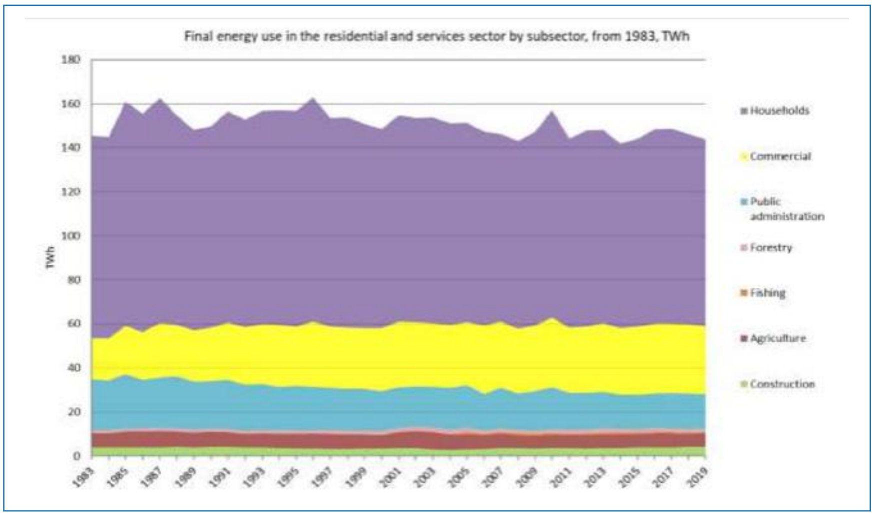

Fig. 1. Final energy use in the residential and service sector by subsector, 1983 to 2019
Source: Swedish Energy Agency and Statistics Sweden. CC BY-NC. energy-in-sweden-facts-and-figures-2021_210205-1.xlsx (live.com) (tab 3.2)

Electricity and district heating account for more than 80% of the energy used in the residential and service sector.

Electricity is the most common energy carrier for heating in houses, followed by biofuels and district heating. In multi-dwelling buildings and non-residential facilities district heating is by far the most common energy carrier.

The use of electricity in the residential and service sector increased considerably since the introduction of nuclear power in the mid-1970 to replace oil for heating.

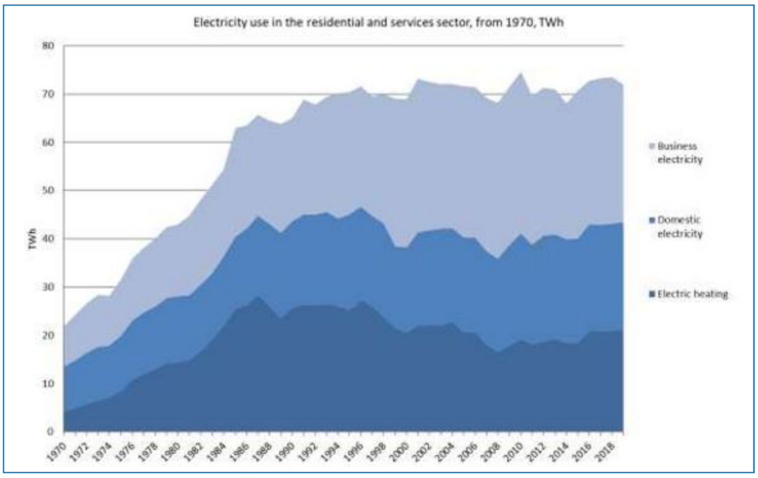

Fig. 2. Electricity use in the residential and service sector from 1970
Source: Swedish Energy Agency and Statistics Sweden. CC BY-NC. energy-in-sweden-facts-and-figures-2021_210205-1.xlsx (live.com) (tab 3.3)

Energy partition between single houses, apartments buildings and office buildings

One- and two-dwelling buildings	Multi-dwelling buildings	Non-residential premises	Total
305	207	172	**684**

Table 4. Heated area in dwellings and non-residential premises, 2019, million m
Source: Swedish Energy Agency and Statistics Sweden. energy-in-sweden-facts-and-figures-2021_210205-1.xlsx (live.com)
Public data.

Which systems are mostly used for heating?

Electricity is the most common energy carrier for heating in houses, followed by biofuels and district heating.

The most common heating source in densely populated areas (from small towns up to large cities) is district heating.

Petroleum products can be used for heating but are mainly used for machinery in agriculture, foresting, fishing and construction.

- Local systems (Furnaces, electric heating, heat pumps, solar thermal panels, geothermal systems, etc.)?

Electricity accounts for around 50% of the energy used in the residential and service sector. Electricity direct heating and heat pumps are the most common systems. Solar panels are growing fast and are supported by national investment subsidies. But still, solar power only counts for around 1% of the total electricity generation.

- Heat networks (hot water, steam). In this case, which energy sources are used? What is the CO_2 content per MWhth?

District heating account for a little more than 30% of the energy used in the residential and service sector.

The heat market produces around 75 TWh yearly. Our well-developed district heating systems enable us to utilise energy resources that would otherwise be wasted, such as waste heat from industry and energy from the recycling of waste. Combined heat and power ensure the best possible use of these resources.

The CO_2 content per MWhth has decreased from around 325 kg/MWh in 1980 to 50 kg/MWh in 2019 thanks to the replacement of fossil fuels with biomass and recovered heat.

One- and two-dwelling buildings					
Oil	District heating	Electric heating	Natural gas	Boimass	total
0,4	5,5	15,3	0,3	8,8	**30,2**

Multi-dwelling buildings					
Oil	District heating	Electric heating	Natural gas	Boimass	total
0,1	23,6	2,1	0,2	0,1	**26,1**

Non-residential premises					
Oil	District heating	Electric heating	Natural gas	Boimass	total
0,3	15,9	3,6	0,3	0,4	**20,4**

Table 5. Energy use for heating and hot water in dwellings and non-residential premises, 2019, TWh

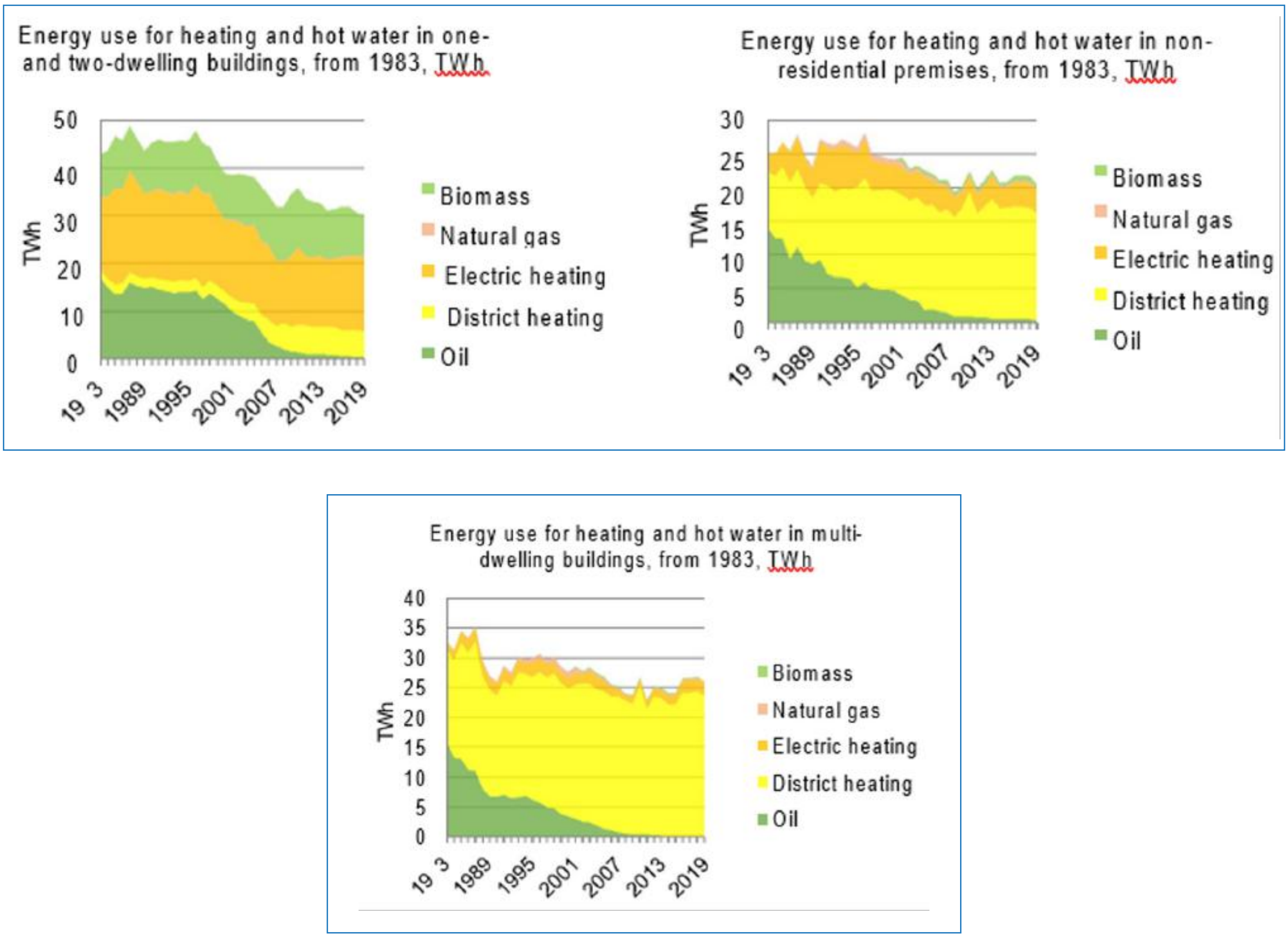

Fig. 3. Historical energy use for heating and hot water since 1983
Source: All figures and graphs from Sweden Energy Agency – Energy Facts and figures 2021. CC BY-NC.
energy-in-sweden-facts-and-figures-2021_210205-1.xlsx (live.com) (tab .04)

What are the main choices of the national policy

– if there is one – to reduce the emissions from the existing stock of buildings? To make this reduction affordable.

A CO_2 tax which taxes fossil fuel for heating. There are also building codes for improving building performance and a building declaration system which requires buildings to have an energy declaration when they change owner.

- **From a technological point of view? (Insulation, heat pumps, low CO_2 district network, geothermal systems, local PV production, etc.).**
- **From a regulatory point of view? Through land ownership regulations?**
- **Through subsidies, different financial mechanisms? Which are the priorities: reducing CO_2 or energy; Better inclusivity.**
- **Replacing parts of the existing stock of buildings?**
- **Is there a specific roadmap for this subject?**

A **roadmap for fossil-free heating** has been developed in collaboration with about fifty actors in the heating market (district heating companies, heat pump companies, biofuel companies, property owners and builders, municipalities, county councils and regions). **The roadmap is part of the governmental initiative Fossil Free Sweden.**

The heating sector will be fossil fuel free by 2030. In 2045, it will be a carbon sink that helps in reducing the total Swedish greenhouse gas emissions.

To achieve this goal, the actors in the heating sector have, among other things, undertaken to:

- completely phase out the use of remaining fossil fuels and base also this district heating production on recycled energy;
- promote the development towards being fossil fuel free by setting ambitious energy and climate targets in municipalities, regions and county councils;
- sort and/or facilitate sorting of waste, especially plastics, to minimize fossil content in residual waste;
- through technology development, make heat pumps and system solutions more efficient to reduce electricity consumption and peak power requirements.
- The heating sector is ready to take on this challenge. This means that the industry needs to bind carbon dioxide emissions, for example by using CCS (Carbon Capture and Storage) technology. For the bio-based fuel, the impact could be climate-positive since carbon atoms that are already included in the natural cycle are removed. In addition, it can contribute to climate-negative emissions in Sweden as a whole. Furthermore:
- Create incentives for increased cogeneration of heat and power by valuing power and not just energy.
- Introduce policy instruments that provide incentives ”Early in the chain”, for example, already in product design and procurement, in order to turn plastics away from residual waste.
- Support research, development and demonstration of new technology such as bio- and waste-CCS, bio-coal, solar heat, seasonal heat storage, combined heat and power production with higher electricity exchange, small-scale combined heat and power technology, fourth generation district heating and recycling refinery for plastic waste.
- Ensure conversion from electric heating to district heating, heat pump or biofuel.

Are there some case studies or best practices you would like to share?

- Test site for Bio-CCS in Stockholm is in operation since 2020 (Bio-CCS - Stockholm Exergi)
- An installation for the elimination of plastic waste from residual waste submitted for incineration is under construction in the Stockholm region.
- Several district heating companies are phasing out the last fossil fuels, for example the largest coal-fired combined heat and power plant in the country is decommissioned since 2020. Öresundsverket Malmö.

New buildings

Does your country have a national policy regarding new buildings?

If yes, what are the priorities? (For housing and for office buildings)

The construction and civil engineering sector, including the property sector, currently accounts for one-fifth of Sweden's climate impact.

Within the governmental initiative Fossil Free Sweden, **a roadmap for the construction and civil engineering sector** establishes goals to achieve a carbon-neutral value chain in the construction and civil engineering sector. Goals for the following years are:

2020–2022: Key players within the construction and civil engineering sector have mapped their emissions and established carbon goals.

2025: Greenhouse gas emissions clearly demonstrate a declining trend.

2030: 50 percent reduction in greenhouse gas emissions (cf. 2015).

2040: 75 percent reduction in greenhouse gas emissions (cf. 2015)

2045: Net zero greenhouse gas emissions

Source: The construction and civil engineering sector - Fossilfritt Sverige

Are some technologies prioritised?

At the building level? At the infrastructure level? (Development of district networks, prohibiting connection to the gas network…)

The roadmap actors have committed to:

- intensify work on energy efficiency that reduces the heating and power requirement in newly produced and renovated buildings.
- push technology development in terms of reduced power peaks, energy storage, solar energy and solar heat.
- make better use of excess heat.

How are they supported? Through regulations? Subsidies?

Investment subsidies for installation of solar cells at private properties

Are there some case studies or best practices you would like to share?

1. Sustainable cities and smart cities https://smartcitysweden.com/best-practice/
2. Viva – Housing with Minimum Climate Footprint BRF Viva – Housing with Minimum Climate Footprint | Best practice - Smart City Sweden
3. Vallastaden – a Model for Sustainable Planning of Cities and Districts Vallastaden - a Model for Sustainable Planning of Cities and Districts | Best practice - Smart City Sweden
4. The Environmentally Sustainable City of Tomorrow in Malmö's Western Harbour The Environmentally Sustainable City of Tomorrow in Malmö's Western Harbour | Best practice -Smart City Sweden
5. H22 City Expo Showcases Big Ambitions for Building a Smarter City (H22 City Expo Showcases Big Ambitions for Building a Smarter City | Best practice - Smart City Sweden)

Uruguay

National energy profile 2019

For a population of around 3.5 million inhabitants, the total consumption of energy in Uruguay was 72.3 TWh in the year 2020, 60% of which was provided by renewable energies. The electricity consumption was about 20%, provided at the rate of 98% by renewable energies such as hydro, wind, solar and biomass. Oil is mainly used in the transport sector. The use of biomass is highly relevant with the presence of about 40% of the energy consumed.

Energy perspectives 2030 - 2050

If possible, give the national perspectives for 2030 and 2050 or the roadmap to 2030 and 2050 if they exist.

Does your country have national roadmaps regarding energy production and GHG emissions?

What legal status do these documents have? What is their timeline?

There is a roadmap with a time horizon of 2030. The highlight is to produce a robust energy mix based on renewable sources, promote energy efficiency, and introduce electrical transport [http://www.eficienciaenergetica.gub.uy/documents/20182/22528/Pol%C3%ADtica+Energ%C3%A9tica+2005-2030/841defd5-0b57-43fc-be56-94342af619a0]. Moreover, a National Plan defining Energy Efficiency by 2024 is in place [http://www.eficienciaenergetica.gub.uy/plan-nacional-de-eficiencia-energetica].

Roadmap for the energy mix

The mix of energies in Uruguay includes a strong contribution of renewables. Basically, they are the only native energy sources. The country has a plan to introduce electricity and hydrogen in the transport sector.

Roadmap for the GHG emissions (country, per capita)

For a number of years, Uruguay is already developing a CO_2 inventory database [https://visualizador.gobiernoabierto.gub.uy/visualizador/api/repos/%3Apublic%3Aorganismos%3Aambiente%3Avisualizador_inventario.wcdf/generatedContent]. The emission of CO_{2e} was 20 Mt in 2020.

Roadmap for the electricity mix

Uruguay has only renewable energies to increase supply. Solar power shows an incipient use with an installed power of 246 MW. All of the national territory is adequate to convert to this energy. The installed wind power is about 1 500 MW and basically, all the regions of the country are suitable for exploiting this energy source. The capacity could be increased to twice its present status without significant negative effects. The hydro resource is basically 100% exploited. Energy from biomass could still be increased significantly.

CO_2 emissions from electricity production

The emissions of CO_{2e} in the electricity sector were 6.215 Mt in 2020.

Energy balance (energy sources to end-uses)

The following results were taken from the "National Energy Balance" (4.606 ktep = 53,7 TWh)

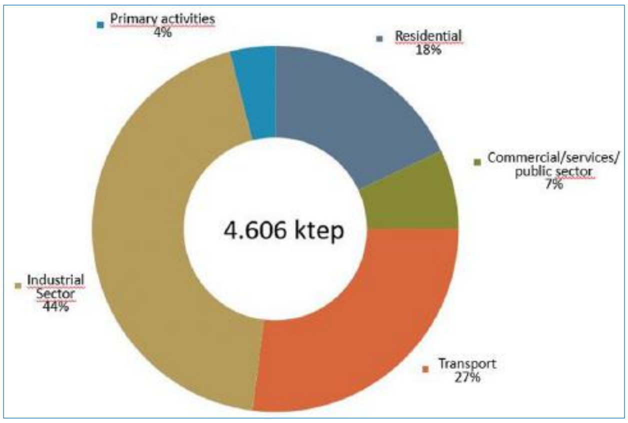

Fig. 1: Energy Balance. Source: National Energy Balance.
Reproduction and translation permitted
URL: https://catalogodatos.gub.uy/dataset/miem-consumo-final-energetico-por-sector

Building sector

For some of the issues, there may be at present nothing concrete in place, but a collection of laws and decrees with related aims does exist.

Existing buildings

Which systems are mostly used for heating?

- Local systems (Furnaces, electric heating, heat pumps, solar thermal panels, geothermal systems, etc.)?

Fireplaces and heat pumps. Between the fireplaces based on wood the open front has a high presence and also other close systems.

- Heat networks (hot water, steam). In this case, which energy sources are used? What is the CO_2 content per MWh_{th}?

Wood and electricity. CO_2 emissions data are available for the total consumption.

Which systems are mostly used for cooling? (local systems, cooling networks…)

Heat pump

What are the main choices of the national policy

Specifically, there is no national policy to reduce emissions in the stock of buildings but there are some linked policies. The first one is the increasing introduction of renewable energies in the network. The second one is the promotion of high-efficiency biomass combustion systems for households. And a third one is the use of renewable energies in households with net tariffs.

Is there some roadmap for making existing cities more sustainable?

The actions in this sense are developed by the Government Department. As examples could be quoted: LED illumination, solid waste as an energy source, and the application of energy efficiency practice on the city hall installations. Also, as a joint task, the introduction of collective electrical transport.

Are there some case studies or best practices you would like to share?

A new test rig to test high-efficiency systems based on biomass for residential applications is available in the School of Engineering, Universidad de la República. The promotion of adequate electrical tariffs for use in households. The recommendation is to introduce devices with increased energy efficiency such as new electrical water tanks, biomass heating, and LED illumination, among others.

New buildings

Does your country have a national policy regarding new buildings?

The introduction of solar water heating in hotels, sports clubs, and health institutions on a national scale; the use of thermal insulation in new buildings is recommended by Montevideo City Hall.

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Argentina

Current situation

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

According to ANI (Academia Nacional de Ingeniería) data, Latin America's situation with respect to the intensity levels of emissions from refineries is clearly worse than that of the leading regions in the world on this matter, namely US & Canada, Western Europe and the Middle East. For Argentina the following issues are taken into account:

Technological and energy efficiency management developments continue to offer opportunities to reduce consumption and emissions in industrial facilities.

Refinery fuel gas (mainly methane, ethane, and by-products from refinery process units) is the main source of energy for burning in processes furnaces and steam generator boilers.

Electricity demand is satisfied mainly through onsite generation (from conventional steam boilers & generators, and/or cogeneration turbines with natural gas)

Burning of refinery fuel gas for process energy is at present the only method of disposing of this by-product stream. If this source of energy is not enough to satisfy the energy balance of the refinery, liquid fuels (diesel, fuel oil) or natural gas from the public network are used in addition. In the following table, the impact of Argentina's gas emission for refining in comparison with the total one can be evaluated.

GREENHOUSE GAS EMISSION FROM THE FUEL REFINING PROCESS

	Total ARG	Energy Sector	O&G (EPR)	Refining
Mton (CO_{2eq})	364	193	76	5
%	Base	33.00%	21.80%	1.40%
%	--	Base	10.8	2.60%
%	--	--	Base	6.60%

Source: National GHG Inventory 2019 - the latest data available is for 2016

Table 1. Greenhouse Gas Emissions from the Fuel Refining process[1] PUBLIC INFORMATION

[1] Combustion activities supporting the refining of petroleum products, including on-site flaring for the generation of electricity and heat for own use.

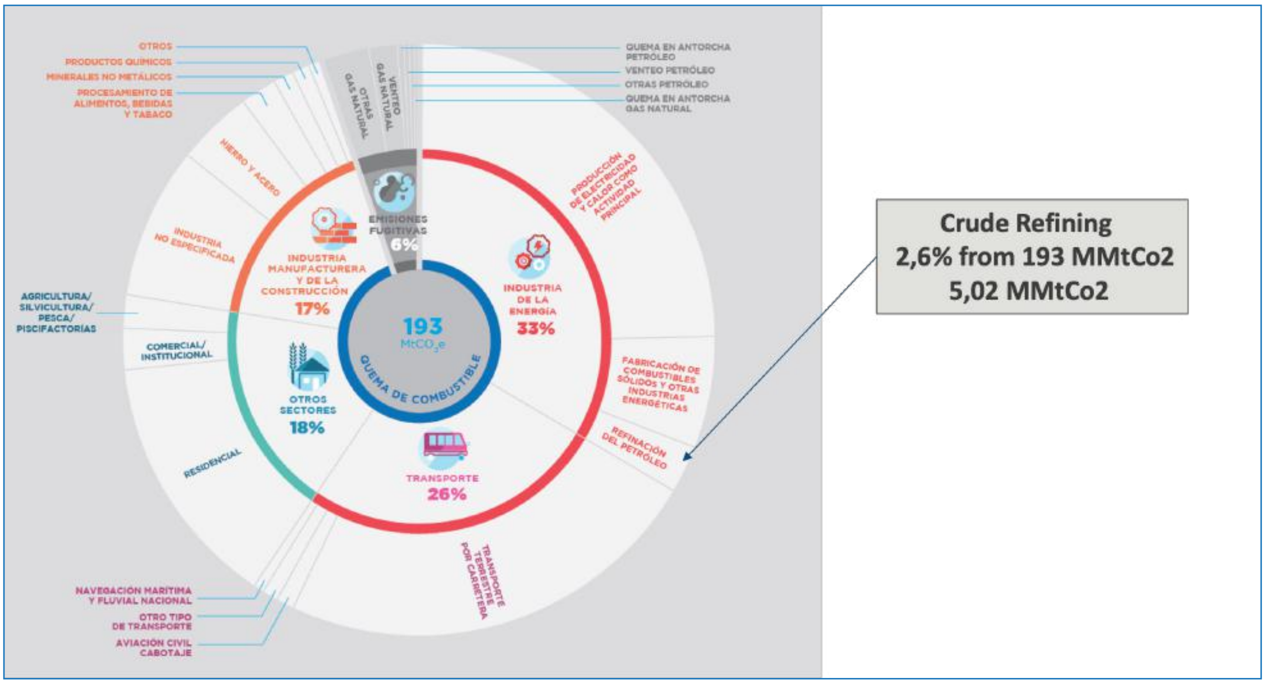

Fig. 1. Crude Refining impact in the total Argentina Energy GHG Emissions. Source Inventario Nacional del GEI 2019
Source: Inventario Nacional del GEI 2019. PUBLIC INFORMATION

Are the best available low-carbon technologies used/considered?

The actions of Argentina's refineries to reduce emissions are:

A. Energy & emissions efficiency in processes

- Improvements in heating equipment; improved heat integration of process streams; replacing combustion equipment / steam turbines / electric motors with more efficient ones; optimising operational and catalytic performance are all practices normally applied in the refining industry and can be further expanded. This is usually driven by means of the implementation of a site-wide energy management system.
- Thermal energy generation optimisation (e.g., replacement of steam boilers & turbines by cogeneration/ combined cycle with higher generation efficiency).
- Flaring reduction programmes, tank vents recovery/recycle.
- Extension of maintenance cycles of process units and utility complexes.

B. Use of low-carbon energy sources

- Replacement of liquid fuels by natural gas in process furnaces or steam generation boilers, resulting in reduced GHG emissions per energy unit released.
- Increasing the proportion of electricity supply generated from renewable sources (It is enforced by regulation).

Is there a roadmap to decrease GHG emissions for 2030 - 2050? If yes, what are the intermediary steps?

There is no road map defined by the government, but the private companies have an evergreen continuous improvement activity to increase energy efficiency and reduce oil losses resulting in GHG emission reduction as follows:

- Heater hardware upgrading or replacement to improve energy recovery.
- Isolation maintenance programmes to reduce energy losses; compressed air and steam traps to minimise material loss.
- Improved heat integration of process streams

- Efficiency optimisation of thermal energy generation via replacement of steam boilers and turbines by cogeneration.
- In the long term, for example, Yacimientos Petrolíferos Fiscales (YPF, ypf.com) is analysing how to implement new technologies to produce H2 and electricity via renewable sources.
- Major technology changes in Hydroprocessing by using natural bio raw materials instead of petroleum byproducts.
- Operation cycle extension including turnaround optimisation cycles.
- Vapour and gas recovery systems to minimise venting or flaring.

Is the implementation of low-carbon technologies helped by the government?

For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

To date, there is no specific governmental programme or incentives focusing on the implementation of low-carbon technologies.

During the last years, the focus of government environmental policies for the refining industry in Argentina was oriented to fuel specifications (sulphur reduction in gasoline and diesel), resulting in the implementation of sizeable investment programmes in the different refineries in the country in this area.

Another investment focus during the last years in local refineries was on increasing conversion/processing capacity and adapting the refineries for processing the (increasingly available) Vaca Muerta shale crude oil and reducing product imports.

Are there incentives for carbon capture, utilisation, and storage? How?

Currently, there are no governmental programmes or incentives in this respect

If relevant, what about recycling? What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

Not applicable

Are there some case studies or best practices you would like to share?

From Raízen Argentina we can share some examples of implementation in Refinería Buenos Aires on:

- Replacement of liquid fuel for natural gas in Boilers No. 10 and 11.
- Programme to optimise the efficiency of the thermal energy generation park (electricity/steam).
- Recovery of flare gases via compressors.
- Vapour recovery from light product tanks and truck dispatch islands.

YPF Information

- Regarding GHG emissions, in 2018 the company undertook to reduce by 10% the intensity of direct emissions (scope 1 GHG) by 2023. It has in place an internal Emission Management regulation.
- Thus, a series of actions have been set in motion to optimise energy management, reduce vented and flared gas, expand electrification and digitalisation of operations, and incorporate low-carbon energy sources.
- The target is 10% reduction of direct GHG emissions intensity by 2023 from Base Year: 2017: 0.38 tCO_{2e}/ production unit.

To 2020: company GHG emissions intensity is 0,366 tCO_{2e}/ production unit

Indicator	Unit	2020	2019	2018	2017
Direct GHG emissions (Scope 1) KGJ					
Total direct GHG emissions (Scope 1) *	**tCO_2e**	**15 204 794**	**16 981 198**	**17 951 758**	**17 012 559**
Carbon dioxide (CO_2) emissions	tCO_2	11 352 215	12 792 308	13 557 352	13 007 777
Methane (CH_4) emissions **	tCH_4	147 393	159 857	167 426	152 868
Nitrous oxide (N_2 O) emissions	tN_2O	563	646	701	614
GHG Emissions by Business (Scope 1)					
Upstream	tCO_2e	8 685 380	9 991 616	10 565 160	10 570 443
Refining ***	tCO_2e	2 751 091	3 448 653	3 511 116	3 554 540
Chemistry****	tCO_2e	529 395	678 542	638 610	614 360
Logistics	tCO_2e	142 699	1 460 217	190 044	171 561
Gas and Energy *****	tCO_2e	3 081 476	2 689 022	3 033 476	2 087 814

* Considering CO2, N20 and CH4

** They represent 24% of total emissions in 2020 and 2019; 23% in 2018

*** Corresponds 57% to the La Plata Refinery (Buenos Aires); 40% to the Lujan de Cuyo refinery (Mendoza) and 3% to emissions from the Plaza Huincul Refinery (Neuquen)

**** 81% of these emissions correspond to the La Plata Chemical Complex (Buenos Aires) and the remaining 19% to emissions from the Methanol Silver of the Plaza Huincul Industrial Complex (Neuquen)

***** The increase is linked to the incorporation during 2020 of the operations of the Termicas de La Plata Cogeneracion II (Buenos Aires) and El Bracho (Tucuman) plants

Table 2. GHG Emissions
Information provided by YPF with permission to reproduce

Intensity of GHG Emissions	Unit	2020	2019	2018	2017
YPF (balanced)	tCO_2/MWh electricity produced	0,366	0,374	0,382	0,380
Upstream	tCO_2e/t Oil & Gas produced	0,400	0,410	0,420	0,410
Downstream	tCO e/t Processed crude	0,290	0,310	0,300	0,290
Gas and Energy	tCO_2/t Electricity emissions/t produced	0,340	0,350	0,360	0,390
Upstream Methane Intensity	**Unit**	**2020**	**2019**	**2018**	**2017**
	tCH_4/t Oil & Gas produced	0,0068	0,0065	0,0066	0,0060

Table 3. Emissions Intensity
Information provided by YPF with permission to reproduce

- Clean Development Mechanisms

YPF has implemented efficient processes in the different stages of crude oil refining to reduce GHG releases. For example, both in the industrial complex of La Plata and in that of Luján de Cuyo, waste gases are compressed and injected into the system to feed furnaces and boilers and avoid the use of natural gas and petroleum derivatives. Both complexes are recorded as “clean development mechanisms” (CDM) with the United Nations. The reductions achieved thanks to these processes were lower in 2019 due to failures and maintenance work on compressors.

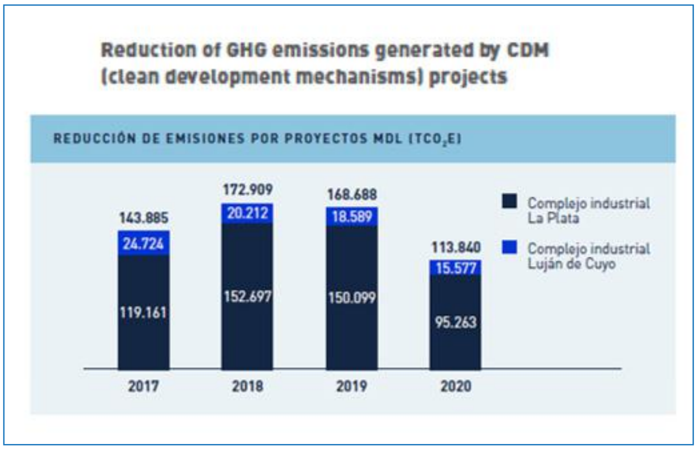

Fig. 2. Reduction of GHG emissions by project
Information provided by YPF with permission to reproduce

- Energy Efficiency

Downstream, the most relevant projects in 2020 were associated with the renovation of processing units in Luján Cuyo and La Plata. In this last complex, it also started operating a new cogeneration plant (89 MW), which will allow it to work on an island, feed surpluses into the interconnected system and have a more efficient supply of steam for the refinery.

Instead of producing steam by burning gas, steam is generated from the thermal energy of the exhaust gases from the turbine that produces electricity. In the future, processing of more unconventional crude oil will help to continue lowering the CO_2 intensity, since being lighter, it requires less energy to be transformed into a more efficient product.

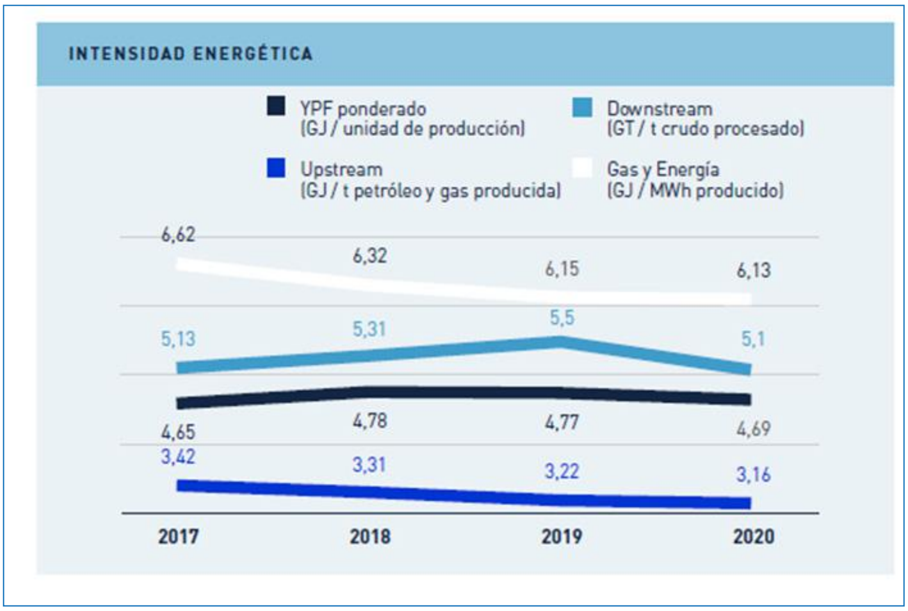

Fig. 3. YPF Energy Intensity
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In case studies of DECARBONISATION OF ENERGY END-USES, YPF, through Y-TEC, is currently exploring technologies for the capture and use of CO_2 with the focus on circular economy

- natural solvents,
- capture through microorganisms and valorisation of biomass,
- CO_2 capture and use for water treatment of the operation.

At the same time, a space for collaboration between more than 40 companies active in the energy value chain, was launched in 2020 to develop a strategy for the development of the hydrogen economy for the country.

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Sweden

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

In 2019, the chemical industry used approximately 12 TWh of energy (Swedish Energy Agency). Fossil and other fuels are the energy sources and account for 60 per cent. Other fuels include process and residual gases with fossil origin but originating from the chemical production processes themselves. The second largest share of energy comes from electricity. A small but increasing energy source comes from bioenergy.

GHG emissions were around 1,5 Mtonnes, which account for approximately 10% of the total industrial emissions.

Are the best available low-carbon technologies used/considered?

If not, is it an economic problem? A matter of regulation? Or some social issues?

The chemical industry's transition pathway is described below.

- **Mechanical and chemical recycling of materials:** Through resource-efficient and circular material flows, a closed cycle for plastics can be created.
- **Transition to bio-based raw materials:** By using bio-based raw materials in the production process, the chemical industry can contribute to a developed bioeconomy and a greater share of bio-based materials. Bio-based raw material can, for example, come from rapeseed oil, straw, wood chips, algae, sugar cane and waste from the forest industry and agriculture. Methane in the form of natural gas is an important raw material in the chemical industry. Biogas fed into the natural gas network can be used as a bio raw material.
- **Transition to bio-based fuels:** Bio-based alternatives to fossil fuels can be used provided they are equivalent in terms of availability, function, quality and price.
- **Carbon capture and storage (CCS):** A step-by-step transition to bio-based raw materials and fuels in the processes provides the opportunity for negative emissions through CCS.
- **Recycling of CO_2 into new raw materials:** By recycling the carbon dioxide generated in production processes, it is able to enter as a raw material in production processes instead of being released.
- **Energy efficiency:** is an ongoing activity in the chemical industry. One way to achieve this is to facilitate the exchange of residual energies between industry and society, which promotes both lower CO_2 emissions and better use of resources.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

Members of **IKEM – Innovation and Chemical Industries in Sweden** have identified ways to reduce emissions by ~85% by 2045 by combining five main strategies:

- **Climate-neutral energy:** A combination of electrification, hydrogen and biofuels replace today's fuels, often to produce heat with very high temperature.
- **Carbon capture and storage (CCS):** Capture, transport and storage of CO_2
- **Bio-based raw materials:** Production of fuels and chemicals from bio-raw materials, often with completely new production processes and hydrogen needs as a complement.
- **Circular economy - recycled raw materials and CCU recycling by:** virgin raw materials are replaced by recycled plastics, metals or waste, or captured CO_2 is used in hydrogen as a raw material for the production of chemicals (CCU).
- **Resource-efficient systems:** Possibilities to use residues such as waste heat and development of industrial symbiosis.

If relevant, what about recycling?

What percentage is recycled? What are the obstacles to increase recycling? Is a policy to increase recycling already in place or in project?

However, an important difference is that one of the main measures is to work towards circularity. There are projects on developing waste-plastic refineries. If successful, this would in the long run make it possible to phase out the use of (fossil) oil as feedstock for producing new plastics. Instead, such recirculation processes will make it possible to transform the plastic back to its original building blocks (monomers) which is different to today's recycling which is based on simple thermochemical melting processes.

Are there some case studies or best practices you would like to share?

Projects with the aim to develop waste-plastic refineries are ongoing, e.g., cooperation between a chemical plant in Stenungsund and a university (Borealis and Chalmers).

As for the emissions from the refinery sites, the Preem refinery is planning to apply for CCS and has recently successfully carried out pilot tests with post-combustion capture at one of their refineries (Preem refinery in Lysekil). There are also projects on using hydrogen from electrolysis with electricity supplied by renewable electricity.

CEMENT INDUSTRY ANALYSIS

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China

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

The energy consumption in the cement production process mainly includes 2 parts. One is the electricity consumption for the production line, which is about 100 kWh/t for a typical 5 000t/d cement clinker production line. The other one is the fuel combustion for heat production for cement clinker calcination. In China, most cement production enterprises in China use coal as fuel, and the standard coal consumption in clinker calcination is around 100kg/t. 40% of the heat provided in this process is lost due to heat dissipation of the kiln barrel and the heat taken away by the kiln flue gas.

According to CO_2 emission factors of coal combustion (2.66 kg CO_2/kg coal) and electricity production (0.8 kg CO_2/kWh) in China, the CO_2 emission factor of energy consumption in the calcination process is 266 kg CO_2/t clinker, the indirect CO_2 emission factor is 80 kg CO_2/t cement. Another part of CO_2 emission in cement production is from limestone decomposition. 85% of the main raw material for cement is limestone. The CO_2 emission related to this is about 302 kg/t cement.

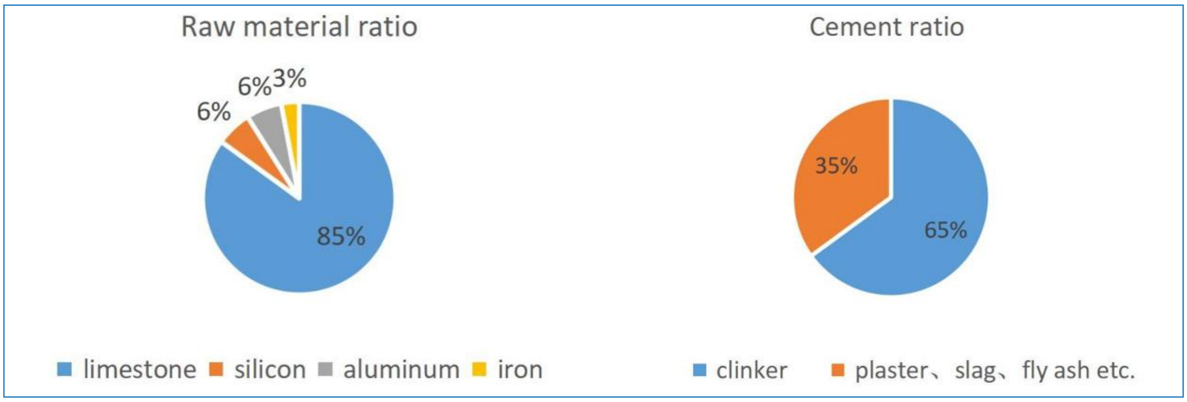

Fig. 1. a) (left) Raw materials used for cement production and b) (right): Composition of cement (ratio clinker/other materials)
Source: Based on data from: Wang Lan. Shoulder the Responsibility of Zero Carbon Process Reengineering in Cement Industry. China Cement,2021(05): 36-39. Reproduced with permission

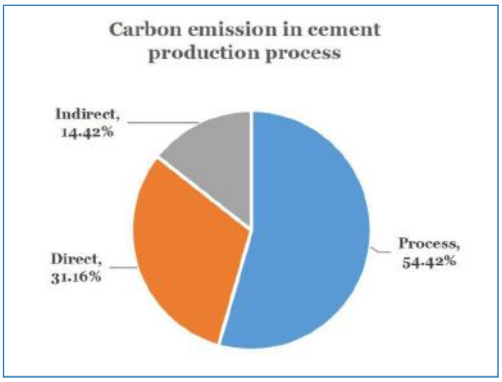

Fig. 2. CO_2 emissions in the different parts of the cement production process
Source: Based on data from: Wang Lan. Shoulder the Responsibility of Zero Carbon Process Reengineering in Cement Industry. China Cement,2021(05): 36-39. Reproduced with permission

In total, under current manufacturing technology, the CO_2 emissions per cement clinker production and cement (while the clinker content of cement is 65%) are 860 kg/t and 563 kg/t, respectively. Other greenhouse gases in the cement production process are negligible.

The carbon emission intensity is similar because of the similarity of the producing technology all over the world. However, it should be noted that in 2020, the cement production in China is about 2.4 billion tons, accounting for 53% of the world's total cement production.

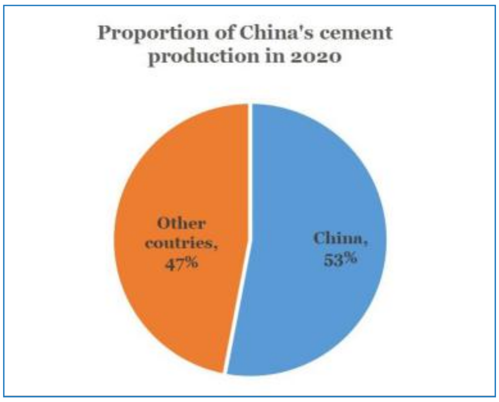

Fig. 3. China's share in worldwide cement production
Source: Based on data from: [Cement Statistics and Information | U.S. Geological Survey (usgs.gov)](), Statista, 2021 Open Source

Are the best available low-carbon technologies used/considered?

If not, is it an economic problem? A matter of regulation? Or some social issues?

Energy conservation and emission reduction are highly emphasized in China's cement industry. The best technologies have been applied, including roller press or vertical mill grinding technology, pre-calcining kiln calcination technology and waste heat power generation technology. The carbon emission per unit of cement is significantly reduced with the improvement of energy efficiency.

Currently, the recommended technologies to reduce CO_2 emissions include alternative raw material technology, alternative fuel technology, low-carbon cement technology, etc. Calcium carbide slag has been used in some cement production factories instead of limestone to reduce carbon emissions. Partial replacement of limestone with steel slag has also been considered. However, it is limited by the supply of calcium carbide slag or steel slag. Alternative fuels, such as industrial solid waste, and crop straws, have been used by some manufacturers. However, the sources of these fuels as well as the cost of their application remain problems for massive implementation. Lots of research has been conducted on low-carbon cement development, including reducing the content of CaO in cement clinker, reducing the amount of clinker in cement, or developing new cement. It is expected that these technologies will be applicable in the next 3 to 5 years.

The Chinese government has enacted incentive policies for the comprehensive utilization of resources. The application of low-carbon technologies will attract more support for the development of a carbon market in China.

Is there a roadmap to decrease GHG emissions for 2030 - 2050

If yes, what are the intermediary steps?

The Chinese government has committed to peak its carbon emissions before 2030 and achieve carbon neutrality by 2060 (hereinafter referred to as "peak carbon emissions, and carbon neutrality"). Some studies predict that China's cement industry will reach its carbon emission peak in the next two or three years.

The cement production will be around 2.45 billion tons at that time, and it will decrease to 1.8 billion tons by 2030 and 900 million tons by 2060.

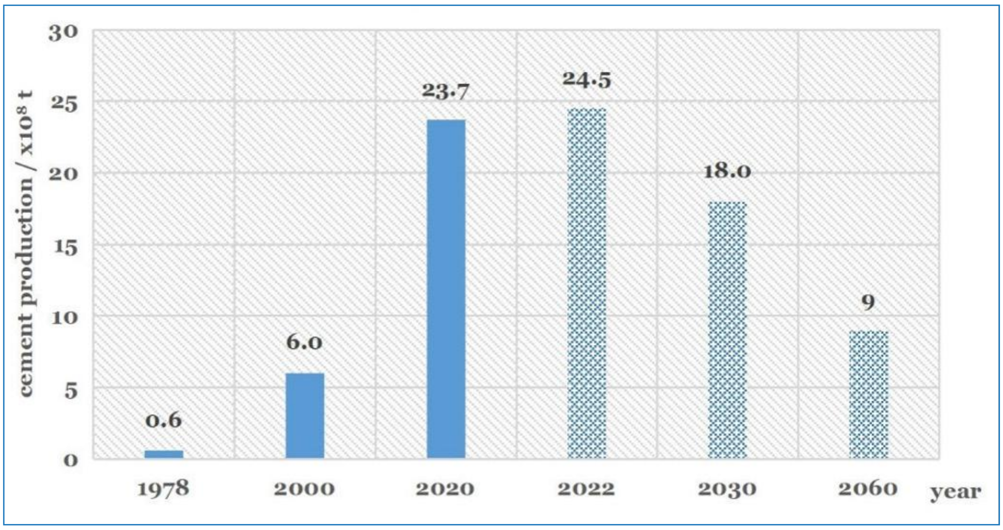

Fig. 4. A prediction of Cement Production in China
Source: Based on data from: Wang Lan. Low Carbon/Zero Carbon Process Reengineering in Cement Industry. Xiangshan Science Conference. 2021. Reproduced with permission

Currently, the National Development and Reform Commission and the Ministry of Industry and Information Technology of China are scheduling the national and industrial plan for the "Peak Carbon Emission and Carbon Neutrality" target. Some cement producers also make their own plans. For enterprises, alternative raw material and fuel technologies, low-carbon cement technologies or CCUS technologies are most considered. And they have also proposed a range of possible decreases in CO_2 emissions under different implementation scenarios in these plans.

The cement manufacturers, as the main body of CO_2 emissions, have an urgent need for CO_2 emission reduction technologies. Technology development at the industry level should be encouraged. It is also important to have more incentive policies at the national level.

Is the implementation of low-carbon technologies helped by the government?

For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

The Chinese government, including the national government and provincial governments, are supportive of the implementation of low-carbon technologies, such as the application of energy-saving, emission-reduction and new technologies in the cement industry. The provincial governments have provided subsidies for waste heat utilization technology applications and equipment upgrading, etc., as well as incentives for integrated utilization of resources. The central government has developed energy efficiency rating standards for cement production enterprises for benchmark management, as well as assessment methods for CO_2 emissions for cement manufacturers, which provide motivation for promoting carbon emission reduction in these enterprises.

Are there incentives for carbon capture, utilisation, and storage? How?

China is developing technology policies or incentive policies now.

If relevant, what about recycling?

What percentage is recycled? What are the obstacles to increasing recycling? Is a policy to increase recycling already in place or at the project stage?

Cement will be mixed with aggregates such as sands and stones to prepare concrete for use in construction projects. Then the hydraulic reaction of cement happens during the application process when water is added. It is hard to recycle cement. However, there are currently studies going on regarding the use of construction waste (including cement hydration products) as raw materials for cement production.

Are there some case studies or best practices you would like to share?
In 2018, the CONCH company commissioned a CCS device to produce 50 kt/a

CO_2 ice with cement kiln gas. Another cement production company is planning to capture CO_2 for oil displacement or landfilling.

China has a large production capacity in the cement industry. The technologies are developing very fast. It is expected that a series of low-carbon technologies will be mature and applicable in the coming 3-5 years, which could further contribute to the low-carbon development of the world's cement industry.

Croatia

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

There are three operating cement plants in Croatia. The production capacity of the Croatian cement industry is approximately 3.9 million tons of cement per year, and about 3 million tons of clinker, with an average clinker factor of 0.77. Regarding the energy balance in the Croatian cement industry, two balances need to be considered separately. The first one is the electricity consumption for the production line, which is about 113 kWh/t of cement. Here we need to emphasize that cement production plants in Croatia buy green electricity certificates that certify that the electricity has been produced by renewable energy sources. That means that there are no indirect CO_2 emissions from cement plants in Croatia. The second energy balance is fuel combustion. In this case, the fuel is used for heat production for the calcination process and clinker production. In Croatia, the average value of specific heat consumption is 3.4 GJ/t of clinker. The fuels predominately used are petroleum coke and coal, with an increasing share of alternative fuels like RDF (Refuse Derived Fuel), sewage sludge and waste oil. The total direct CO_2 emissions of the cement industry were about 2.5 million tons.

Are the best available low-carbon technologies used/considered?

If not, is it an economic problem? A matter of regulation? Or some social issues?

In Croatian cement plants, the dry pre-calciner rotary kiln process is in use. Therefore, the best available technologies have been applied. Over the years by implementing this energy-efficient production process, the CO_2 emission per unit of produced cement has significantly been reduced.

Alternative fuels are used for around 20% of the total, like old tires, waste textile, RDF/SRF (Solid Recovered Fuels), sewage sludge and waste oil, bone meal etc.

Is there a roadmap to decrease GHG emissions for 2030 - 2050

If yes, what are the intermediary steps?

Croatia as an EU Member State implements the EU Green Deal policy. The European Green Deal is a set of policy initiatives by the European Commission with an aim of making Europe climate neutral in 2050. An impact-assessed plan will also be presented to increase the EU's greenhouse gas emission reduction target for 2030 to at least 50% and towards 55% compared with 1990 levels. This implies that cement manufacturing will have to reduce its emissions. All EU cement manufacturers, including Croatian manufacturers, are taking part in the EU Emissions Trading System (EU-ETS). EU-ETS is seen as a cornerstone of the European Union's policy to combat climate change. The current price of CO_2 allowance at a level of 60 EUR/t is pushing cement manufacturers in the EU to implement their own plans for using alternative raw material and fuel technologies, low-carbon cement technologies or CCUS technologies.

Is the implementation of low-carbon technologies helped by the government?

For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

The Croatian government is implementing the EU Green Deal policy in the local economy, including the cement industry sector. It is implementing the policy by supporting energy efficiency improvements, low-carbon technologies, and emission reduction technologies in the cement industry through structural projects. These structural projects offer funding to cement producers for improving their production process. These are close cooperation projects with research institutes, that offer the possibility to cement manufacturers to transform their production to be more environmentally efficient.

Are there incentives for carbon capture, utilisation, and storage? How?

Currently, there are no incentives for carbon capture, utilisation, and storage projects in Croatia.

If relevant, what about recycling?

What percentage is recycled? What are the obstacles to increasing recycling? Is a policy to increase recycling already in place or in the state of a project?

Under Croatian and EU legislation, construction waste materials are defined as special waste that needs to be handled in a special procedure. The processing of waste concrete, asphalt and other construction waste materials lead to valuable raw materials and buffer materials that are used exclusively in road construction instead of new stone materials from the quarry. This reduces the need for raw materials in the road construction industry.

Are there some case studies or best practices you would like to share?

NEXE Ltd., a Croatian cement producer, made an environmental assessment study in 2021, in which the enterprise elaborates on the next steps in going 100% to alternative fuels. The share present share of 18% of alternative fuels will be increased in several stages to 100%. Petroleum coke and coal, the two fossil fuels that are now predominately used as sources for heat production, will be replaced by RDF, sewage sludge and waste oil in the coming years. The plan is that in the coming 3-5 years, only alternative fuels will be used in cement production, fostering the circular economy and decreasing the rate of waste landfilling in Croatia. This will contribute to the low-carbon economic development in Croatia.

India

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

The Indian cement industry is one of the best-performing industries across various industrial sectors in terms of energy efficiency, quality control, environmental sustainability, and adaptive to venturing into new technology.

India is the second largest producer of cement in the world. India's overall cement installed capacity was nearly 545 million tonnes (Mt) in FY20 whereas actual cement production (demand based) was 294.4 million tons (Mt) in FY21. Cement production in India is expected to reach 550-600 Million Tonnes Per Annum (MtPA) by 2025 and 800 (MtPA) by 2030 and will continue to grow due to the continuation of the massive infrastructure and housing programme. The largest cement manufacturer in India has a consolidated capacity of 102.75 MtPA distributed all across India, as the cement plants are located all over India.

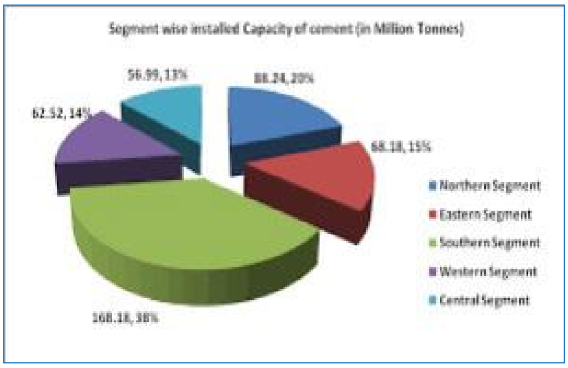

Fig. 1. Installed cement capacity in India by geographical area
International Journal of Research in Geography (IJRG) Volume 4, Issue 2, 2018, PP 72-78 "Experiences of Cement Industry in India" Vigneshwar Mekha, Adma Kamalakar Reddy. Page 74
Source: Survey of Cement industry & Directory, 2015, Reproduced with Permission. https://www.arcjournals.org/pdfs/ijrg/v4-i2/7.pdf

Fig. 2. Location of major centres of the cement industry in India
Reproduced with permission. https://www.sarthaks.com/745192/describing-the-factors-localisation-cement-industry-india-mention-major-producing-areas

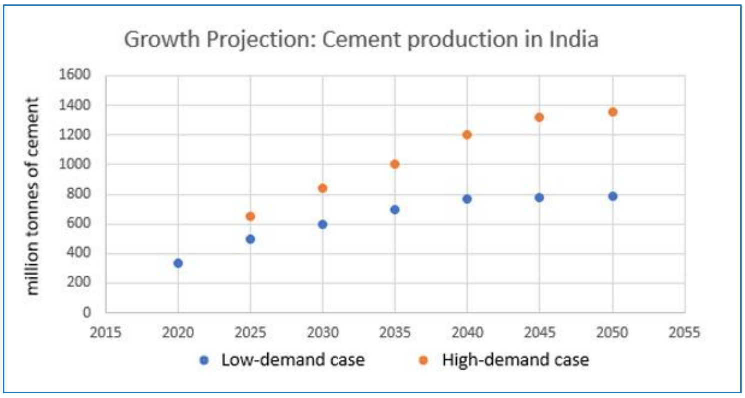

Fig. 3. Projected growth in cement production in India. 2020: actual production.
Source: Constructed from various sources

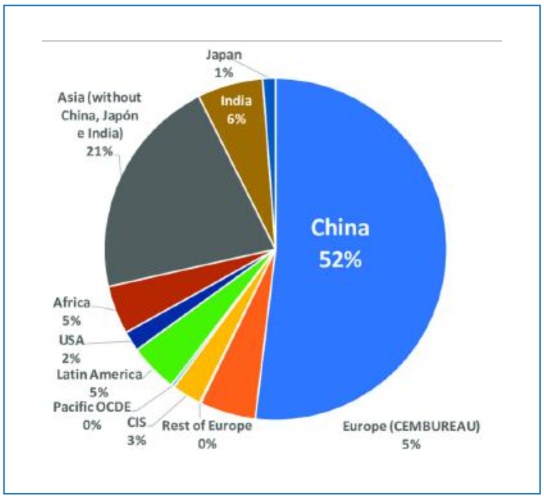

Fig. 4. World cement production in 2016
Source: Applied Sciences, "Carbon Dioxide Uptake by Cement-Based Materials": A Spanish Case Study Miguel Ángel Sanjuán, Carmen Andrade, Pedro Mora and Aniceto Zaragoza. Page 5. CC BY.
https://www.researchgate.net/figure/World-cement-production-in-2016-by-region-and-main-countries-465-Gt-4_fig1_338371313

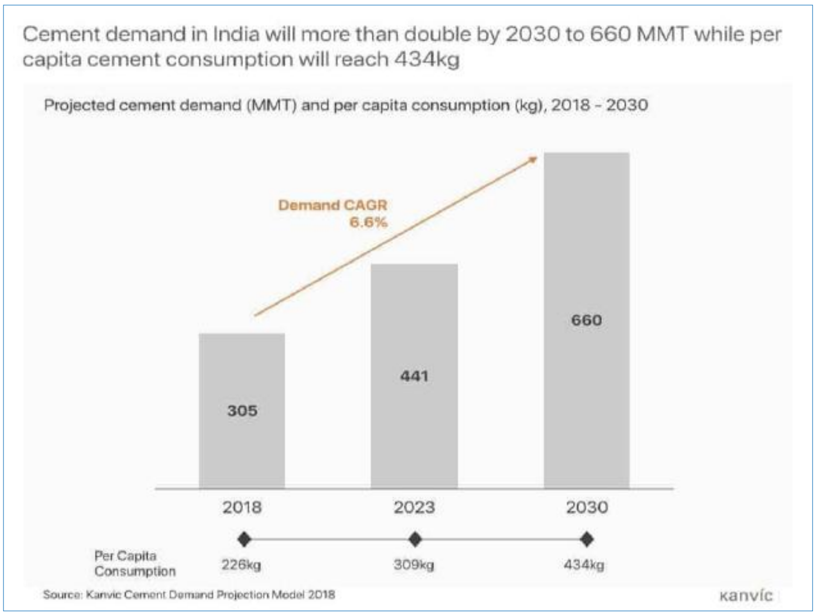

Fig. 5. Growth of cement demand in India from 2018 to 2030
Source: Kanvik Consulting, Article 1 December 2018, "Building a New India - The future of Indian cement is bright" Authors: Shiv Sharma, Matthew Wright. Reproduced with Permission. https://www.kanvic.com/grey-matter/building-a-new-india

India – Energy supply by fuel

Cement is one of the energy-intensive industries. The Indian cement industry is a trendsetter in the world of cement and has been consistent in adopting the latest technologies for energy conservation.

At the present time, coal represents the major source of cement thermal energy consumption in India, due to its widespread availability, high heating value and low cost. Natural gas and oil are also used as fuel.

The best energy consumption levels achieved across Indian cement plants are 676 kcal per kg clinker and 64 kWh per Mt of cement whereas the average energy consumption levels are 740 kcal per kg of clinker and 76 kWh per Mt of cement.

Alternative fuel used by the cement industry is defined by the Thermal Substitution Rate (TSR), which refers to the percentage of alternative fuel used to replace fossil fuels. From the TSR level of 4% in 2016 (it was 0.6% in 2010), the Indian cement industry targets to achieve 25% TSR by 2025 and 30% by 2030.

India has joined hands with Switzerland and other European countries to reduce energy consumption and develop newer methods for more efficient cement production.

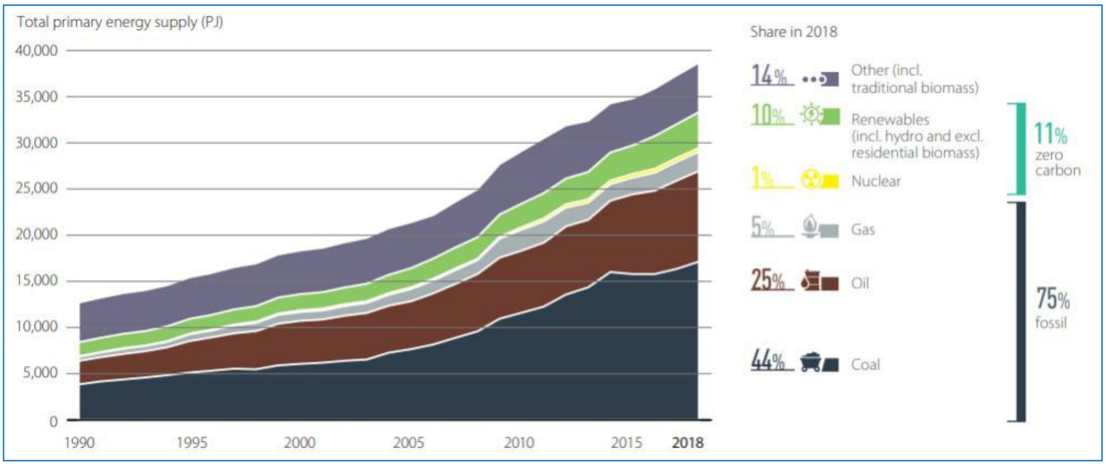

Fig. 6. Energy mix in the Indian Cement Industry
Source: ET Energyworld/The Economic Times, INFOGRAPHIC: India's energy mix. Secondary Sources: Enerdata 2019, Brown to Green: The G20 Transition Towards A Net-Zero Emissions Economy 2019 report
https://energy.economictimes.indiatimes.com/news/power/infographic-indias-energy-mix-2019/72277786
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Currently, the industry is focusing on increasing the sources of renewable energy.

Potential Renewable Energy Projects in Cement Plants

India ranks 3rd, behind U.S. and China, among 40 countries with a focus on renewable energy. The government has decided to substantially alter the energy mix that powers India in the future, such that, by 2030, at least 40 per cent of India's total power capacity will come from renewable sources.

1. Waste Heat Recovery System (WHRS)

WHRS has the potential to generate about 20% to 30% of plant power requirements (reducing purchased/ captive power needs) using the Steam Rankine cycle/Organic Rankine cycle/Kalina cycle.

Energy saving potential		
Electrical	4.4	kWh per tonne of clinker
	2.3	kWh per mt of cement after grinding and packing
	5.3	kWh per mt of total cement
Thermal	4.0	kCal per kg of clinker

Table 1. Energy saving potential

Cement plants in India have installed WHR plants with a total capacity of 400MW (up to PAT Cycle II), with a potential of around 1,200 MW. By generating 400 MW of WHR-based power, around 2.2 Mt of coal have been saved. This saving of fossil fuel is the reason these projects were considered under the Clean Development Mechanism (CDM) of the United Nations Framework

Convention on Climate Change (UNFCCC).

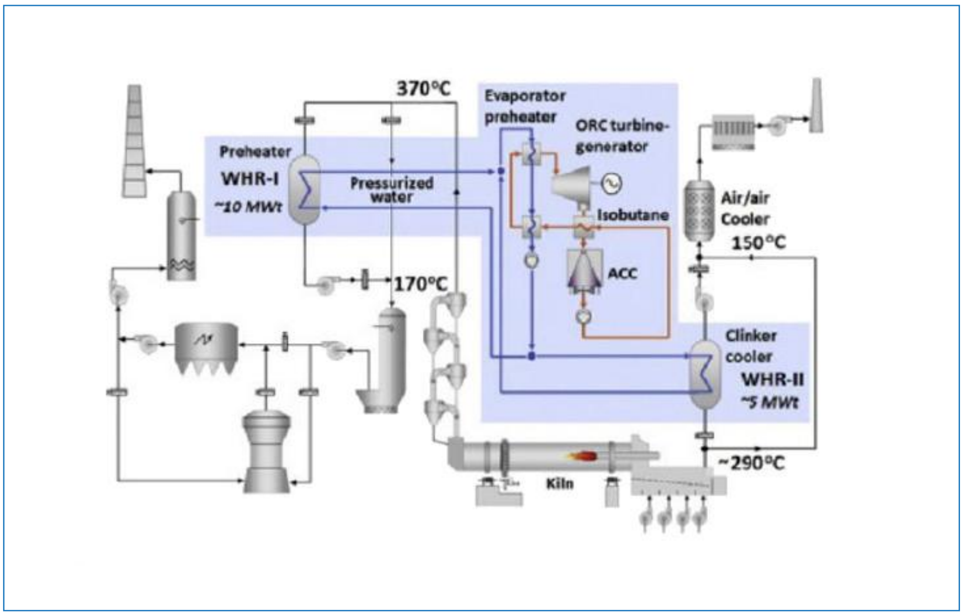

Fig. 7. Waste Heat Recovery in Cement Plant
Source: Redko, A., Redko, and R. DiPippo. Low-Temperature Energy Systems with Applications of Renewable Energy, Chapter 9: Industrial Waste Heat Resources; Academic Press: Cambridge, MA, USA (2020): 329-362. CCC RightsLink License N° 5471960500631
https://www.sciencedirect.com/science/article/pii/B9780128162491000091

Major Indian cement companies are planning to set up 175 MW of waste heat recovery system (WHRS) by 2022. It has emerged as one of the cheapest sources of power generation given the negligible input costs.

2. Solar Energy

By installing solar power plants and water heating systems, cement plants can meet obligations under both Renewable Purchase Obligation (RPO) and Performance Achieve and Trade (PAT) mechanisms as well as a reduction in greenhouse gas (GHG) emissions.

Most cement plants in India are located in dry and hot areas with enormous solar radiation and have huge amounts of unused, un-shaded arid land, ideal for the deployment of solar power plants. Solar energy can be harnessed either by Solar PV or Solar Thermal (CSP-Concentrated Solar Power) Technologies.

Solar PV Plant- Based on the typical brown-field 3 000 TPD cement plant, the available rooftop could harness solar power of appx. 1.8-1.9 MW (Open space for ground solar PV is separate).

Solar thermal (CSP) technology - can be integrated with existing (steam cycle) based plants (Coal, nuclear, CCGT, biomass) at various stages in the process (feed water heating, direct steam generation) and augment conversion efficiency.

3. Windmills

It is also used by a few Indian cement manufacturers in coastal areas, as an alternate source of energy.

GHG emissions

The cement sector is the third largest industrial source of pollution, emitting more than 500,000 tons per year of CO_2, SO_2 and NOx.

Fuel emissions account for approximately 35% to 40% of total CO_2 emissions from cement manufacturing. The Indian cement industry is responsible for 8% of the total national emissions. These emissions are a product of electricity usage (13%), combustion of fossil fuel (coal, gas etc. for energy use) (31%), and the conversion process of limestone into lime (process emissions) (56%). The CO_2 emission intensity of the Indian cement industry in 2018 was 576 kg CO_2/ton of cement produced whereas the global average is 634 kgCO_2/ton of cement produced.

Indian cement industry has achieved a reduction of CO_2 emission factor from 1.12 t of CO_2/t of cement in 1996 to 0.670 t of CO_2/t of cement in 2017, enhanced blended cement production from 68% in 2010 to 73% of total cement production in 2017.

The adoption of Waste Heat Recovery Systems (WHRS) by cement plants in India has offered mitigation of greenhouse gas (GHG) emissions.

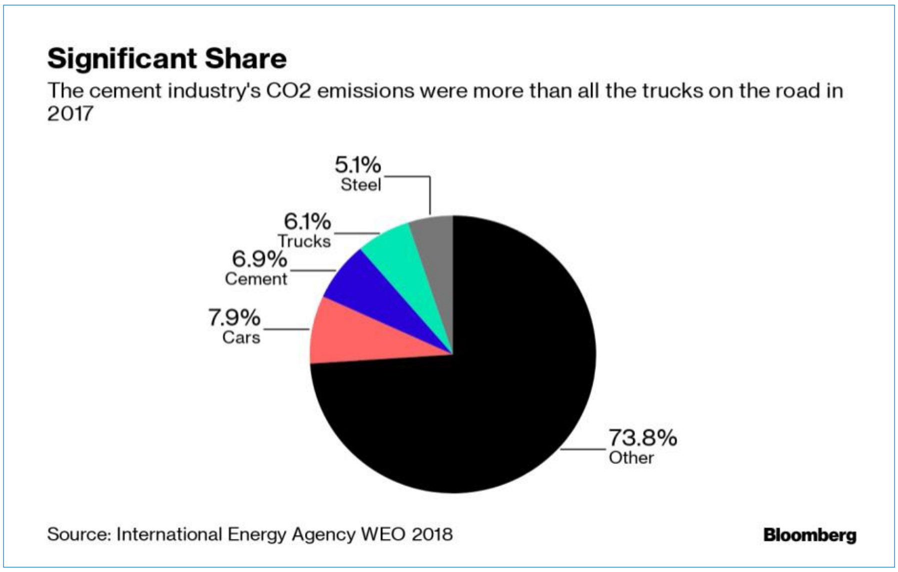

Fig. 8. Cement – significant share for global CO_2 emission, **IEA**
https://www.iea.org/reports/world-energy-outlook-2018/themes

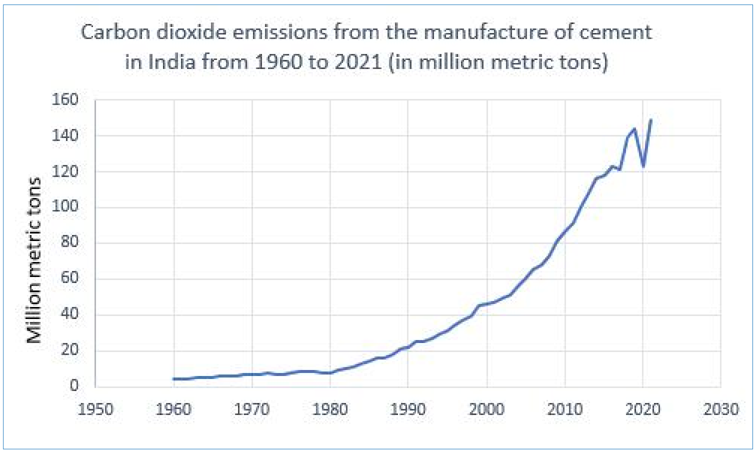

Fig. 9. CO_2 emissions from cement production in India from 1960 to 2019 (Mt)
Source: Compiled from the Global Carbon Project:
http://www.globalcarbonatlas.org/en/CO2-emissions, Global Carbon Project; Fridlignstein et al. 2020.
Reproduced with Permission.

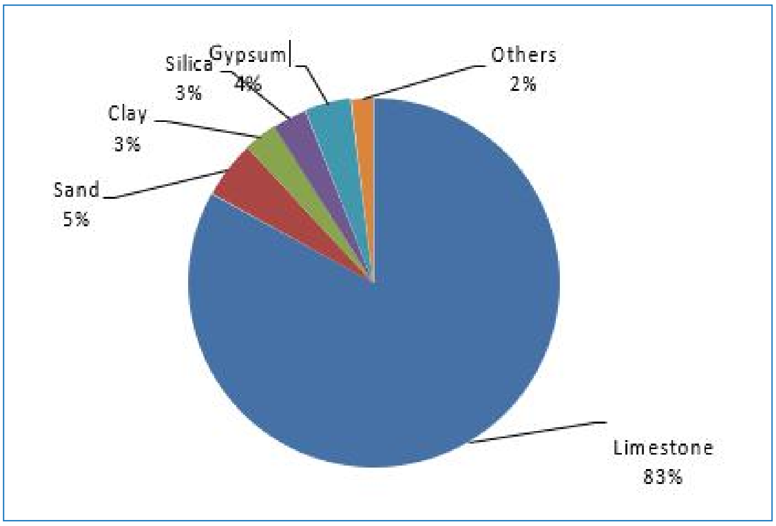

Fig. 10. Raw materials Ratio- India
Source: Compiled from various sources.

2018 League Table Rank	Company	League Table Weighted Rank
1	Dalmia Bharat	4.64
2	Ambuja Cement	5.62
3	Cementos Argos	5.90
4	Shree Cement	5.91
5	Lafarge Holcim (LH)	6.03
6	Heidelberg Cement	6.08
7	CRH	6.85
8	ACC (working with LH)	7.02
9	Ultra Tech Cement	7.32
10	CEMEX	8.04

Table 2. Carbon Disclosure Project (CDP) Global Cement Sector Ranking

Five Indian cement Companies (highlighted) are among the top 10 world ranks on business readiness for a low-carbon transition. An Indian company has recently been qualified “Climate Defenders” in recognition of the CDP on low carbon economy and commitment to a negative carbon footprint cement production by 2040.

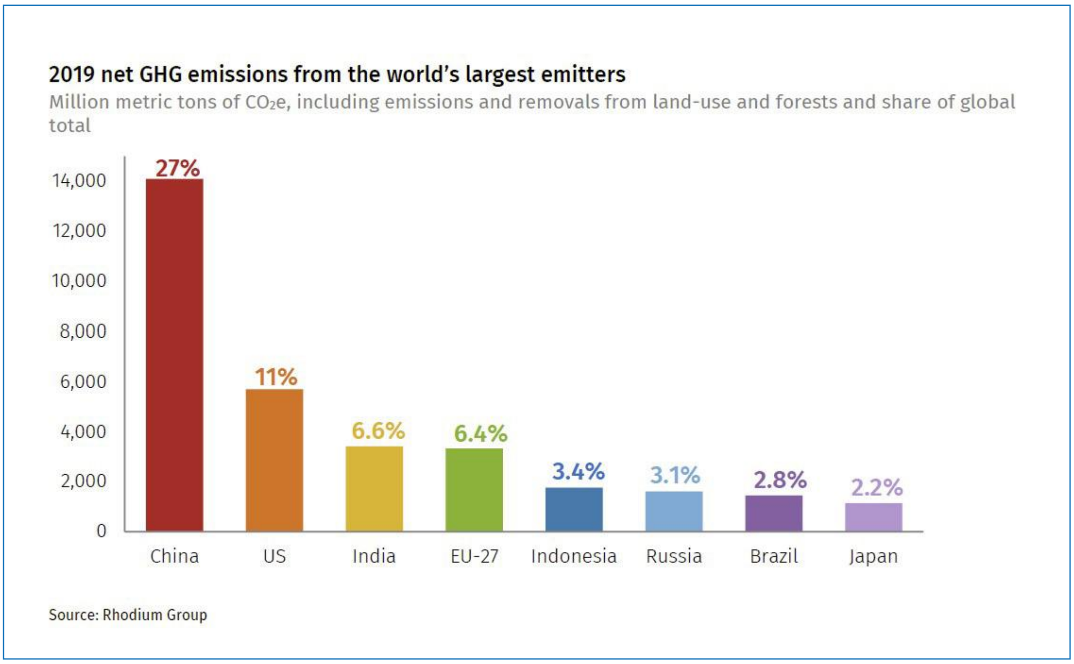

Fig. 11. Larges Greenhouse gas emitters worldwide, 2019
Source: Rhodium Group. Reproduced with permission.
https://politicalcalculations.blogspot.com/2021/05/the-worlds-largest-emitter-of-carbon.html#.ZBhCt3ZBzY0

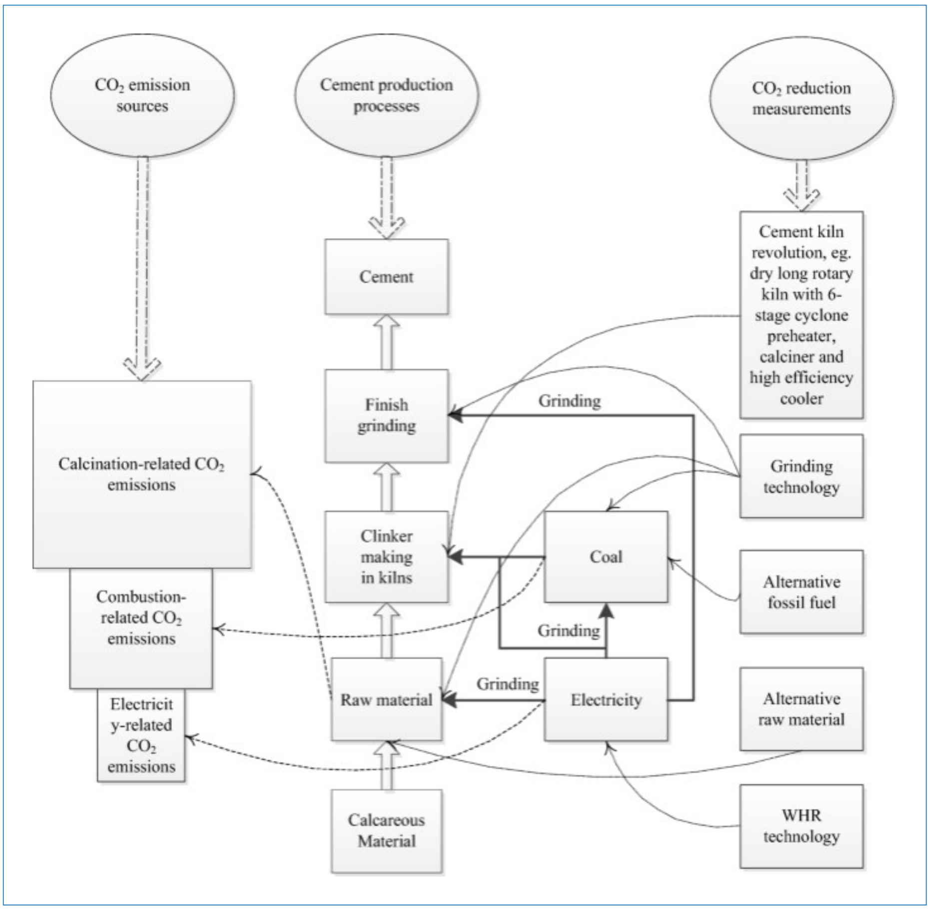

Fig. 12. Evaluation and mitigation of cement CO_2
Source: "Evaluation and mitigation of cement CO_2 emissions: projection of emission scenarios toward 2030 in China and proposal of the roadmap to a low-carbon world by 2050", Junxiao Wei, Kuang Cen & Yuanbo Geng Permission to reproduce via CCC Copyright Clearance Centre Marketplace, Order License ID: 1337729-1 https://link.springer.com/article/10.1007/s11027-018-9813-0

Are the best available low-carbon technologies used/considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

Energy Efficiency (EE) is a strong motivator for decarbonisation. Currently, cement plants in India are among the most efficient ones in the world in terms of energy conservation and in emission reduction, because India's large cement industry has phased out old technologies along with the following improvements (operations and energy consumption):

1. kiln thermal efficiency improvements,
2. milling/grinding electrical efficiency improvements,
3. low-carbon fuel utilization– (wind, solar or biomass),
4. lower-carbon cement or Portland-Limestone Cement (PLC),
5. clinker-to-cement ratio reductions by mixing clay, blast furnace slag, fly ash etc.

Selected Indian cement companies are currently working on at-plant carbon capture and sequestration and utilization in association with European companies.

Economic Problem:

- high investments and operational costs,
- minimal demand for green products, for consumers being unwilling to pay a premium for these products.
- awareness of the benefits and confidence in the technical aspects is lacking.

Social problem: Co-processing using hazardous waste in cement industries has been encouraged, in the right environmentally safe manner.

Regulations: Certain incentives have been leveraged for green products. For Carbon Capture and Utilisation projects, an adjustment of a border tax has been given to encourage deployments.

India started to address climate change issues through its comprehensive National Action Plan for Climate Change (NAPCC). Gaps in the regulatory and policy framework create barriers to an effective transition to green technologies. Also, policy-targeted incentives and support measures are needed to increase the demand and supply of green alternatives.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

Each ton of cement generates approximately 0.7–0.93 tonnes of CO_2 depending on the kiln technology used. The top 10 cement-producing countries along with the European Union emit 1 445 million tonnes of CO_2 each year.

Indian cement companies are not required by regulations to make climate commitments or plan roadmaps for their emission reduction, they have done so at the top level of the cement industry through voluntary actions. Some of them are listed below:

1. Construction of the largest Carbon Capture and Utilisation (CCU) facility at a plant site with new technologies from the UK and Europe. Indian industries are leading some of the largest projects exploring CCUS technologies. They have recognised the role of CCUS during the transition period and the adoption of CCS/CCUS technologies should therefore be promoted in India.
2. Ambitious target of becoming carbon-negative by 2040.
3. India plans to reduce its carbon footprint by 33-35% of its 2005 levels by 2030.
4. Aiming to increase the percentage of renewables in its overall electricity consumption – with a target of 100% RE by 2030.
5. Doubling energy productivity by 2030
6. Recycling of waste and by-products for energy and raw materials
7. Reduce clinker-to-cement ratio.
8. Driving the transformation of hard to decarbonise and energy-intensive sectors along with other countries in the European Union.
9. Commitment to Science-Based Targets (SBTs)

10. Developing third-party assured integrated reporting based on the International Integrated Reporting Council (IIRC) framework.
11. Indian cement industry's Vision 2030: Building a New India
12. Use of digital technology, data science and performance-based measurement to assure optimum economic processes and fulfil the commitments.
13. Use of Carbon Cure Concrete – Carbon Cure Technology (CCT) – introduces recycled CO_2 into fresh concrete to reduce its carbon footprint without compromising performance. Once injected, the CO_2 undergoes a mineralization process and becomes permanently embedded.

This technology is encouraged for reducing concrete industry CO_2 emissions globally by 500 million metric tonnes annually by 2030.

Besides CCT the reduction in consumption of concrete products reused concrete and concrete products could be used on a large scale to reduce carbon emissions.

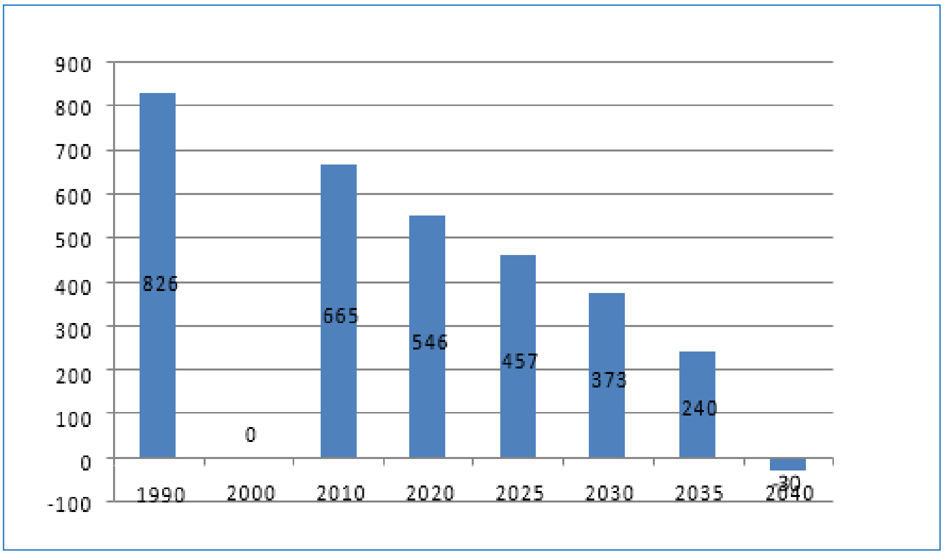

Fig. 13. India - Roadmap for carbon negative transition in selected companies
Source: Compiled from various sources.

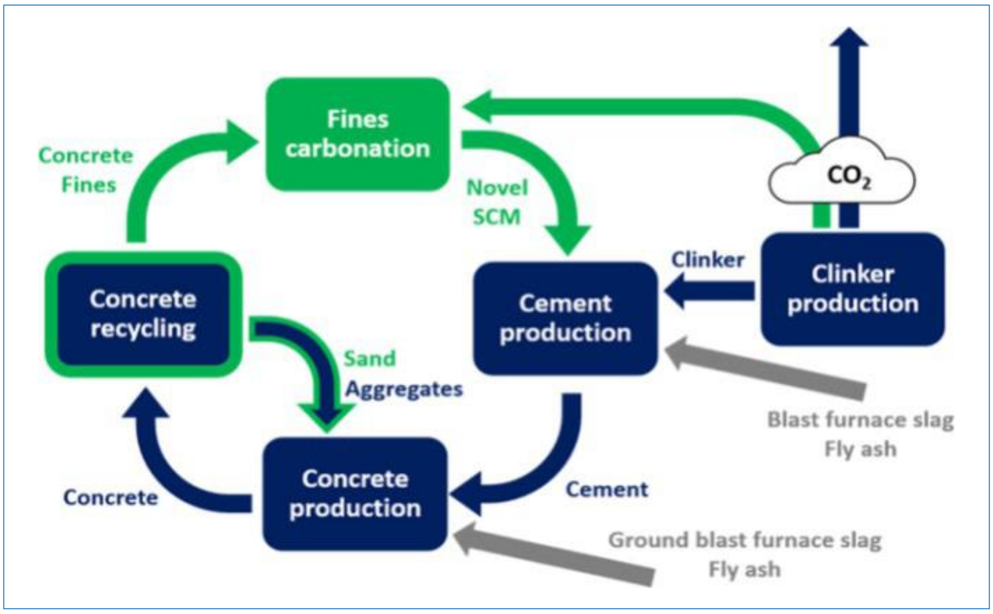

Fig. 14. Concrete recycling in production of cement
Source: Cement production with substantially lower CO_2 emissions. Skocek, J., zajac, M. & Ben Haha, M. Carbon Capture and Utilization by mineralization of cement pastes derived from recycled concrete. Sci Rep 10, 5614 (2020). Open Access. https://www.nature.com/articles/s41598-020-62503-z

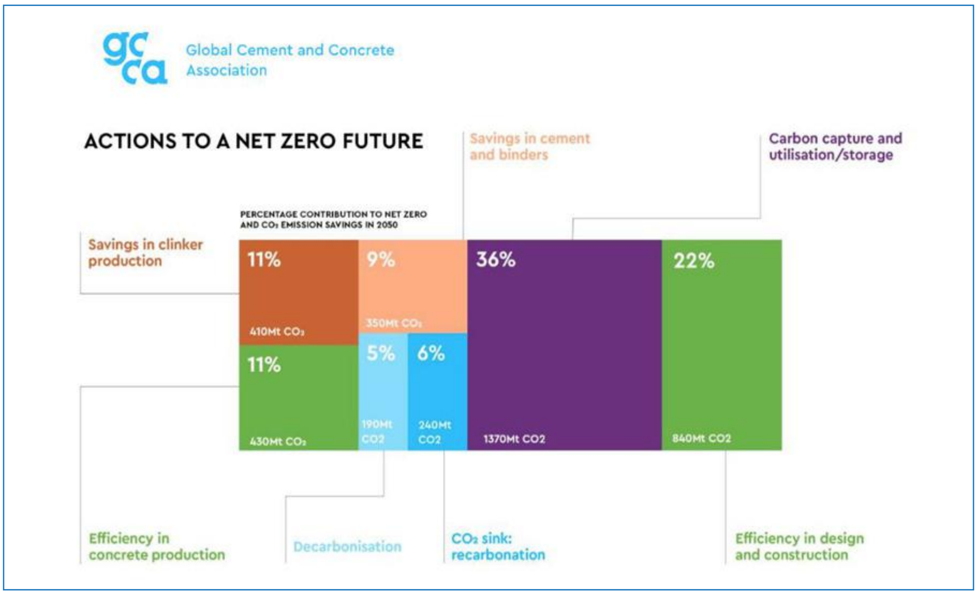

Fig. 15. Target pathway
Source: Global Cement and Concrete Association. Reproduced with permission.
https://gccassociation.org/concretefuture/actions-to-a-net-zero-future/

Is the implementation of low-carbon technologies helped by the government?

For refurbishing or replacing equipment? How are public authorities pushing the transformation? Through benchmarking? Audits?

The Bureau of Energy Efficiency's (BEE) Perform, Achieve, Trade (PAT) Cycle -1 (2012-15) included 478 units (Designated Consumers or DCs) from eight energy-intensive sectors, including cement. The minimum annual energy consumption of each DC was 30 000 tonnes of oil equivalent (toe). About 85 cement plants in India were notified as DCs under PAT I. As against a total saving target of 0.815 million toe (Mtoe), the sector achieved 1.48Mtoe of energy savings and 4.34 Mt of CO_2 savings.

The Confederation of Indian Industry (CII) is encouraging cement plants through its well-tested Energy Benchmarking Manual. The manual has been recognized as a useful tool for performance assessment, energy efficiency improvement and target setting across the industry to help cement plants achieve the status of efficient role model units. The CII has conducted its energy benchmarking study in 18 cement plants to date. These plants have realized a total energy saving potential of USD 19mn from the 516 energy-saving proposals identified during the energy benchmarking studies.

Other initiatives: The Bureau of Energy Efficiency (BEE) and the United Nations Industrial Development Organisation (UNIDO) have jointly created the Facility for Low Carbon Technology Deployment, a five-year programme that aims to promote innovative low-carbon technologies among industrial and other sectors of the Indian economy. The CII is working with the BEE and UNIDO to implement the programme, under which annual "innovation challenges" are being conducted to identify innovative technologies and solutions to improve efficient end use of energy and reduce greenhouse gas emissions.

Are there incentives for carbon capture, utilisation, and storage? How?

The Department of Biotechnology (DBT) and Department of Science and Technology (DST), along with Accelerating CCUS Technologies (ACT) initiative under Mission Innovation (MI), has played an essential role in refocussing on CCS/CCUS in the Indian context by peer technology exchange and allocating funds for R&D.

The recently launched roadmap 2030 for India-UK future relations considers CCUS under clean energy and transport focus areas (MEA 2021). Thus, multiple initiatives highlight the resumption of the application of CCUS across industries in India.

Indian industries and public sector undertakings (PSUs) are leading the way towards the promotion of CCS facilities while recognising the need to stay carbon-neutral in the broader context of sustainability and competitiveness.

If relevant, what about recycling?

What percentage is recycled? What are the obstacles to increasing recycling? Is a policy to increase recycling already in place or at the project stage?

At present, India recycles one per cent of its Construction and Demolition(C&D) waste. The Indian cement industry is contributing to the circular economy primarily by (i) Circular Supply Chain, (ii) Recovery and Recycling. Waste from various industries is being utilized by the cement industry as Alternative Fuels and Raw materials (AFR).

Besides C&D waste, recovery of energy in the form of Biomass, Urban, Industrial and Agricultural Waste, Refuse Derived Fuel (RDF) from Municipal Solid Waste (MSW) and used tyres for meeting captive power and thermal needs of cement plants. India generates over 150,000 tonnes of municipal solid waste per day, 8-9% of which contains plastics. It needs segregation and motivation with the objective of using various technologies at various stages including artificial intelligence.

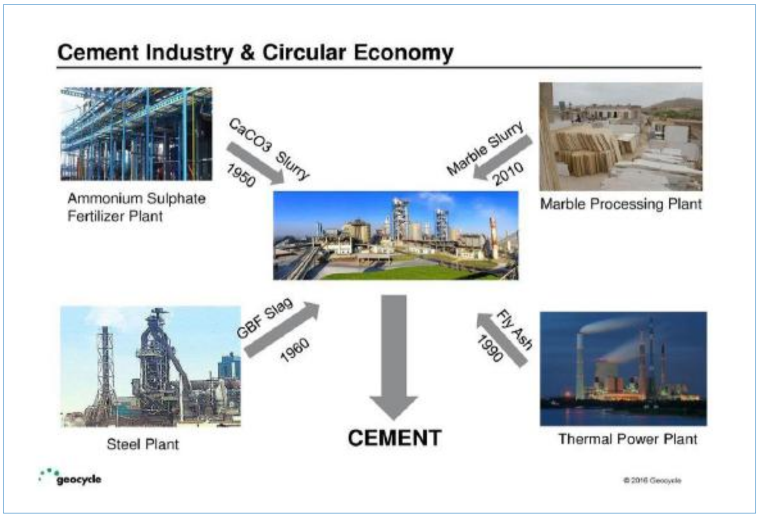

Fig. 16. Cement Industry & Circular Economy
Source: EricThomson, Environmentally Sound Management of Plastic Wastes through Cement Kiln Co-processing Ulhas Parlikar Dy Head, Geocycle India ACC Limited 2016-04-14. Reproduced with Permission. https://slideplayer.com/slide/14094617/

Co-processing puts the cement industry at the heart of the circular economy and plays a key role in terms of waste management in local areas and municipalities and CO_2 is saved by replacing fossil fuels.

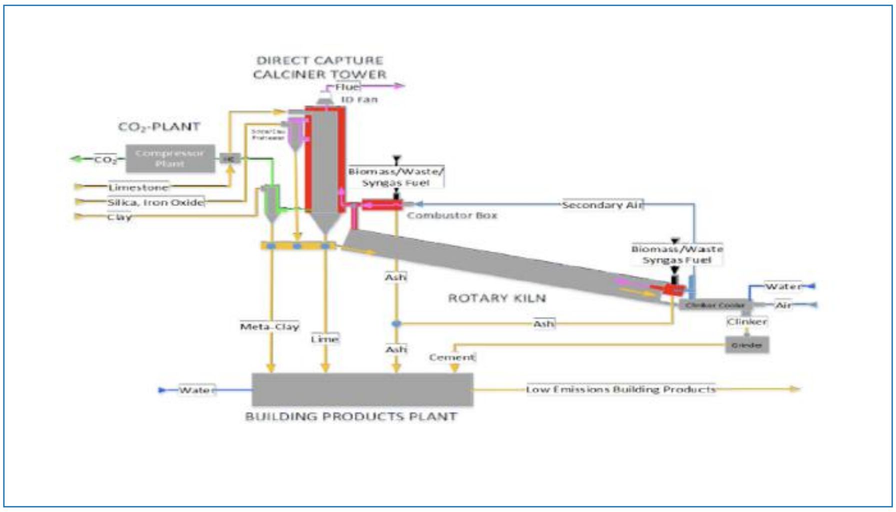

Fig. 17. Cement Kiln coprocessing
Schematic flow sheet of the indirect calcination process with downstream option
Source: Article "Veering Towards Carbon Capture and Transformation – An Emerging Technological Need for Carbon Dioxide Abatement Strategy" – by Dr. Anjan K Chatterjee, Conmat Technologies Pvt Ltd, Kolkata, India. See also "Cement Production Technology, Principles and Practice", Anjan Kumar Chatterjee, CRC Press, Taylor and Francis Group, page 356, FIGURE 10.17: https://nasiri.iut.ac.ir/sites/nasiri.iut.ac.ir/files//files_course/cement_production_technology_principles_and_practice.pdf Reproduced with Permission.

Production of blended cement, composite cement, and utilising performance improvers in cement also support the circular economy. The use of fly ash, granule blast furnace slag (GBFS) in the production of blended cement types, i.e. Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) is also beneficial for the conservation of natural resources, lowering the clinker factor in cement and reducing CO_2 emission along with environmental sustainability.

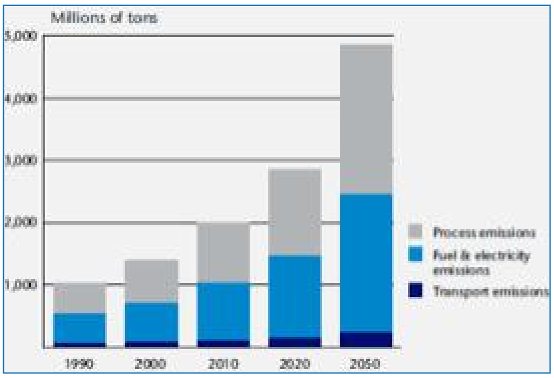

Fig. 18. Target - Coprocessing of Municipal solid waste

Source: Historical and projected CO2 emissions of the global cement industry (Campisano 2011) DOE OSTI, ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY, Ali Hasanbeigi, Hongyou Lu, Christopher Williams, Lynn Price : "International Best Practices for Pre-Processing and Co-Processing Municipal Solid Waste and Sewage Sludge in the Cement Industry", July 2012. CC BY-NC. https://www.osti.gov/servlets/purl/1213537

Barriers to the implementation of Recycling

- Limited involvement of government agencies/departments; lack of urgency.
- Transportation and segregation issues
- Lack of monitoring capacity/resources
- Lack of capacity and experience
- Lack of confidence in the quality and durability of recycled products
- Poor accountability framework

Are there some case studies or best practices you would like to share:

Case study 1

Indian industries are leading some of the largest projects exploring the role of CCUS, but more stakeholders and sponsors are needed to promote the adoption of CCS/CCUS technology for the transitional period to a green economy in India.

Dalmia Cement, in order to reach the level of –30 $kgCO_2$/ton of cement by 2040, has announced the installation of a large-scale CCUS facility of capacity 0.5 $MtCO_2$ per annum at one of its plants in Tamil Nadu, India. For the implementation of this facility, Dalmia Cement and Carbon Clean Solutions, UK, have come together to adopt the latter's patented technology, CDRMax (Global CCS Insitute 2019).

The technology is far from becoming mainstream, but the Government of India and the Indian industry are trying to better understand the techno-economic feasibility and scalability of this technology.

Indian industries and public sector undertakings (PSUs) are leading the way towards the promotion of CCS facilities while recognising the need to stay carbon-neutral in the broader context of sustainability and competitiveness.

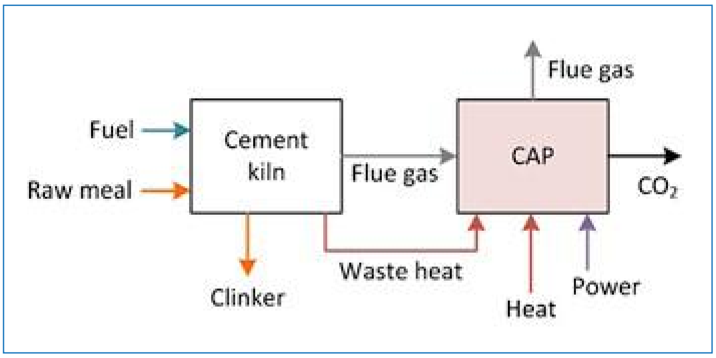

Fig. 19. The CAP Process for recovery of waste heat and capture and separation of flue gases, integrated into a cement plant (Dalmia Cement). CAP: CO_2 Capture unit.
Source: Comparison of Technologies for CO_2 Capture from Cement Production – Part 2: Cost Analysis, Energies & MDPI, February 2019, Open Access Creative Common CC BY license. https://core.ac.uk/download/pdf/195747385.pdf

Case study 2

Co-processing of plastic waste in cement kiln – ACC Ltd, Gagal Cement Works in Himachal Pradesh.

The project started with the collection of 50 kg of plastic waste per week. At present, it has reached the level of approximately two Tonnes of plastic waste collected per week. This gave a clear indication that the stakeholders were increasingly becoming more aware of the need for waste sorting and concerned about their environment.

The investment required for this project is very minimal as the method was already developed.

Co-processing of waste at a cement kiln is the best disposal option compared to conventional options, such as landfilling and incineration, with the benefit of substituting fossil fuels.

The initiative can be replicated countrywide by other cement factories, as well as at a global level. The beauty of the initiative is that by keeping the ideas intact, the projects can easily be adapted to suit the climate, topography and biodiversity of any area across India.

Besides, ACC Limited, Kymore Cement Works established the system and infrastructure for the co-processing of polythene garbage in its Kiln and the system is in operation since June 2008.

Case study 3

A Waste Heat Recovery System was installed in 3 kilns (kiln capacity 4 300, 5 000 and 5 000 for kiln 1, 2 and 3 respectively) at JK Lakshmi Cement Ltd. Rajasthan (Sirohi) plant with a total capacity of 12 MW. Sources of heat for boilers are exhaust gases from the preheater and cooler of kiln-1, 2 and 3. It was not feasible to install an AQC boiler because waste gases from kiln 3 cooler are being used for the flyash drier.

South-Africa

The South African Cement industry mainly consists of 6 large cement manufacturing companies with a combined production capacity of approximately 22 million tonnes of cement per year but currently only producing around 13 million tonnes. The industry is well regulated, with very strict Labour Laws, Mining Laws, Transformation requirements, compulsory National Standards adopted from European standards and Carbon Taxes. The industry is severely affected by cheap imports currently in excess of one million tonnes from countries with no labour laws, standards for quality assurance, environmental legislation or carbon taxes.

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

Vosloo and Mathews (2017) estimated that about 88% of the energy supplied to cement plants comes from coal, with the remaining 12% coming from electricity. Due to the relative price difference, coal makes up only 61% of the energy cost, with electricity making up the remaining 39%. Electrical efficiency is thus a priority and large manufacturers have started retrofitting and recapitalizing heating and grinding processes in their plants.

The abundance of locally available coal makes it the most cost-effective source of energy. Alternative sources of energy, such as waste tires, are used in a couple of cement kilns, but constant and reliable streams of waste materials fit for generating heat efficiently remain problematic.

In South Africa, electricity is mainly generated in coal-fired power stations, producing large volumes of fly ash that is used to reduce the clinker content of manufactured cement. It is estimated that the South African cement industry managed to reduce the CO_2 emitted per ton of manufactured cement from 783 kgCO_2/t cement in 1999 to 665 kgCO_2/t in 2015. This value is slightly above the 2020 average international value as indicated by the GNR indicator[1].

In 2010 the South African Concrete Institute commissioned a study on GHG emissions indicating the benefits of using blended cements as shown in *Table 1*. These values confirm that it would be possible to further reduce the GHG emissions by reducing the clinker content of South African cements, as indicated by the Ordinary Portland Cement (OPC) content in the table below.

Cement type	Composition (%)				Total GHG emissions (kgCO_2/ton)
	OPC	Fly ash	GBBS*	Limestone	
CEM I	100	0	0	0	985
CEM II A-L	85	0	0	15	839
CEM II A-S	80	0	20	0	814
CEM II A-V	80	20	0	0	789
CEM II B-L	73	0	0	27	722
CEM II B-S	70	0	30	0	728
CEM II B-V	70	30	0	0	690
CEM III A	50	0	50	0	557
CEM IV A	65	35	0	0	641
CEM IV B	58	42	0	0	572
CEM V A	57	18	25	0	594
CEM V B	38	31	31	0	414

Table 1. GHG in kgCO_2/ton per type of South African cement (InEnergy, 2010).
* Ground Granulated Blast-furnace Slag
Source: Edward Volek, InEnergy, 2010. Reproduced with Permission

[1] Getting the Numbers Right (GNR) is an independently managed database of CO_2 and energy performance information on the global cement industry.

Are the best available low-carbon technologies used/considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

Where possible, the local cement manufacturers use the most appropriate low-carbon technologies such as electricity efficiency, thermal efficiency, alternative fuels, and reduction of the clinker-to-cement ratio. Although the modernisation of plants is considered, current economic conditions make this difficult. As more than 30 million tons of fly ash is produced annually by the coal-fired power plants in South Africa, reducing the clinker content of cement via an increase of fly ash, is the most obvious way of reducing the carbon footprint.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

Local manufacturers are increasingly manufacturing blended cements containing larger percentages of limestone, fly ash and Ground Granulated Blast-Furnace Slag (GGBS). In 1990, clinker substitution reached a level of 12% and this increased to 23% in 2000 and 41% in 2009. It is estimated that the clinker replacement level in South Africa would reach 60% by 2030. The nearly unlimited volume of high-quality fly ash available in South Africa will ensure availability for use at high clinker replacement levels until 2050 and beyond. South Africa is in the process of adopting EN 197-5 which allows for further extension of types of cement.

Is the implementation of low-carbon technologies helped by the government?

Carbon taxes have been implemented and currently, negotiations are taking place to finalise the second round of Carbon taxes. Unfair competition from cheap unregulated cement imports remains a major stumbling block limiting the ability of local cement manufacturers to reduce GHG emissions while retaining their market share.

The South African National Accreditation System (SANAS) launched a programme for the accreditation of GHG validation and verification bodies for GHG quantification against the requirements of ISO 14065 that can be used in mandatory GHG reporting and evaluation of the implications of a carbon tax.

In October 2021 the South African National Treasury issued a circular, indicating that the cement sector has been designated as a sector for local production and content, thus all cement types used in state-funded contracts, must now be manufactured using locally produced clinker and locally sourced secondary materials. This should protect the local cement industry to the extent that it would be affordable to consider plant modifications required to reduce GHG emissions.

If relevant, what about recycling?

Although cement is not recycled and there are no mandatory policies in place, practices such as the reuse of wash water at concrete plants and recycling of old concrete and demolition waste are widely used.

Are there some case studies or best practices you would like to share?

Cement is used as a constituent of concrete and the carbon footprint of the cement and concrete industry can be minimized by optimizing the use of cement. Although concrete consists of about 70% fine and coarse aggregate, 20% water and 10% cement, the GHG emission of the concrete is dominantly that of the cement manufacturing process. It is thus important to not only limit the CO_2 emissions per kg of cement produced but also limit the kg cement used per m^3 of concrete. Although the production of water-reducing admixtures results in significant GHG emissions, small volumes of these admixtures can result in up to a 30% reduction in both water and cement content, reducing the carbon footprint of the resulting concrete. When considering the decarbonisation of energy end uses, it is thus important to not only focus on the cement production process but also on limiting the carbon footprint of the concrete produced and the infrastructure containing the concrete.

Sweden

Cementa, which is part of the Heidelberg Cement group, is the only cement producer in Sweden with a capacity of approximately 3 Mt cement per year.

What is the energy balance (energy sources used)? And the GHG intensity, compared to other countries?

Total energy around	**4.0**
Coal and coke	1.0
Waste (fossil origin)	1.8
Electricity	0.4
Biofuels	0.8

Table. 1. Energy sources for cement production in TWh/year

The Swedish cement industry emits around 2.5 Mt of CO_2 annually, equivalent to around 15% of the total industrial CO_2 emissions. The CO_2 emissions are both from the energy supply and in the form of process emissions (from the calcination process).

Are the best available low-carbon technologies used/considered? If not, is it an economic problem? A matter of regulation? Or some social issues?

Within the framework of the Fossil Free Sweden initiative, a roadmap for carbon-neutral cement and concrete for the cement industry has been developed by Cementa.

Cementa works **towards a zero vision for carbon dioxide emissions** during the life cycle of concrete products. The target is to achieve climate-neutral construction with cement and concrete in 2030 as illustrated in *Fig. 1*, where the dark green area represents the remaining CO_2 emissions after reduction due to the elements described in the list below and represented by lighter shades.

Efforts to reduce emissions are being driven in five main areas in steps as shown in *Fig. 1.*:

- energy efficiency
- decarbonisation by increasing the share of bio-based fuels
- development of new cement products with a smaller carbon footprint
- research into increased carbon dioxide uptake of existing concrete structures
- carbon capture followed by reuse or geological storage, which in the long term means a return to rock minerals

Investments have made it possible to replace more than half of coal in production with alternative and bio-based fuels.

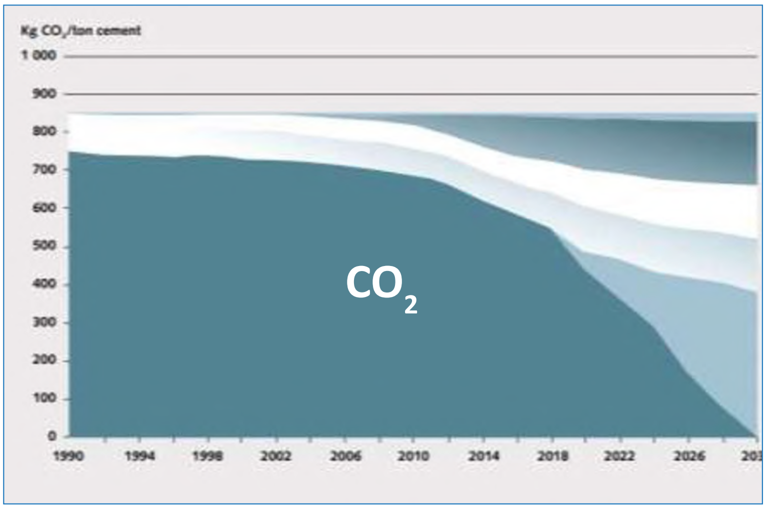

Fig. 1. Cement Roadmap
Source: Cementa roadmap: https://www.cementa.se/sites/default/files/assets/document/9a/c0/fardplan_cement-for_klimatneutralt_betongbyggande-20180424.pdf (page 9, in Swedish). Values are meant to be indicative only. Reproduction with permission

Cementa has a plan to apply CCS to capture basically all CO_2 emissions from their largest plant (in Slite, Gotland) by Year 2030. Since they are also using renewable fuels, this may, depending on capture rate and the share of renewable fuels, results in net negative emissions from cement production: Sweden first in the world with carbon-neutral cement plant | Cementa.

There are also possibilities to use alternative binders. The captured CO_2 will most likely be stored under the seabed in the North Sea as part of the Northern Light project.

(At the moment there are discussions on the permitting of continued cement production in Slite).

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

There are three roadmaps developed within the Fossil Free Sweden initiative which are relevant for the cement industry: The **cement roadmap** (The cement industry - Fossilfritt Sverige), the **Concrete roadmap** (The concrete industry -Fossilfritt Sverige) and the **roadmap for the building and construction industry** (The construction and civil engineering sector - Fossilfritt Sverige)

The Swedish cement industry roadmap is targeting climate neutrality by 2030, with the main focus being on biofuels together with CCS.

All these have the aim to meet the Swedish target of net zero emissions by 2045.

If relevant, what about recycling?

What percentage is recycled? What are the obstacles to increasing recycling? Is a policy to increase recycling already in place or in project?

Concrete is a fully recyclable material but handling and transport create financial thresholds for recycling in concrete production. Incentives are needed for a higher degree of recycling, including of whole concrete structures.

Are there some case studies or best practices you would like to share?

Cementa, part of the Heidelberg group, is currently planning a large-scale implementation of CCS at their Norwegian sister factory (Norcem) in Brevik, Norway. Being part of the so-called Lanskip-project, which is linked to the Northern Light project, Norcem will capture around 400 ktCO_2/year. https://www.norcem.no/no/PressMediaCCS.

Together with Vattenfall, Cementa is also pursuing electrification through its CemZero project, with a pre-feasibility study released in 2018. Vattenfall and Cementa take the next step toward climate-neutral cement. Even with electrification or using biomass to abate the energy-related emissions, process emissions remain, and CCS still needs to be applied. However, the electrification serves to purify the flue gas streams which eases CO_2 capture.

IRON AND STEEL INDUSTRY ANALYSIS

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China

What is the energy balance (energy sources used)? And the GHG-intensity, compared to other countries?

In China, the main production process in the Iron and Steel Industry is the Blast Furnace – Basic Oxygen Furnace (BF-BOF) process. Crude steel production accounts for more than 90% of total production in China in 2020.

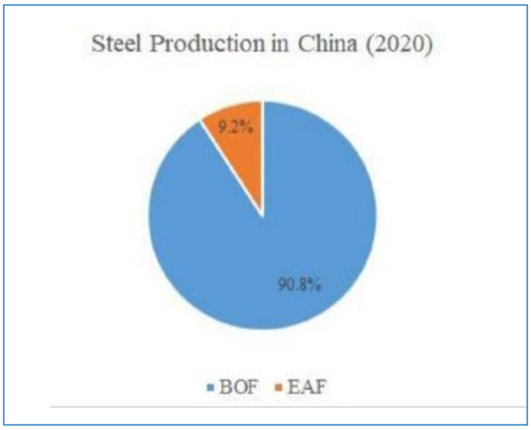

Fig. 1. Chinese Steel Production in 2020
Source: Based on data from: World Steel Association, World Steel in Figures 2021. Open source

In 2020, the energy consumption in the Iron and Steel Industry is about 16% of the total energy consumption in China. The use of coal for energy in this Industry accounts for more than 70% of the total, which causes high CO_2 emissions. For the BF-BOF process, the CO_2 emission is about 2 tonnes per tonne of steel. The total ironmaking process (including ironmaking per se, sintering, steelmaking, and rolling) produces 87% of CO_2 emissions in the overall process (see *Fig. 2*). For Electric Arc Furnace (EAF) process, the CO_2 emissions are about 0.35-0.5 tonnes per tonne of steel.

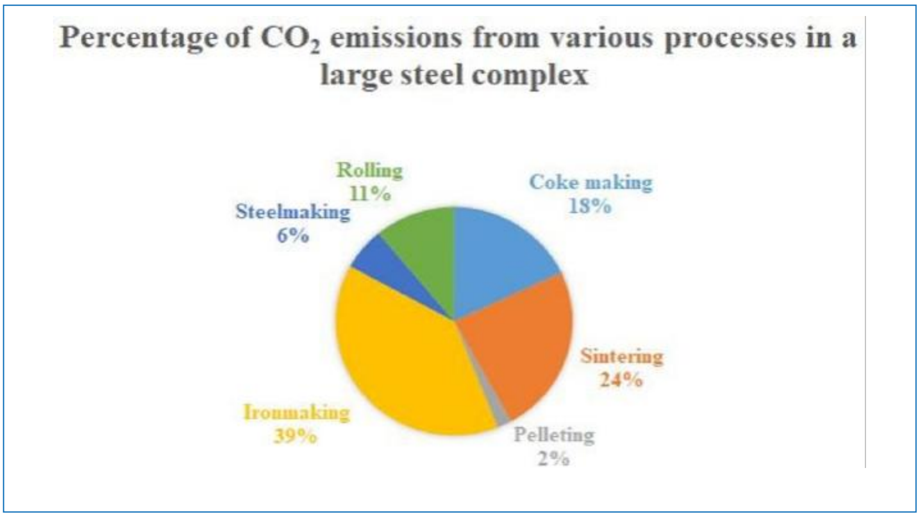

Fig. 2. CO_2 emissions from different processes in a large steel plant
Source: Based on data from: ZHANG Qi, SHEN Jia-lin, XU Li-song. Carbon peak and low-carbon transition path of China's iron and steel industry[J]. Iron and Steel, 2021, 56(10): 152-163.

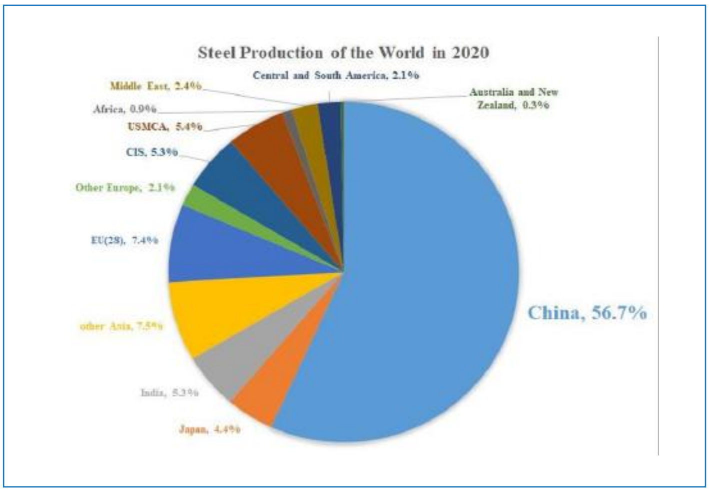

Fig. 3. Global Steel Production 2020

In 2020, the crude steel production in China is 1.065 billion tons, around 56.7% of the global production.

Are the best available low-carbon technologies used/considered?

The energy-saving and emission-reduction technologies have been widely applied in large and medium-sized Iron and Steel enterprises in China with the development of a modern Industry. Some technologies, such as coke dry quenching, coal moisture control, waste heat recovery from the sintering process, electricity generation with residual pressure of top gas of blast furnace, etc., are state-of-the-art technologies in the world and are encouraged to be applied in the whole Iron and Steel Industry.

Further developments in emission-decreasing technologies have been conducted, such as hydrogen-rich ironmaking in BF, oxygen-rich ironmaking in BF, using tail gas of steel plants as carbon resources to produce ethanol by connecting steel and chemical industry, hydrogen metallurgy, etc. EAF process can decrease 2/3 of the CO_2 emission compared with BF-BOF process, which is considered as an effective way in the future.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

The Steel Association and the steel companies in China are making plans for peak carbon emissions recently. According to the primary planning, it is expected that the iron and steel industry will peak carbon emissions by around 2024, and carbon emissions from the steel industry in 2030 will be reduced by 30% compared with 2020.

Is the implementation of low-carbon technologies helped by the government?

The Chinese government, including the national government and provincial governments, are supportive of the implementation of low-carbon technologies, such as the application of energy-saving, emission-reduction and new technologies in the steel industry.

The government has developed assessment methods for CO_2 emissions for steel manufacturers, which provide motivation for promoting carbon emission reduction in production enterprises.

Are there incentives for carbon capture, utilisation, and storage? How?

China is now developing technology incentive policies.

If relevant, what about recycling?

The EAF process is considered one of the important ways to reduce CO_2 emissions in the steel industry. For the EAF process, the feedstock could be steel scrap, which means the recycling of steel will become rather important. The increase in the steel scrap ratio in the BOF process could also reduce CO_2 emissions. It is planned that the utilisation of steel scrap as feedstock will be increased to 30% by 2025, and the ratio of EAF process in the steel industry will be enhanced to 15%-20% by then.

The relatively high cost of steel scrap and electricity, and the low amount of available steel scrap have so far limited the development of the EAF process in China. But this situation may change in the future.

Are there some case studies or best practices you would like to share?

Hydrogen metallurgy is an ideal green metallurgical process. At present, China has carried out in-depth research in hydrogen metallurgy technologies. In January 2019, CNNC, Baosteel and Tsinghua University have signed a cooperation framework agreement on the research of hydrogen utilisation in metallurgy. In November 2019, the Hegang group established the hydrogen energy technology and industrial innovation centre, cooperated with the Italian Tenova group in hydrogen metallurgy technology, and is planning to construct one of the world's first hydrogen metallurgy demonstration projects with a capacity of 1.2 million tons steel.

Korea

Which energy vectors are currently used for the processes in question (electricity, fossil fuels, bioenergy, etc.)?

In 2019 Korean Steel production was approximately 71 MT, which was 6th overall globally. The apparent steel use per capita in 2019 was 1 039 kg, which ranked 1st globally. The ratio of the domestic steel production between the integrated steel route (BF-BOF) and the electric arc furnace route was approximately 70% (49.7 MT) to 30% (21.3MT), respectively. The energy consumption of the integrated steel route and the EAF steel route is given below.

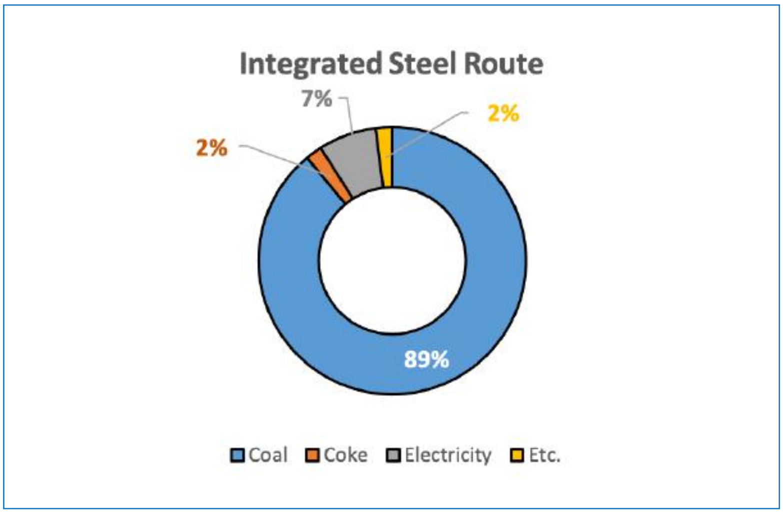

Fig. 1. Integrated Steel Route: Energy consumption in %

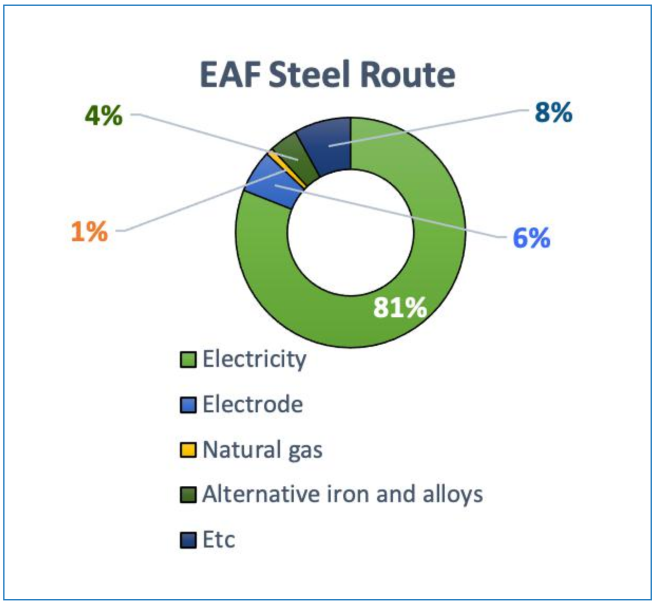

Fig. 2. Electric arc furnace: Energy and Alternative iron and alloys (e.g. scrap iron and steel) in %
Source: 2022 data for Fig. 1 and 2 were obtained from the Korea Iron and Steel Association and are reproduced with permission.

As can be seen, the use of carbon-based reductants accounts for more than 91% of the total energy use (10.43 GJ) in the integrated steel route, which is approximately 9.4 GJ/t. Bioenergy or so-called carbon-neutral energy sources are not actively incorporated into the steel manufacturing processes in Korea. There have been commercial scale trials within specific BF and EAF operations, but these resources are not generally used, yet.

How dependent is the decarbonisation of the industry on the energy- and electricity mix of the respective countries or regions and on current regulations?

Currently being assessed.

Which are the principal elements of the value chain? (the economy of the industry, including costs).

Currently being assessed.

Is recycling of scrap metal already a major factor in iron and steel production and what about the availability of the needed quantities of scrap metal in different countries?

Scrap availability and consumption in Korea is provided in the Table below.

Division	'14	'15	'16	'17	'18	'19
Domestic scrap	24 065	23 359	21 604	24 205	23 841	22 920
Imported scrap	8 000	5 750	5 850	6 160	6 450	6 500
Supply	32 065	29 109	27 454	30 365	30 291	29 420
Self sufficiency	75.1%	80.2%	78.7%	79.7%	78.7%	77.9%

Table 1. Scrap supply for the Korean steel industry (Units: kt)
Source: Korea Iron and Steel Association. Reproduced with permission.

Division		'14	'15	'16	'17	'18	'19
Imports	**Japan**	3 830	3 130	3 420	4 000	4 040	4 018
	%	47.9	54.4	58.5	64.9	62.6	61.8
	US	1 640	970	890	520	870	1 108
	%	20.5	16.9	15.2	8.4	13.5	17.0
	Russia	970	880	1 030	1 020	930	712
	%	12.1	15.3	17.6	16.6	14.4	11.0
	Others	1 560	770	510	620	610	662
	%	19.5	13.4	8.7	10.1	9.5	10.2

Table 2. Major scrap import countries into Korea (Units: kt)
Source: Korea Iron and Steel Association. Reproduced with permission.

Social network analysis of the scrap trade indicates most of the scrap to be from Japan, the US, and Russia. Considering the logistics and costs associated with the scrap trade, diversification of the import countries is not likely but could be an option if the costs are competitive. Consumption of scrap is expected to increase, considering the near-term goals for CO_2 emissions control. The integrated steelmakers expect to increase the scrap utilisation in the hot metal ratio to above 25% from its current level of approximately 18% in the near term (2025). Assuming that the production is constant at approximately 49.7 MT, the integrated steelmakers will need approximately 3.5 MT of additional scrap to meet demand. However, at current cost levels, demand for high-quality scrap could exceed supply. Scrap suppliers could supply higher quality scrap in sufficient quantities, but this would require additional handling, increasing costs. Removal of tramp elements such as Cu, Sn, Zn, and others is costly, but the steel producers may not be willing to assume the costs of the higher quality scrap, even though this would be necessary in order to produce the required high-quality flat products.

According to recent publications on the expected scrap supply and quality, Cu will especially be a problem element that needs to be addressed since there will be an eventual accumulation of this element in the scrap supply lowering the quality of scrap. Current refining technologies are still inadequate to remove this element from scrap steel and therefore it is usually diluted. However, greater utilisation of scrap will inevitably increase the Cu content in steel and ways need to be found to remove it prior to the steelmaking operations. EAF steelmakers typically producing long products will also need to integrate more high-quality scrap from the integrated steelmakers in order to be in a position to dilute the low quality scrap.

Considering the costs and availability of scrap and other necessary products, there will likely be an increase in the utilisation of direct reduced iron. Depending on the cost ratios and the operational efficiency, it is expected that overall a 10% scrap mix should be possible in the current state of operations.

Remarks: The sustainability of the steel industry in general requires collaboration between the respective parties. Hydrogen production using renewable energy sources needs to be readily available to the global community at a reasonable price. Developing countries should be in a position to use sustainable energy sources at lower costs than the already developed countries and ensure that the hydrogen-based steel route is widely accepted in those developing countries with the most urgent need for decarbonised steelmaking. It is imperative that these countries with sustainable energy resources attempt to provide the global community with cost-effective and green hydrogen.

Sweden

What is the energy balance (energy sources used)? And the GHG-intensity, compared to other countries?

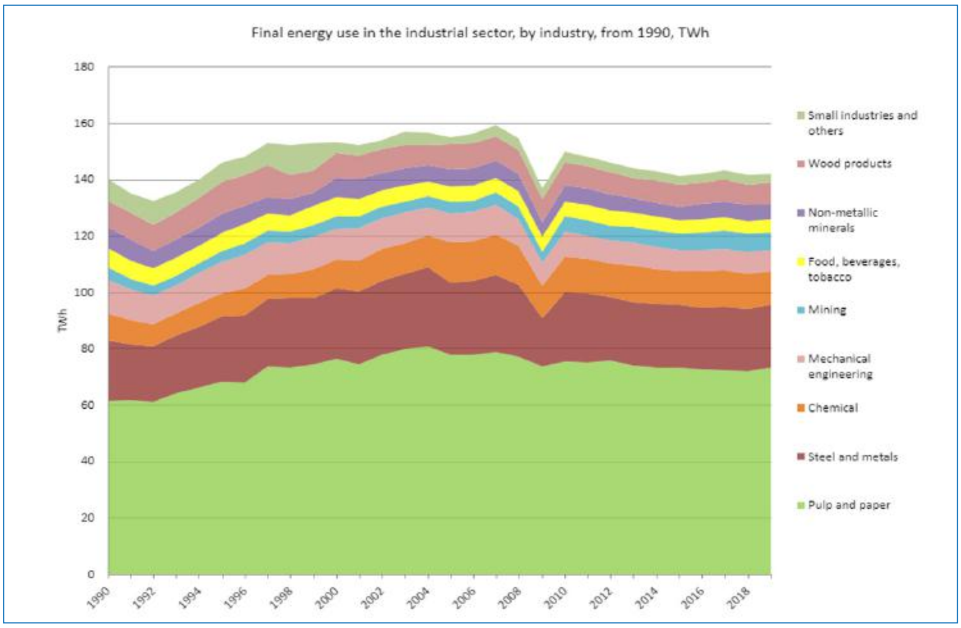

Fig. 1. Total final energy use in the industrial sector, by industry, 1990 -2019
Source: Swedish Energy Agency and Statistics Sweden. CC BY-NC. [energy-in-sweden-facts-and-figures-2021_210205-1.xlsx (live.com)] (tab 4.2)

Three industries account for a large share of energy use. The pulp and paper industry, iron, steel and metalworks, and the chemical industry together accounted for around 75 percent of the industrial sector's final energy consumption in 2019. The engineering industry and the timber industry accounted for a good five per cent each of final energy consumption and other industries accounted for 14 per cent. Other industries include the mining industry, the food industry, the textile industry, the graphic industry, the agricultural and stone industries (manufacture of glass, cement and lime), as well as those industries that are usually classified as smaller industries.

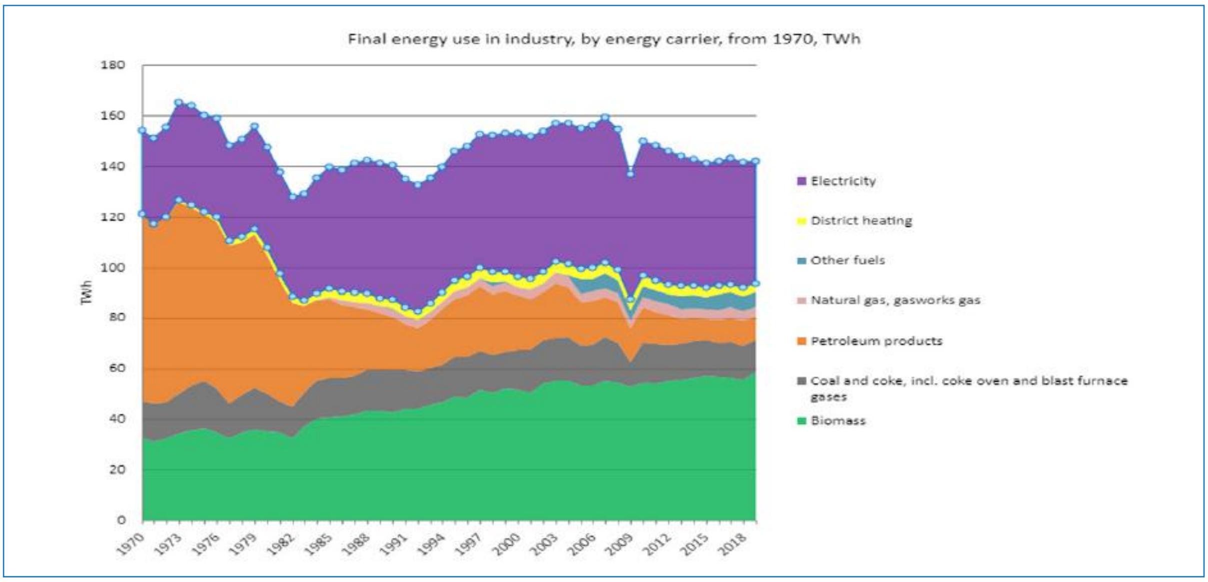

Fig. 2. Total final energy use in industry, by fuel type and other energy vectors
Source: Swedish Energy Agency and Statistics Sweden. CC BY-NC. [energy-in-sweden-facts-and-figures-2021_210205-1.xlsx (live.com)] (tab 4.1)

The pulp and paper industry accounts for more than half of the final energy use within the industrial sector. Mainly biofuels and electricity are used in pulp and paper industrial processes. The use of fossil fuels; such as natural gas, petroleum products, coal and coke; is decreasing. However, their use is still extensive, especially within the iron- and steel industry.

- **Steel industry** (except mining) energy consumption: 22 TWh in 2019

  The energy used are:

Coal incl Coke gas	**11.4**
Electricity	7.5
Gas	2.6
Oil	0.5

  Total emissions in 2019 from the steel industry in Sweden are 6 MT of CO_{2e}, representing 12% of total GHG emissions in Sweden. 85% of that is due to the reduction process of iron ore to iron, mainly in blast furnaces. 12% is from fuels for heating and heat treatment and 3% from raw materials and others.

- **Mining industry** (except cement industry)

  Energy uses around 6 TWh, mostly electricity

  Total CO_2 emissions in 2019 from the mining industry (excluding the cement industry) in Sweden: 1 MT

Are the best available low-carbon technologies used/considered?

Swedish steel industries have highly efficient production processes, and the current best available techniques are used. Swedish steel products have an internationally low climate footprint. But still mainly based on blast furnaces with coal. A high degree of electrification, for example using electric arc processes, means lower life cycle emissions, and specialised products will entail increased resource efficiency when they are used.

Is there a roadmap to decrease GHG emissions for 2030 - 2050 If yes, what are the intermediary steps?

Yes, it is the Climate Roadmap for a fossil-free steel industry (climate-roadmap---summery.pdf (jernkontoret.se))

The Swedish steel industry presented a vision for 2050; “Steel shapes a better future”, with the purpose that we shall have a fossil-free and competitive steel industry in Sweden in 2050.

The most important potential solutions today are:

- The development of brand-new process technologies which apply hydrogen to reduce iron ore to iron instead of using coal and coke in traditional blast furnaces (the Hybrit and H2 Green steel projects). The technology requires a large amount of fossil-free electricity. The idea is that this will to a large extent come from wind power combined with hydrogen storage to avoid high-cost periods of electricity. Yet, a large share of the Swedish electricity mix will be from hydropower and nuclear power.

  At the current level of production, the technique implies an increased need for about 15 TWh of electricity. Decided plans for a new green steel production facility mean another increase of 12-25 TWh of electricity around 2030.
- The development of biocoke for the reduction of iron ore for powder production and for scrap melting processes. This requires access to biomass for biocoke at a comparative cost.
- Electrification of heating and heat-treatment processes. This is mainly possible for heating at temperatures below 1 000°C.
- The use of bio-based gas or hydrogen as a substitute for the fossil fuels used in heating and heat-treatment processes where electrification is not an alternative. This requires access to a fossil-free gas of equivalent quality as natural gas and liquefied petroleum gas. The estimated need is at least 2-3 TWh at the current level of production.

Conditions for success

- Funding for long-term research and knowledge development.
- Secure supply of fossil-free electricity to competitive costs.
- Electricity is an enabler, increased needs in the future.

- Development of an increased supply of biobased fuels and biochar.
- More efficient permit processes for investment in new technologies.
- Holistic view in the political arena with the aim for industrial growth.

Mining Industry

The roadmap for a competitive fossil-free mining and minerals industry in Sweden (fossilrapport-2019-sammanfattning-eng.pdf) is currently under revision and a new version will be published in late 2021.

One of the most important ways to achieve fossil-free operations is via electrification.

Supported by biofuels where electricity cannot be used. Machines and transportation within mining operations can be fossil-free by 2035.

Further automation and digitalisation will reduce energy needs and result in a more efficient and optimized vehicle fleet.

A fossil-free mining and metals sector will need to use more electricity and bioenergy than it does today. As a complement to the roadmap development, a rough estimate of these requirements has been attempted and is now also updated during 2021. Compared to today the industry's new estimates (to be published in late 2021) are that a fossil-free sector in 2045 would require around 70 TWh of electricity and around 3 TWh of bioenergy.

The most important factors where the public sector can make a difference are:

- Effective and fair permitting processes so that new and necessary, climate-efficient investments can be made possible.
- A holistic approach to political decision-making that avoids suboptimal instruments that weaken competitiveness and make fossil-free operations more difficult.
- Investments in research and development for fossil-free production processes and CCS, including test and demonstration facilities.
- Conditions that facilitate access to fossil-free electricity at a low total system cost and high reliability.
- Access to bioenergy at a competitive price.

Fossil-free electricity is the key enabler to the decarbonization of the steel, mining and iron and industry.

The total use of electricity in Sweden has been almost constant for more than 30 years, around 140 TWh. But now a dramatic increase is expected. Many studies of expected electricity needs have been made by different stakeholders. The outcome differs but all of them indicate a strong increase in the next 20-30 years.

The decarbonisation of the steel and mining industry assumes lots of hydrogen through electrolysis with fossil-free electricity and increased electrification processes. The steel and mining industry alone expects in total an **increased demand around the year 2045 of between 60 – 100 TWh** electricity depending on high-level min or max scenario.

Is the implementation of low-carbon technologies helped by the government?

The Swedish Energy Agency is financially supporting new technologies in the industry through the programme Industrial Leap. Flying start for the first investment in a new industry venture (The Industrial Leap) (energimyndigheten.se)

The programme has supported the construction of a pilot plant for fossil-free steel production (the HYBRIT project) that was ready in 2020. The support from the Swedish Energy Agency covers 25 per cent of the cost for the actual pilot plant, and higher percentages of the different scientific projects.

The Swedish Energy Agency is also supporting the construction of a high-pressure underground lined cavern for the storage of fossil-free hydrogen.

Yet, since several automotive manufacturers have targets of climate neutrality, they need climate-neutral steel. Thus, it seems likely that both Hybrit and H2 Green steel will have customers for their climate-neutral steel once it is available. This is promising since economic sustainability obviously requires that the customers (rather than the governments) pay for climate-neutral products in the long run. Also, the additional price required on end products (e.g., a car) for climate-neutral steel should be less than 0.5%.

The budget bill 2022 includes a proposal for economic support for biogas production.

Are there incentives for carbon capture, utilisation, and storage? How?

There are no general incentives for investments outside of public financing of research and education at universities.

If relevant, what about recycling?

Metals are 100% recyclable. There is a well-functioning market for metal scrap and for well-established technologies to use recycled metal in the production of new products. Policies concerning recycling need to be adapted to different material characteristics. For metals, there is no need for policy measures.

Are there some case studies or best practices you would like to share?

In Sweden, more than one billion SEK (about 105 million Euros) is invested each year in steel research. A major part of this research is carried out within the different steel companies.

Three important and world-leading projects are on the way:

HYBRIT (Hydrogen Breakthrough Ironmaking Technology) is set up to develop a fossil-free value chain for iron and steel production using fossil-free electricity and hydrogen for direct reduction with the aim of replacing traditional blast furnace-based technology. The goal is a unique value chain, from mine to fossil-free steel. (Hybrit (hybritdevelopment.se))

H2greenSteel will be a fully integrated greenfield fossil-free steel plant with the aim of bringing emissions down to zero. The technology is more or less the same as HYBRIT: direct reduction with hydrogen and electric arc furnace.

(H2 Green Steel)

Höganäs AB is the world's first plant for demonstrating, on an industrial scale, fossil-free steel metal powder production based on the gasification of biomass by using new technologies. The plant gasifies biomass to energy gas which will replace natural gas in Höganäs AB's metal powder production. Cortus Energy's unique gasifying process Woodroll® is gasifying the biomass.

(Unique plant for renewable energy gas and bio-coke | Höganäs (hoganas.com))

Ovako is initiating the construction of a fossil-free hydrogen production facility to be used as a fuel in heating processes. Cooperation with the transport sector will make hydrogen also available for fuel-cell trucks.

(First in the world to heat steel using hydrogen - Ovako)

LKAB is Europe's leading mining and minerals group, wholly owned by the Swedish State. LKAB's strategy paves the way for zero carbon dioxide emissions from their own processes and products by the year 2045 and secures the company's operations beyond the year 2060.

LKAB is facing the biggest transformation in the company's 130-year history, which could become the biggest industrial investment ever in Sweden. The strategy creates unique possibilities for LKAB and the Swedish industry to take the lead in a necessary conversion.

The strategy consists of changes in three major areas:

- New world standard for mining. Through digitalisation, automation, electrification, new operation methods and carbon dioxide-free production we will set a new world standard for mining.
- Carbon dioxide-free sponge iron with hydrogen technology. Through the shift from iron ore pellets to carbon dioxide-free sponge iron LKAB will take an important step forward in the value chain, increasing the value of its products while giving the customers direct access to carbon dioxide-free iron for steel production.
- Extract critical minerals from mine waste. Using fossil-free technology LKAB will extract strategically important minerals and phosphorus for mineral fertilizers from today's mine waste.

https://www.lkab.com/en/about-lkab/lkab-in-brief/strategy-and-goals/

Sustainable Underground Mining project (SUM) is a test bed project for an integrated, efficient and carbon-free mining system. The goal is to implement carbon dioxide-free and autonomous mining in a physical as well as virtual test mine, and then scale up and introduce the mining methods in LKAB's underground mines in Kiruna and Malmberget. The project has financial support from the Swedish Energy Agency.

SUM industrial collaboration strengthened with the addition of a new partner (lkab.com)

ReeMAP Industrial Park is to become a centre for the chemical engineering industry in northern Sweden which extracts tomorrow's resources using innovative technology. During the processing of iron ore, by-products are created. These by-products, so-called tailings, are deposited in tailings ponds. These tailings sands contain valuable minerals such as phosphorus, rare earth elements and fluorine. In the ReeMAP project, LKAB wants to develop the technology that will allow us to utilize these minerals and convert waste into valuable resources.

ReeMAP Industrial Park | LKAB Minerals | ReeMAP project (ree-map.com)