Deep decarbonization pathways in ARGENTINA

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Lessons from the EU-funded research project IMAGINE

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Introduction (1/2)

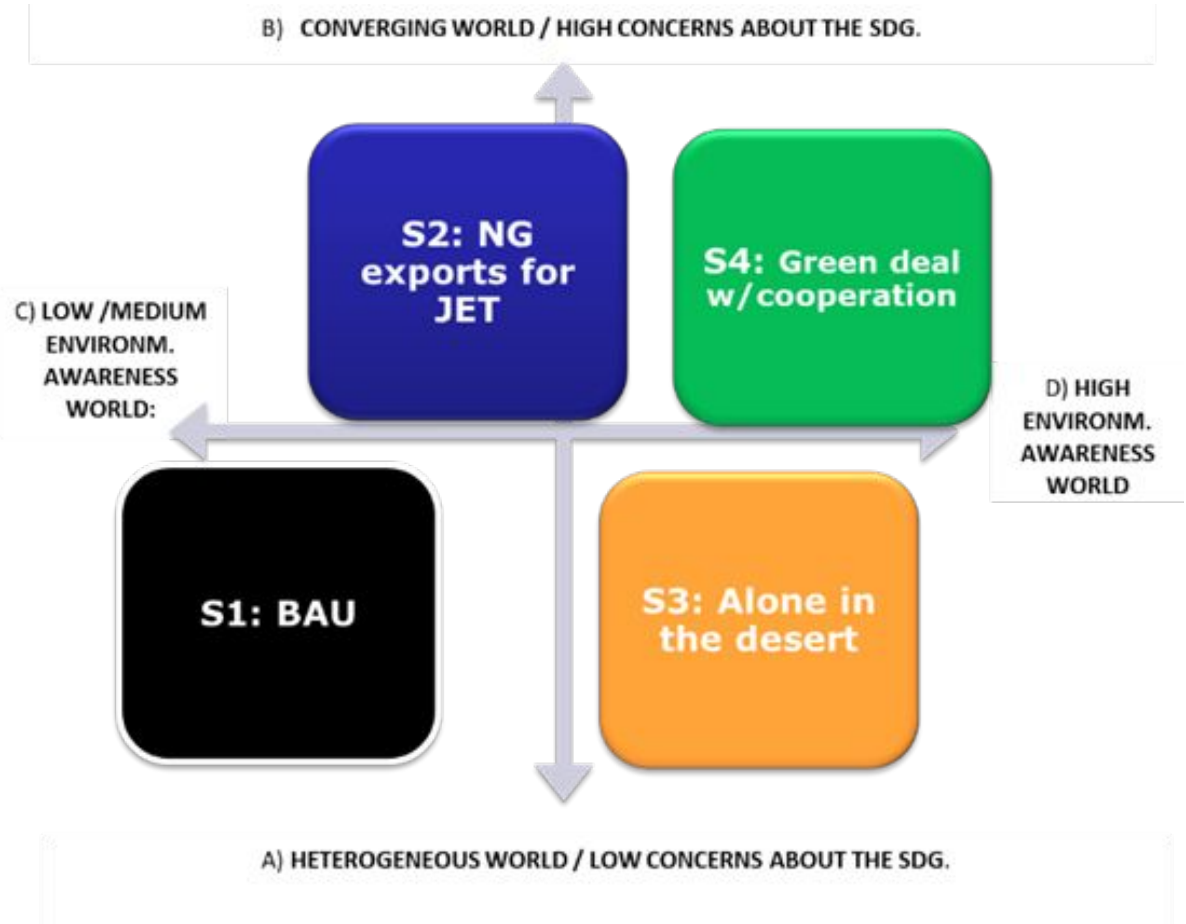
This work takes place in a context where:

- The national economy is characterized by high need of foreign currency and is strongly linked to the energy sector performances.
- Natural Gas (NG) plays a major role in the Argentinian Energy system, representing an important share in of the final consumption (62% households, 58% industries, 11% in Transport). Moreover, huge Non-Conventional Natural Gas Resources were found recently ((67 % of current Argentinean proven reserves of NG), from which 6 trillion m3 are technically exploitable.
- Natural gas is increasingly considered as a transition fuel by many institutions. There is still a significant NG worldwide demand by 2030 and 2050 even in Net Zero Scenarios.
- Argentina's and other countries' neutrality targets will strongly depend on domestic and international enablers, which as defined by the IPCC are the conditions that enhance the feasibility of adaptation and mitigation options, including finance, technological innovation, strengthening policy instruments, institutional capacity, multi-level governance and changes in human behavior and lifestyles (IPCC, 2022). Accessing to those international enablers will impact the mitigation capacities.
- in 2022, Argentina submitted its a long-term strategy (LTS)) to 2050 to the UNFCCC that includes a target to make efforts to reach GHG neutrality by 2050, with a path compatible with human development needs, social inclusion, and poverty eradication; which demands higher international cooperation in terms of technology non-reimbursable funds for developing countries. This LTS highlights the idea of common but differentiated responsibilities. Argentina had previously announced its aim to set a net zero CO_2 target ("carbon neutrality") by 2050 in its second NDC submitted in 2020.
- In its last NDC, Argentina has set an unconditional target of not exceeding 349 $MtCO_2e$ in 2030. This target covers all sectors.

Introduction (2/2)

In this context and under the EU-funded research project IMAGINE, we defined a set of four development pathways :

- **The Business as Usual (BAU) :** this scenario illustrates the current policies mitigation actions. It also includes the preservation of currents trends regarding natural gas exploitation, there is no natural gas expansion due to business and political risks. It is not possible to reach GHG neutrality before 2050 in this scenario, due to limited action on hard-to-abate sectors.
- **The "NG exports for JET" (SCE2) :** this scenario integrates the same mitigation actions as the BAU, plus the additional ones to engage on just energy transition. NG production and exports increase, to finance the JET and to improve the environmental quality of the energy sector within the country.
- **The "Alone in the desert" (SCE3):** this scenario integrates more ambitious climate actions than the SCE2. There is no natural gas exports. There is a lack of international cooperation (international technology transfer and international financial flows) and increases in the national external debt.
- **The "Green deal with cooperation" (SCE4):** this scenario has a similar climate ambitions than the SCE3. SCE4 differs from from more international cooperation & soft-financing of energy industries activities. This allows to produce and export green hydrogen and ammonia (international technology transfer and international financial flows).



Rationales and research questions

1) Which are the potential impacts of a Net Zero Strategy that includes total elimination of NG (consumption and exports) for both the total Argentinean energy system and the macroeconomy, in contrast to other energy scenarios?

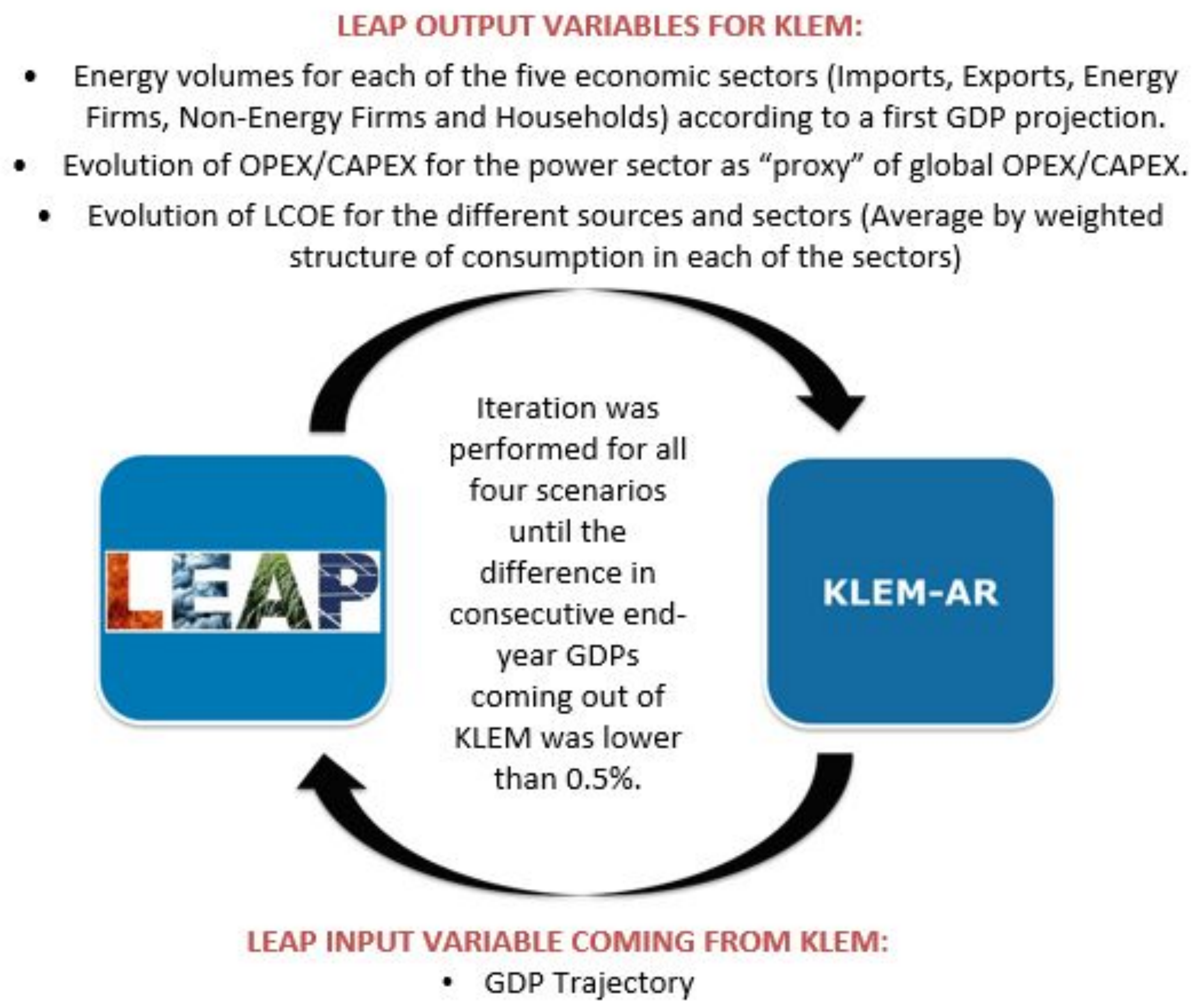
2) How will international enablers facilitate the Argentinian decarbonization and development strategy?

- The comparison of BAU with SCE2 will inform on the feasibility of financing the just energy transition thanks to natural gas export rents and improve economic development.
- The comparison of BAU with SCE4 will inform the additional transformations required to reach net-zero GHG and development objectives by 2050.
- The comparison of SCE3 with SCE4 will inform the economic possibilities allowed by the international cooperation in a high environmental awareness world.
- Comparison of SCE3 with SCE2 / SCE4 will inform on economic impact of high environmental commitments/ambitious without international cooperation.

Other key country-specific questions aim to be informed by this work:

- What are the main emitting sectors and what sectors should be particularly address if we include all greenhouse gas emissions in the carbon neutrality target?
- How could this work support the revision of national development and climate policies and future UNFCCC's commitments?
- What key global and sectoral transformations must be considered to enable national Paris-compatible pathways?
- What are the key international enablers and cooperation needs for these sectoral transformations?

Modelling architecture & improvements



Emissions perimeter: Due to analytical limitations, this set of scenario does not cover GHG emissions related to the waste sector and to LULUCF emissions.

According to Argentina's 4th BUR, in 2018 ENERGY accounted for 51% of emissions, followed by AFOLU 39%, IPPU 6% and waste 4%..

About KLEM (Top-Down Model): It computes macroeconomic trajectories under constraint of exogenous energy system. It models capital (K) and labor (L), energy (E) and the remainder of the economy ('materials' M). Growth is driven by exogenous labor supply/productivity and share of GDP that is devoted to investment

About LEAP (Bottom-Up Model): represents a detailed energy system of a country to formulate nationally consistent energy plans. It covers energy demand, transformation, and supply and can be used to account for both energy and non-energy related GHG emissions and sinks.. It can develop full back casting scenarios that ensure consistency in the energy choices (available technologies, resources, transformation, demand, etc.) towards low-carbon transition allowing for quantification of energy volumes, infrastructure needs and cost accounting.

For more details about modelling framework, see:

- Report on Modelling Improvements (2024). Fundación Bariloche. Specific publication forthcoming.
- Soummane, S., Ghersi, F., Lefèvre, J. (2019). Macroeconomic pathways of the Saudi economy: The challenge of global mitigation action versus the opportunity of national energy reforms. Energy Policy 130, 263–282.
- Le Treut, G., et.al. (2021). The multi-level economic impacts of deep decarbonization strategies for the energy system. Energy Policy 156.

Part 1

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National overview of the deep decarbonization pathways

Nowadays, the power sector, AFOLU and passenger transport are the most emitting sectors in Argentina

The power sector, AFOLU and passenger transport are the most emitting sectors nowadays in Argentina, considering GHG emissions.

- The power sector is the most emitting sector (GHG & CO2) in Argentina due to the high reliance on gas-power plants. See slide 23 for the power generation and slide 24 for extractive activities.
- AFOLU is the second most emitting sector (GHG) in Argentina, mostly due to agricultural activities (enteric fermentation, soybean, wheat and meat production, synthetic fertilizer application): see slide 27 for AFOLU decarbonization strategy.
- For the passenger transport, this is the second most emitting sector in terms of energy-related emissions after the power sector. This is due mostly due to combustion of liquid fuels (see slide 16 for passenger transport decarbonization pathway).

Figure 1. Main indicators for 2018

Indicator	Value in 2018
GHG emissions (MtCO2)	356
CO2 emissions (MtCO2eq)	213
CO2 emissions per capita (MtCO2/cap)	5
Non-CO2 emissions (MtCO2eq)	143
Final energy consumption per capita (GJ/cap)	50
Population (Million)	44
GDP (billion $ 2010)	583
Most emitting sectors (GHG)	power, AFOLU, passenger
Most emitting sectors due to combustion (CO2)	power, passenger, residential

Stabilizing GHG emissions by 2050 while ensuring socio-economic development involves significant efforts

Figure 2. Socio-economic indicators (population, GDP per capita)

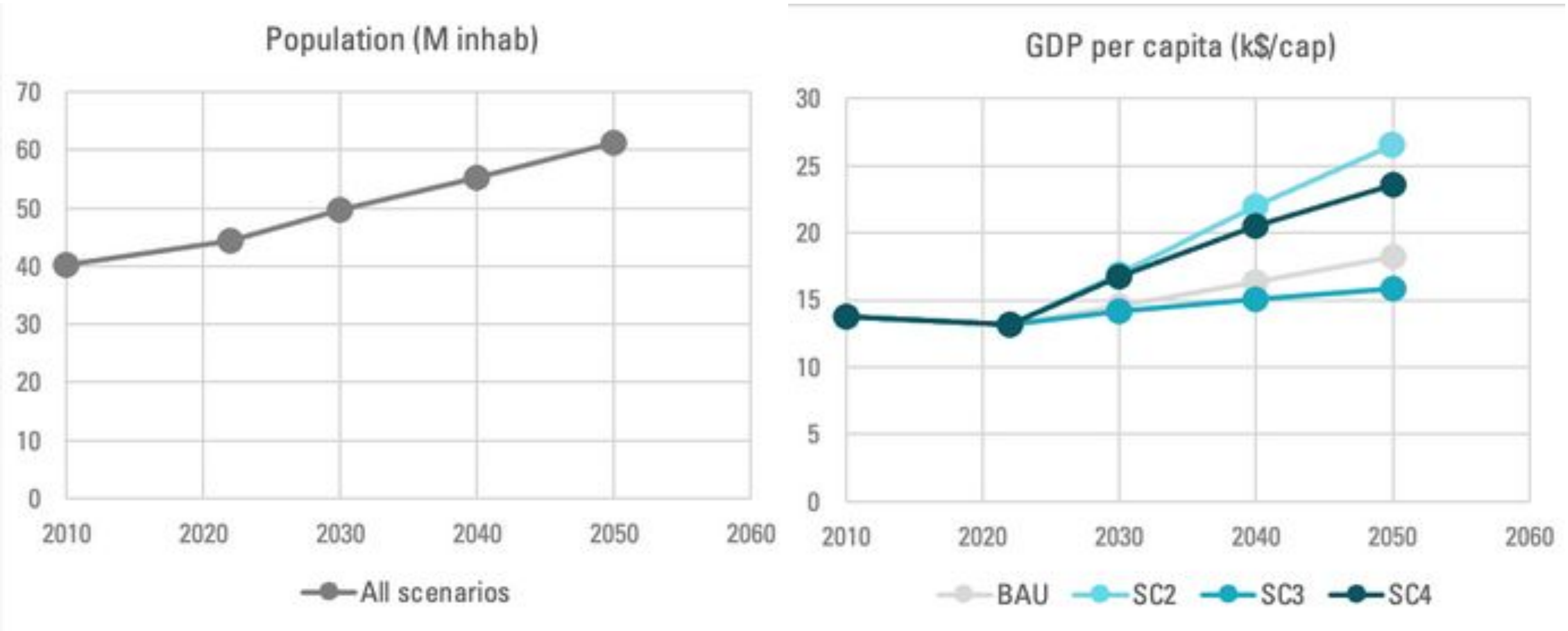
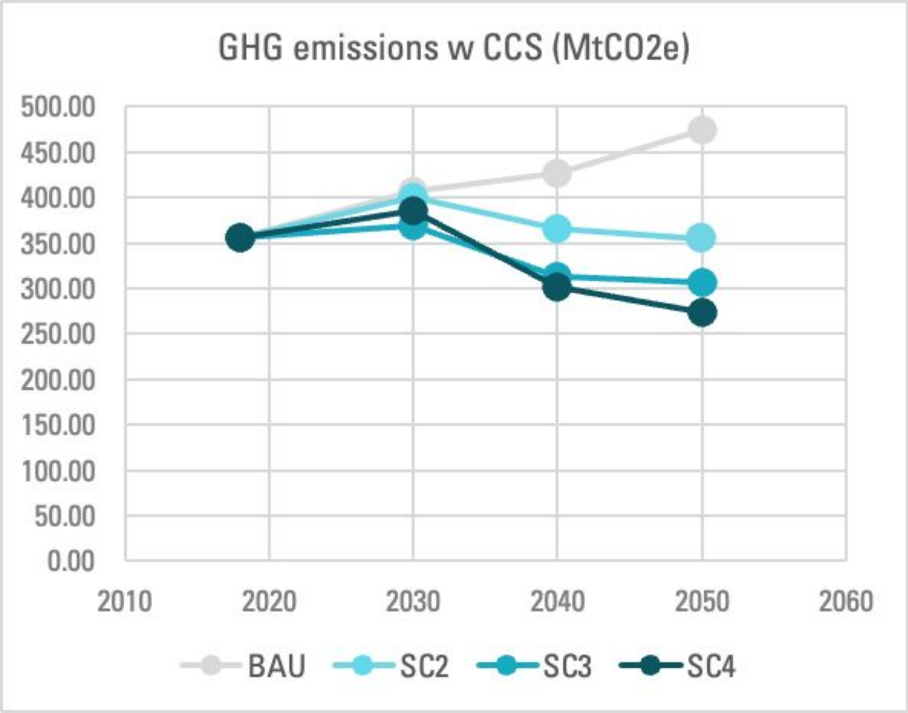


Figure 3. National net GHG emissions

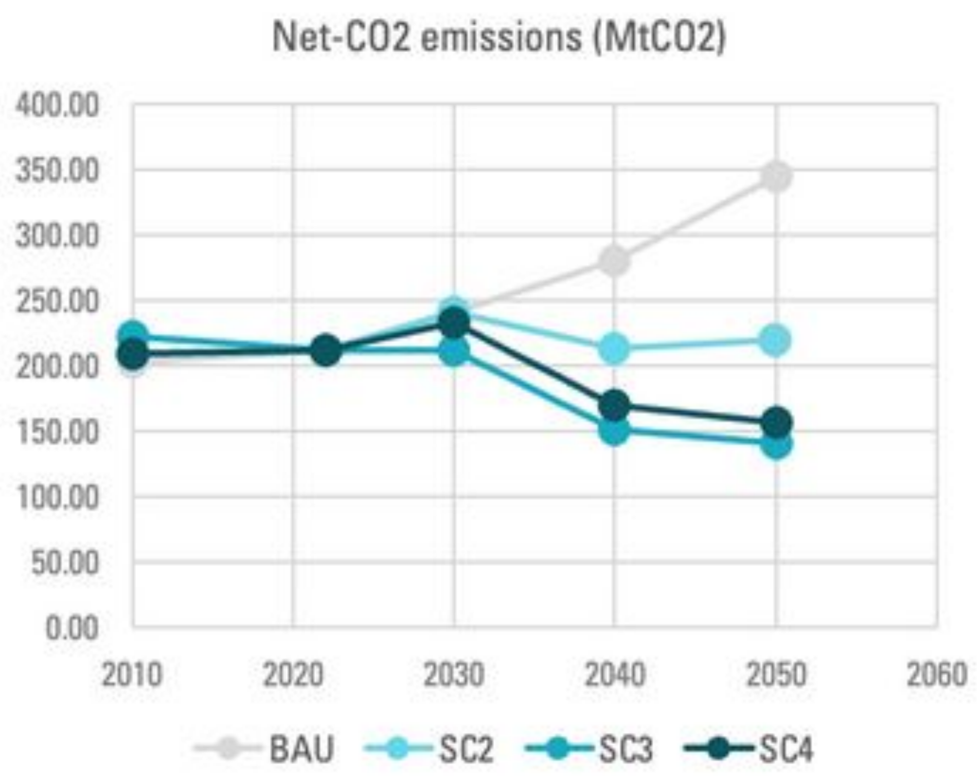


- Argentinian population is expected to grow in all scenarios from 40 million to about 61 million in 2050 and urbanization rate will increase from 91% in 2010 to 97,1% in 2050.
- The GDP per capita will increase up to $18k in the BAU scenarios and further up to $27k in the SCE4 scenario by 2050. The GDP per capita is lower in the SCE3 than in the SC4 due to lack of international cooperation.
- GDP is not an input here but an output from the KLEM model, results from the different energy revenues, either from natural exports (SCE2), green ammonia & hydrogen exports (SCE4) and the convenient financing.

- None of the scenarios reach net-zero by 2050. NDC target (349MtCO2eq) could be addressed but it requires significant efforts greatly exacerbated in high-growth scenarios.
- The SCE3 and SC4 reach lower emission levels in 2050 than the two others, with respectively 312 & 331 mtCO2eq, due to higher environmental ambitions.
- The SCE2 reaches lower levels of GHG emissions than the BAU (397MtCO2eq in comparison to 523 MtCOeq), due to a higher level of climate ambitions and a concentration of natural production mainly for exports.

Total net-CO2 emissions represent about 60% of all net-GHG emissions and could reduce 54% by 2050

Figure 4. National net-CO2 emissions



In 2018, around 75% of CO_2 emissions (excluding LULUCF) comes from fuel combustion and are mainly driven by the energy consumption and the current reliance on fossil fuels notably on natural gas. Emissions from industrial processes represent around 7% of the CO_2 emissions. Agriculture CO_2 emissions represent around 18% of the total CO_2 emissions.

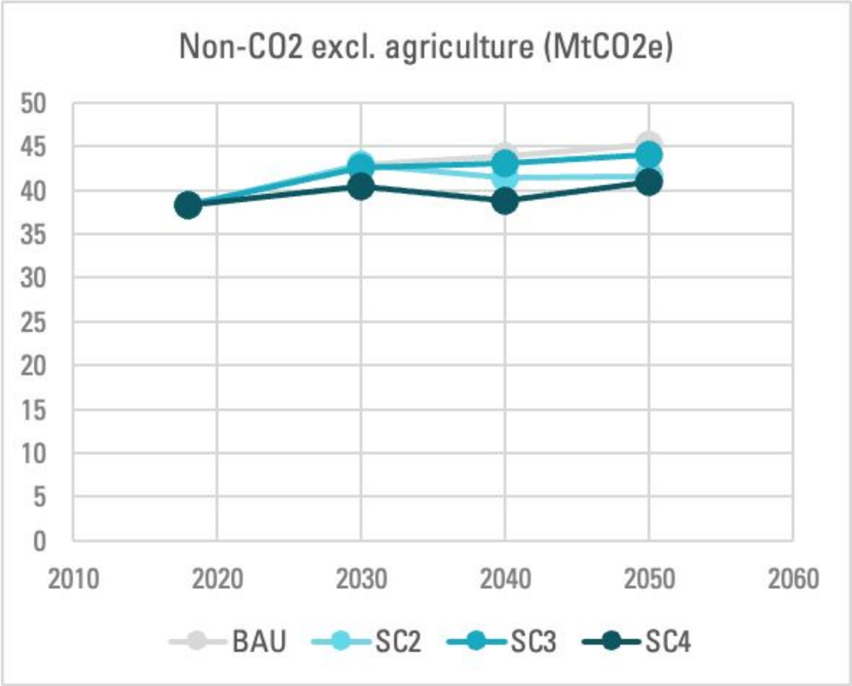
CO_2 emissions sources excluding LULUCF are expected to peak by 2030 in the SCE2 & SCE4. Emissions are only continuously increasing in the BAU, not reaching any peak. Emissions are only decreasing in the SCE3, from nowadays until 2050 because of the reduction in the economic activity.

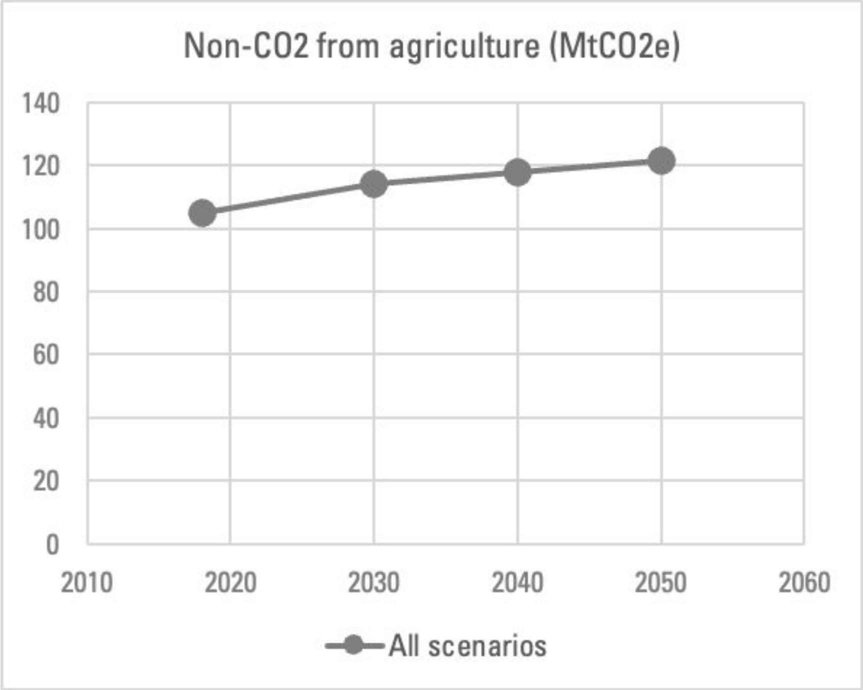
The main decarbonization drivers are :

- the development of renewable energy production (wind and solar panels), and in the case of the SCE4, even the development of green hydrogen and ammonia.
- the international cooperation (facilitating technology and finance flows) in the SCE2 & SC4.
- revenues from natural gas exports, in the SCE2 context, which facilitate the implementation of mitigation energy actions and SDGs.
- In de demand side: the use of efficient and less energy consuming technologies and fuels substitution notably in the buildings and transport sectors.
- In the power sector a strong penetration of RE technologies substituting fossil fuels
- A reduction in fossil fuels production.

Total non-CO2 emissions represent 40% of all GHG emissions

Figure 5. National non-CO2 emissions. Top: Non-CO2 emissions excluding Agriculture. Bottom: Non-CO2 emissions of Agriculture





- Non-CO2 emissions represent 40% of the national GHG emissions. In the scenarios studied here, they follow an identical trajectory. Total non-CO2 emissions increase by 13%. Non-CO2 excluding agriculture increase by 7%, and non-CO2 in agriculture increase by 16%.

- The main emission sectors in Argentina are currently energy, waste and AFOLU, the latter due to the significance of agriculture and cattle raising activities.

- Mitigation strategies for the AFOLU sector are much less developed than the energy sector.

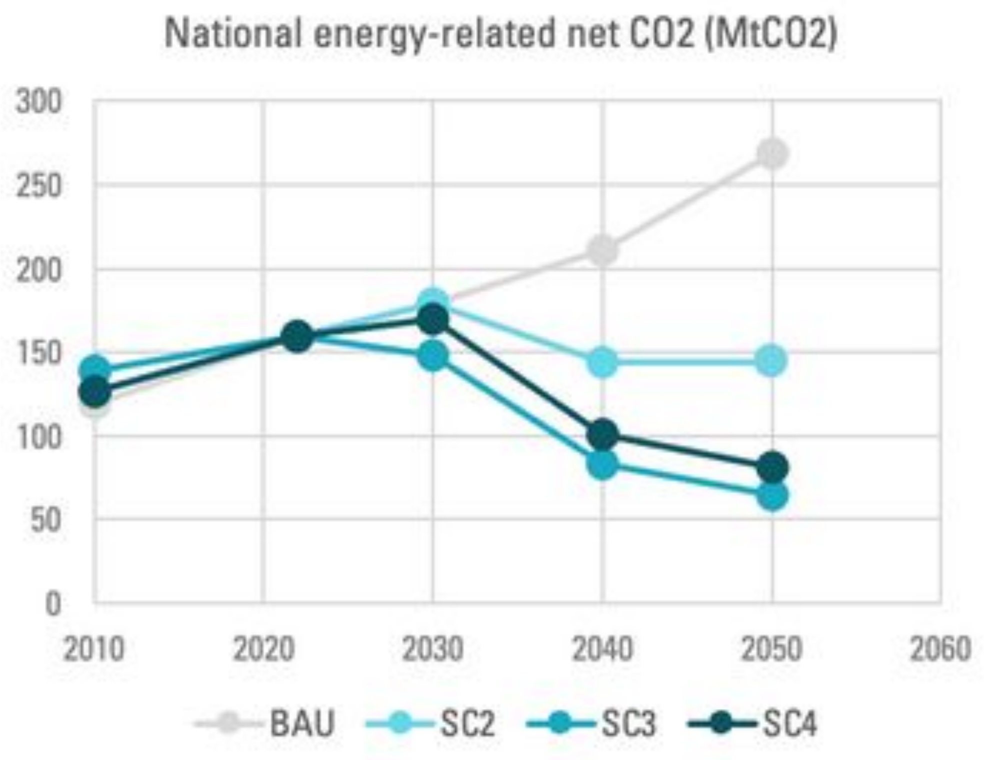
- Decarbonization scenarios, which focus on energy sector mitigation, show a BAU scenario for AFOLU sector which translates into an increase in the relative weight of AFOLU emissions in total emissions towards 2050. This is because AFOLU sector emissions are mainly what remains after the steep reduction in energy sector emissions, since these two sectors are dominant in total emissions.

- According to previous estimations, the mitigation of the remaining emissions through afforestation would require devoting several millions of hectares of land and, according to some studies, would have uncertain negative impacts and cannot guarantee an effective mitigation strategy.

- Thus, mitigation strategies within the livestock/agriculture system are key to achieve deep decarbonization targets.

Total energy-related CO2 emissions represent 40% of all GHG emissions and could be reduced by 49% by 2050 (1/3)

Figure 6. National energy-related CO2 emissions,



- Energy demand is expected to increase in the BAU & SCE2, leading to an increase of the energy-related CO2 emissions, due to a lack of climate policies.

- The high economic growth of SCE2 is not completely offset by climate actions. Those emissions will decrease in the SCE3 due to lower level of energy demand and to higher mitigation ambitions with several economic impacts caused by non compensated efforts. SCE4 has the optimistic narrative of green development substituting gas exports by ammonia trading-off some economic growth (compared to SCE2) by more climate ambition. Energy-efficiency measures also allow a reduction of the energy-related CO2 emissions in last two ones.

- In 2030, DDS SCE4 shows a lower level of energy-related CO2 emissions than the BAU, by 5%. It goes until a difference of 70% in 2050.

- Energy-related CO2-emissions represent most of the CO2 emissions, the drivers of decarbonization are therefore similar : the increasing share of new and renewable energy sources, the use of efficient and less polluting technologies.

Total energy-related CO2 emissions (2/3): Reducing energy-related CO2 emissions requires systemic and technological changes to improve energy efficiency and reduce the fuel carbon content

Figure 7. Energy consumption (GJ/capita)

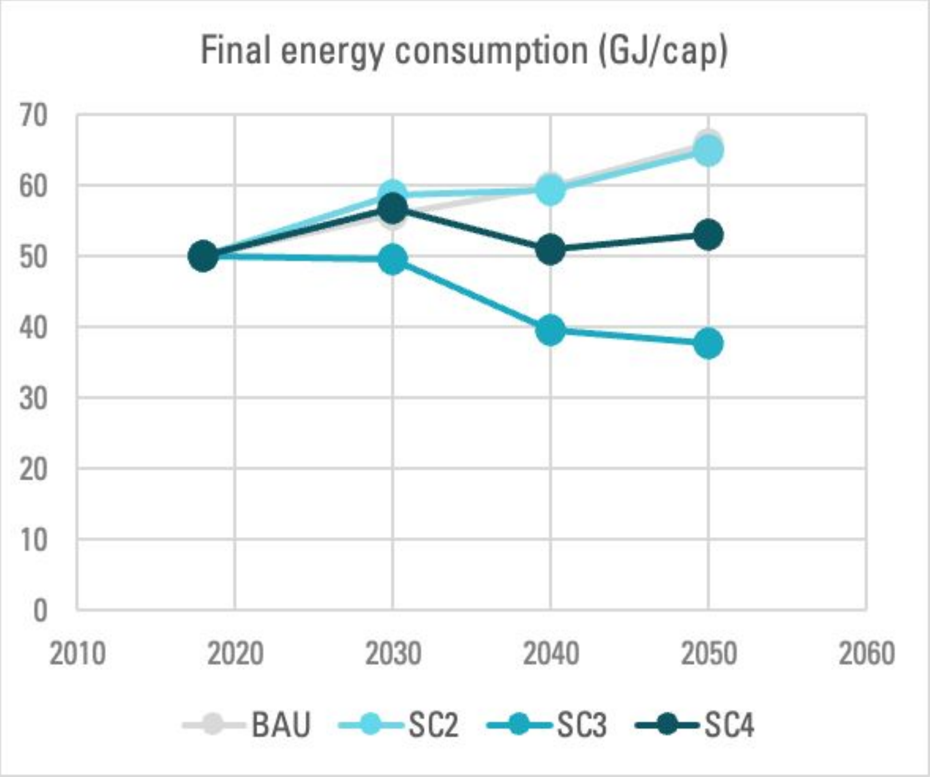
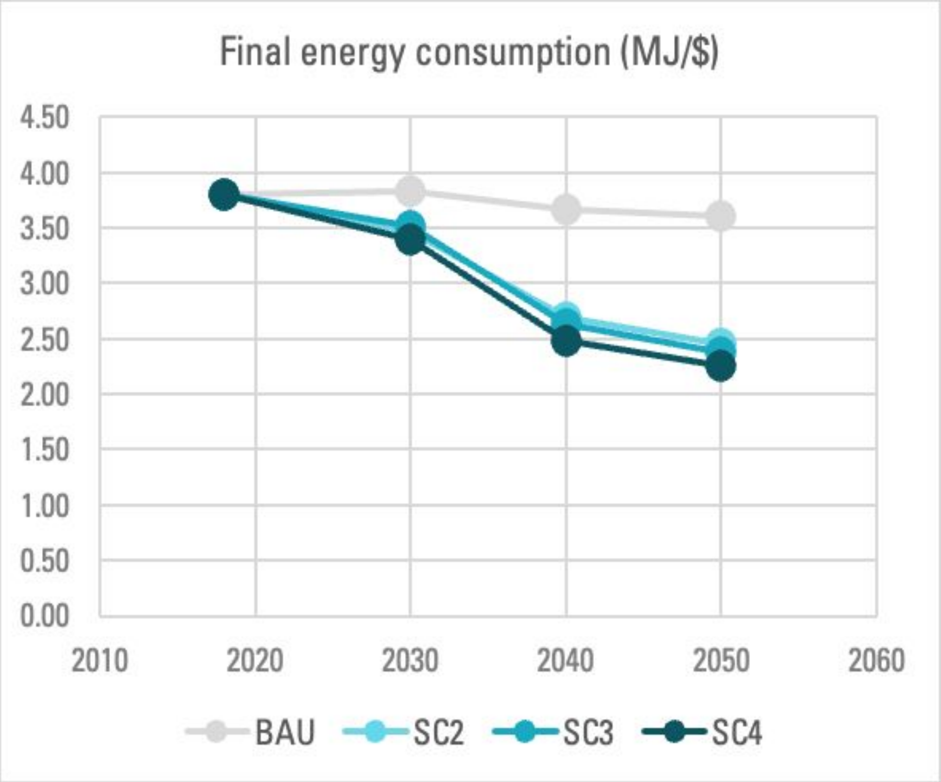


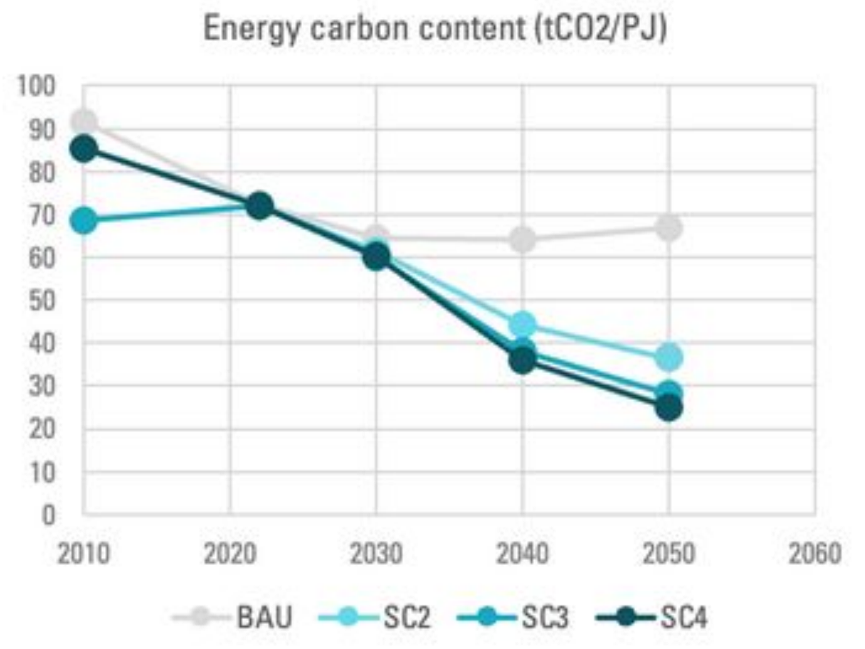
Figure 8. Energy consumption (MJ/$)



- The energy consumption per capita is increasing in the BAU & SCE2 by 2050. We observe an improvement of energy efficiency levels at the national level for the SCE4 and SCE3.

- Energy intensity reduces in all scenarios it peaks in 2018 at 3,8 MJ/$. The SCE4 has a lower level of energy consumption per capita, reaching 2,2 MJ/$ in 2050. It gets lower than the BAU by 38% in 2050.

Figure 9. Energy carbon content (tCO2/PJ)

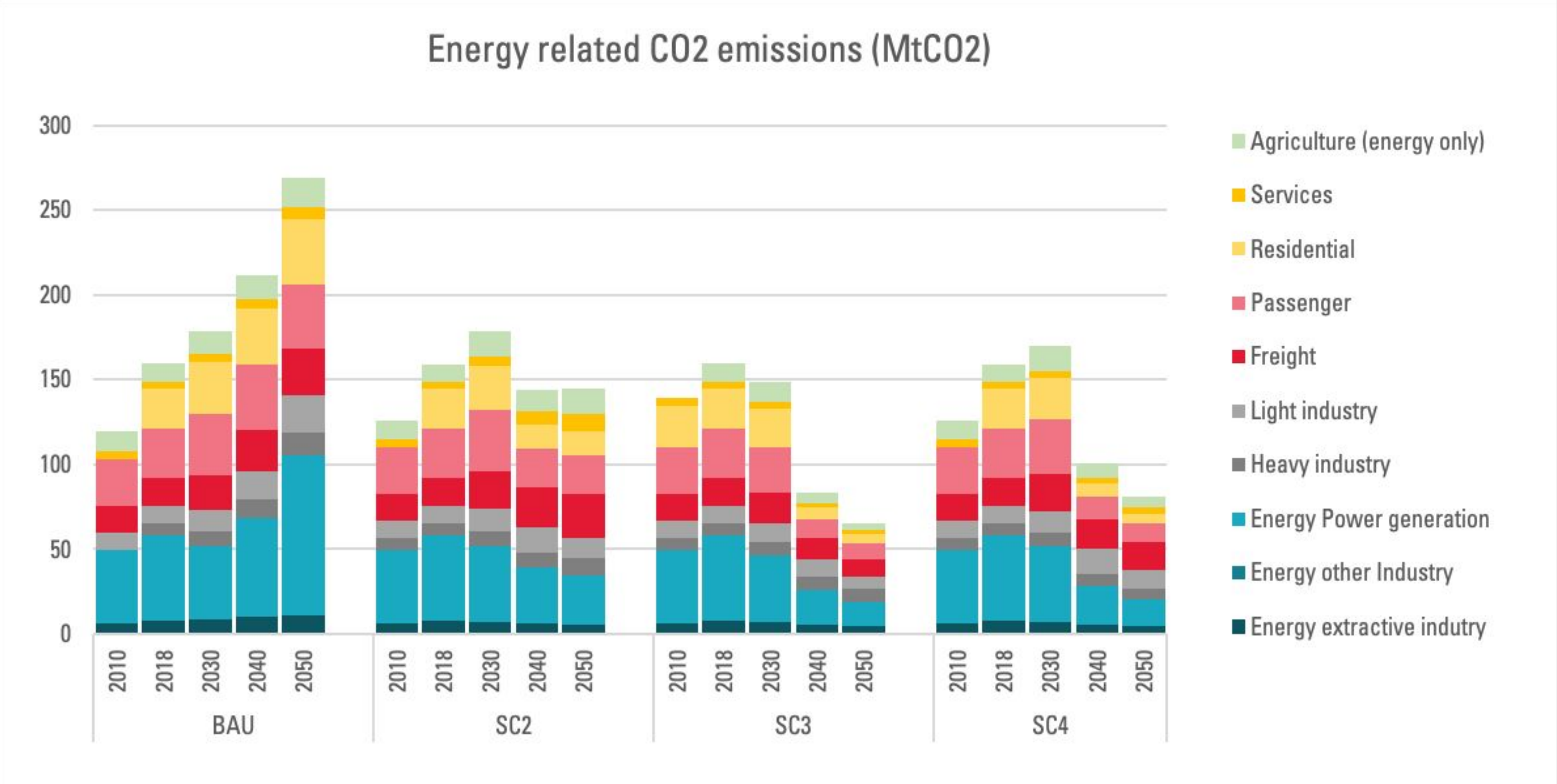


The shift towards zero-emission fuels will enable to decrease the carbon content of fuels, decreasing by 71% by 2050 (SCE4). This can be achieved notably with large-scale deployment of renewables, which will demand significant investments.

SCE4 reaches the lowest level of energy carbon content. SCE3 has relatively lower electricity consumption levels in absolute values compared with SCE2 but it leads to a penalty in terms of economic activity.

Total energy-related CO2 emissions (3/3): The key energy-related sectors for deep decarbonization are the power sector, passenger transport and residential buildings

Figure 10. Energy related CO2 emissions



- From nowadays until 2030, the sectors with the highest emissions are the power sector, passenger transport & residential buildings. To get closer to ENDC objectives, most of the efforts needs to address those sectors' emissions. This will allow to engage on a diminishing emissions curve (SCE4). This will notably be thanks to the development of renewable capacities & the decarbonization of the fuel carbon content in buildings & transports. If the climate ambitions are higher (here SCE4), emissions levels are still comparable to the BAU in 2030, with little differences.
- This difference between the situation in 2030 & 2050 shows that the transformations required in the systems are structural and may demand both time and financial resources.
- When adding international cooperation & therefore increasing the national GDP, the most impacted sectors are freight transport, passenger transport & the power sector.

Part 2

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Sectoral deep decarbonization pathways in the SCE4 scenario

Part 2.1

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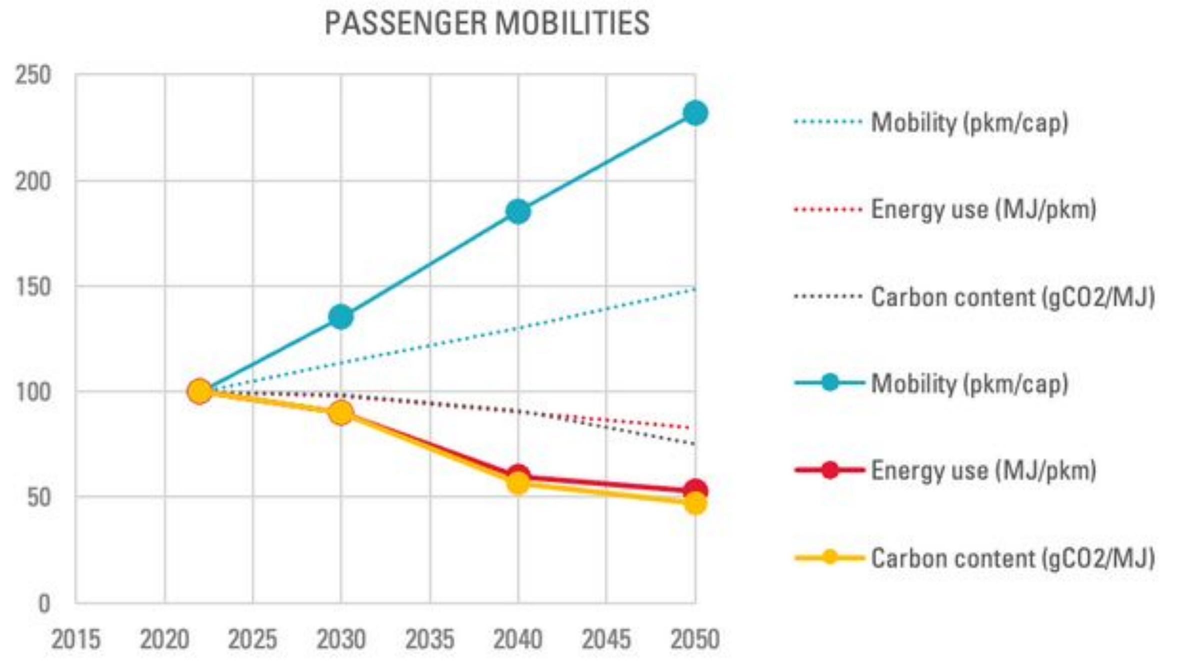
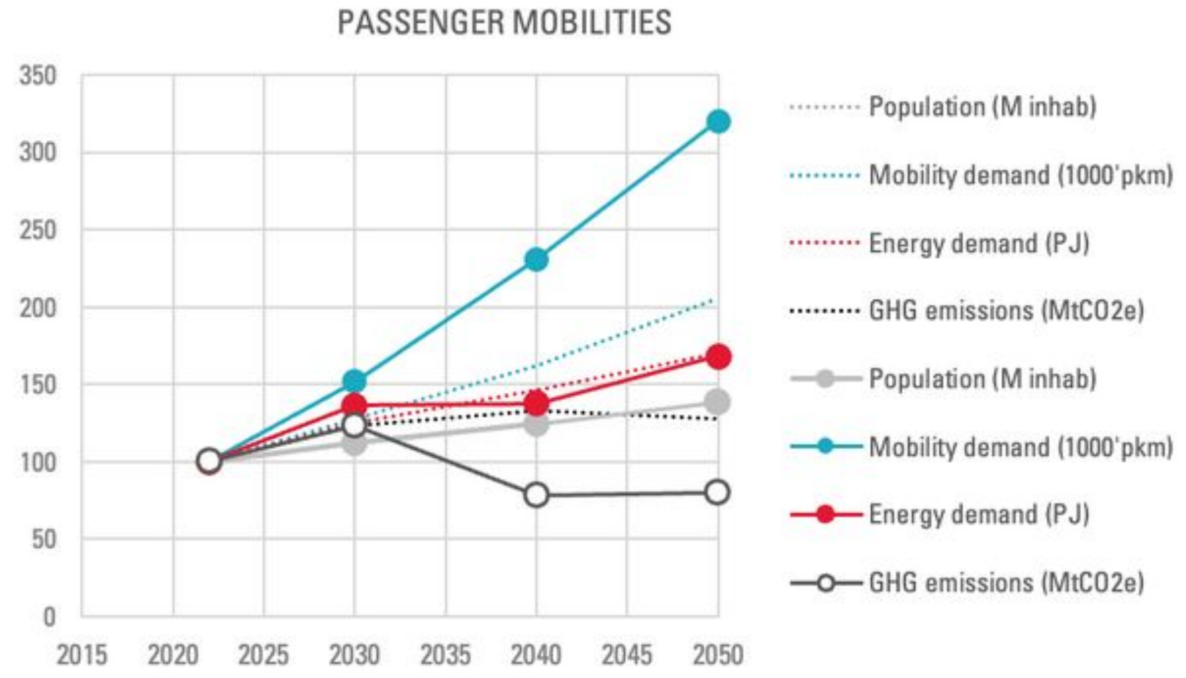
Transition of energy-related emission sectors: Transport, Buildings, non-energy producing Industries

Developing Paris-compatible PASSENGER MOBILITIES

Figure 11. Sectoral emission drivers and main aggregates (Index, 2018 base year)





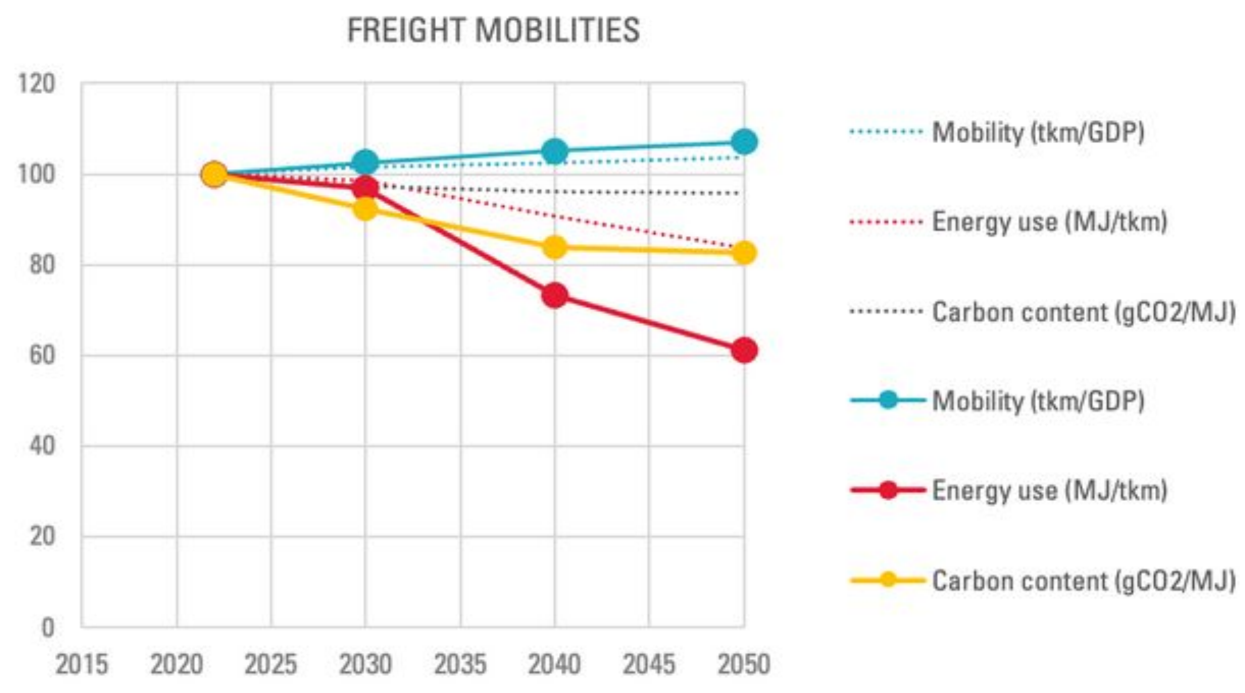
- The motorized mobility demand is expected to double in the S4 scenario reaching up to ca 15'000 pkm per capita by 2050 as people's income level increases more than two times faster than in the BAU following the GDP growth, which is reflected by more interurban and leisure-oriented mobility. The decarbonization strategy does not account yet for any measures to moderate mobility demand. However, while the current policies were already targeting by 2050 a small modal shift in urban areas from cars to bus and non-motorized mobility, the S4 decarbonization strategy reinforces this transition towards buses, trains and private 2 wheelers, driven by more urban policies to reduce car use in cities.

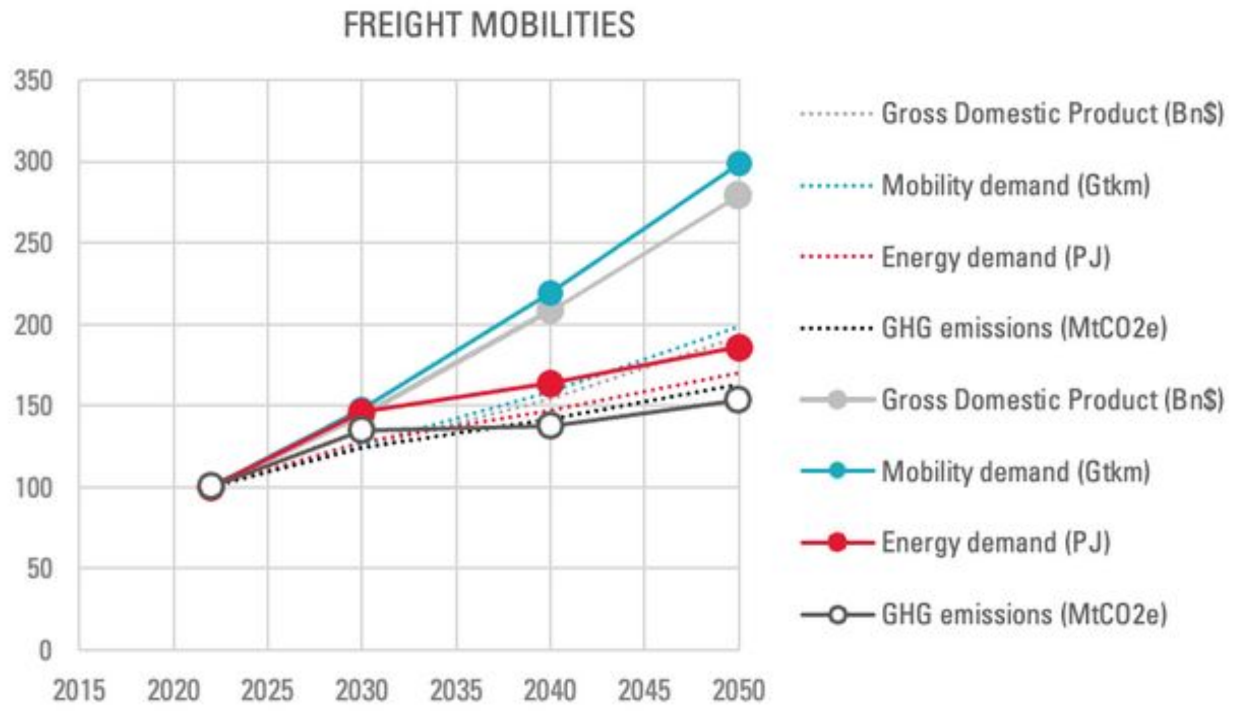
- Regarding the vehicle and fuel transition, the share of non-fossil fuels reaches up to 70% by 2050 compared to 28% in the BAU. This is mostly due to the shift away from thermal engines in the car industry with BEV representing 86% of the car stock and natural gas-powered cars a remaining 10%. For short-distance vehicles and mobility, the complete shift away from thermal engines is also close to final with 95% of BEV taxis, 100% of electric light trains and 100% of 2 wheelers. For interurban mobility, trains will shift from diesel to electric and natural gas-powered locomotives and the share of biodiesel in blended diesel for buses will reach up to 25% by 2050.

- Combined these transformations enable to moderate and stabilize energy consumption from 2030 onwards at an increase of ca. 40% compared to 2010, compared to a continuous increase leading to a doubling of energy consumption in the BAU. S4 transformations enable to cut emissions by 60%, while current policies could lead to +40% increase of emissions over the period 2010-2050.

Developing Paris-compatible FREIGHT MOBILITIES

Figure 12. Sectoral emission drivers and main aggregates (Index, 2018 base year)



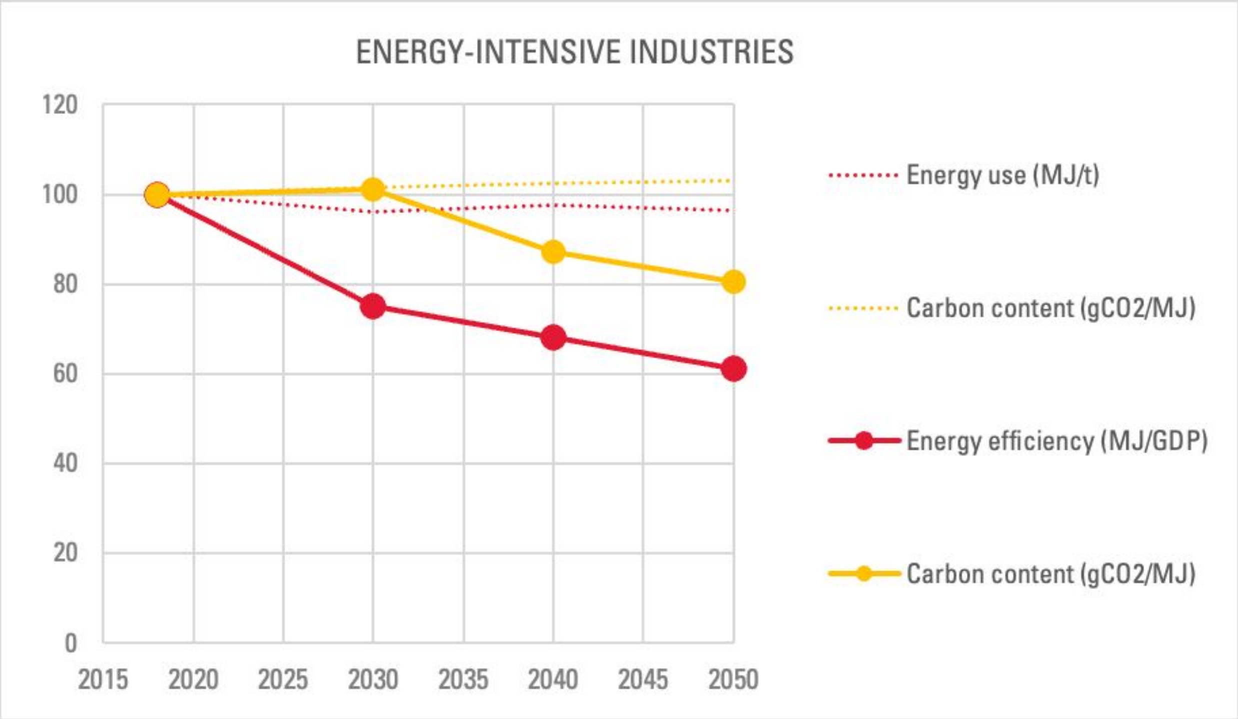


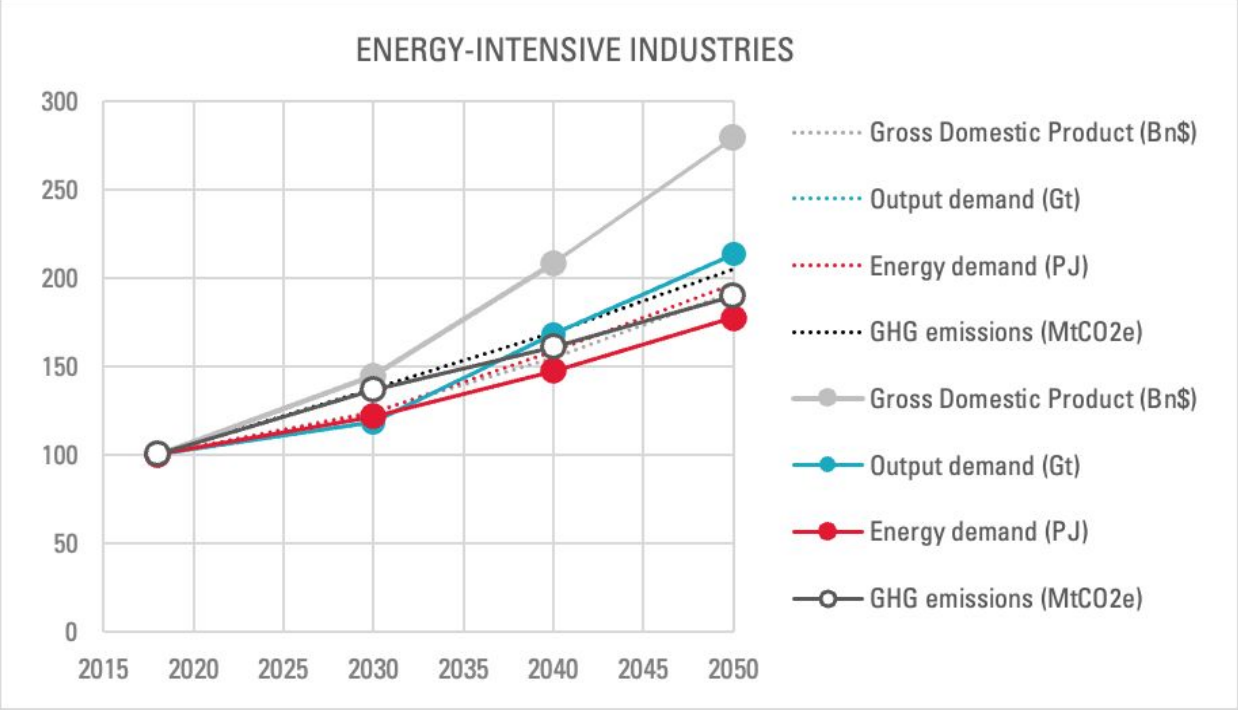
- Current policies (BAU) target by 2050 a modal shift from road to rail. The S4 reinforces this transition and estimates that rail could represent up to 75% of freight transport by 2050 (mostly for long-distance traffics). This decarbonization strategy relies on a significant expansion of the current railway network and adapted regulations for intra modalities. This is undoubtedly a major challenge in terms of infrastructure demand and financing and requires a sufficient time horizon.

- Non-fossil fuels represent 10-12% of the total energy use along the period; and fuel transition towards zero emission fuels (low-carbon electricity, hydrogen and derivatives) is estimated to happen after 2050. In the short/ medium term liquid fuels are supposed to be replaced by NG (mainly LNG and small portion of CNG), reaching up to 65% of the energy consumption in S4 scenario. These actions are part of Governmental energy & environmental strategies and relates to the existence of low-cost NG and a huge installed capacity

Developing Paris-compatible ENERGY-INTENSIVE INDUSTRIES

Figure 13. Sectoral emission drivers and main aggregates (Index, 2018 base year)





There is an augmentation of the emissions in all scenarios, driven by the increase of the GDP. The decarbonization strategies rely essentially on the reduction of the carbon content of fuel used, coupled with energy-efficiency measures after 2030. The carbon content drops until 21g CO_2/MJ by 2050.

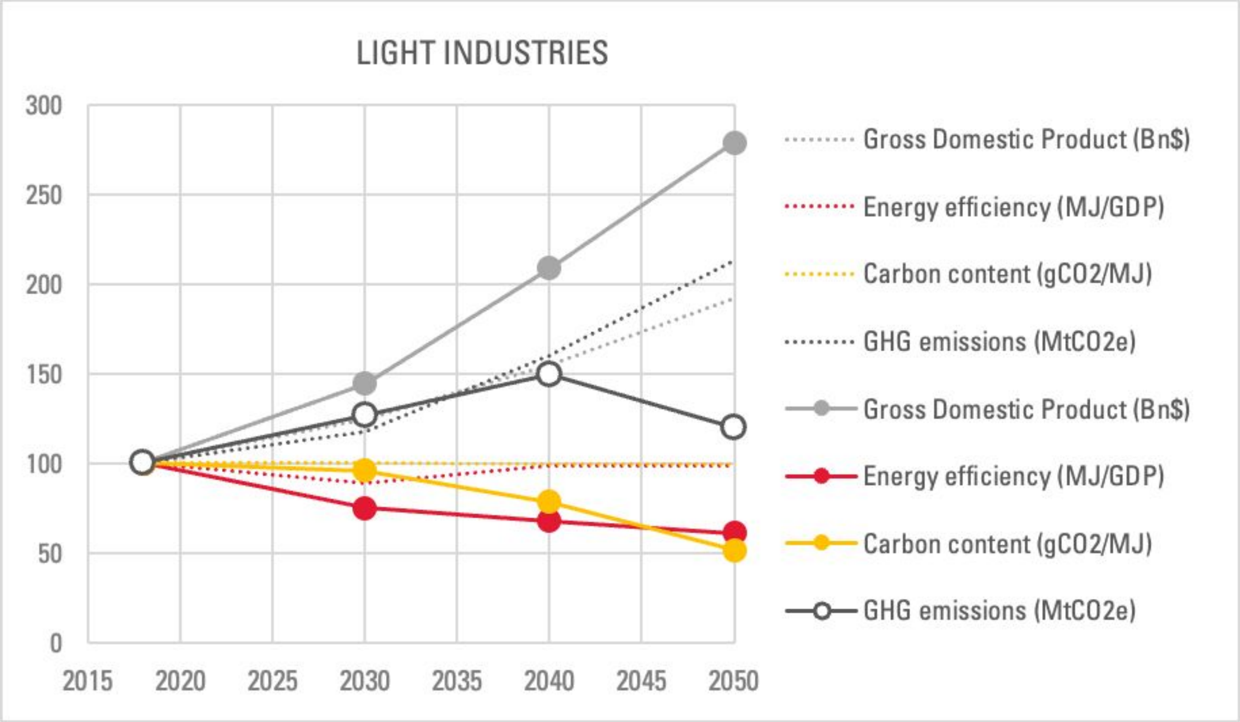
The main drivers of decarbonization paths in SCE4 are :

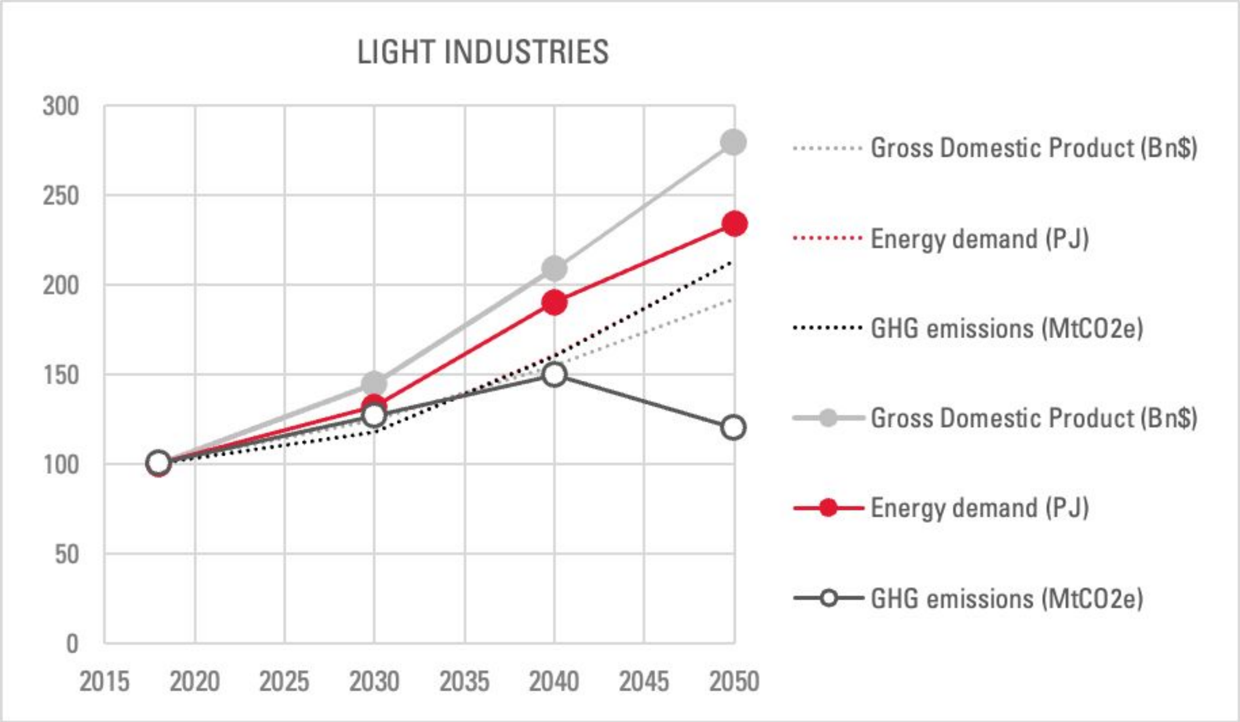
- the electrification in energy-intensive industries (from 30% in 2018 to 37% in 2050), the use of green hydrogen(reaching 10% in 2050) and the reduction of natural gas (falling from 50% in 2030 to 23% in 2050).
- the increase of recycled iron & steel from 2025 (leading to a 4% saving)
- the implementation of energy-efficient measures such as the use of direct heat, and EMS, included the implementation of ISO 50001, leading to a reduction of physical intensity.
- Cogeneration in some cases is also included as existing studies highlight the cogeneration potential of Argentinean industries.

The key additional policies to compared to the BAU should focus on the electrification of all energy-intensives industry usages and the augmentation of biomass fuels.

Developing Paris-compatible LIGHT INDUSTRIES

Figure 14. Sectoral emission drivers and main aggregates (Index, 2018 base year)





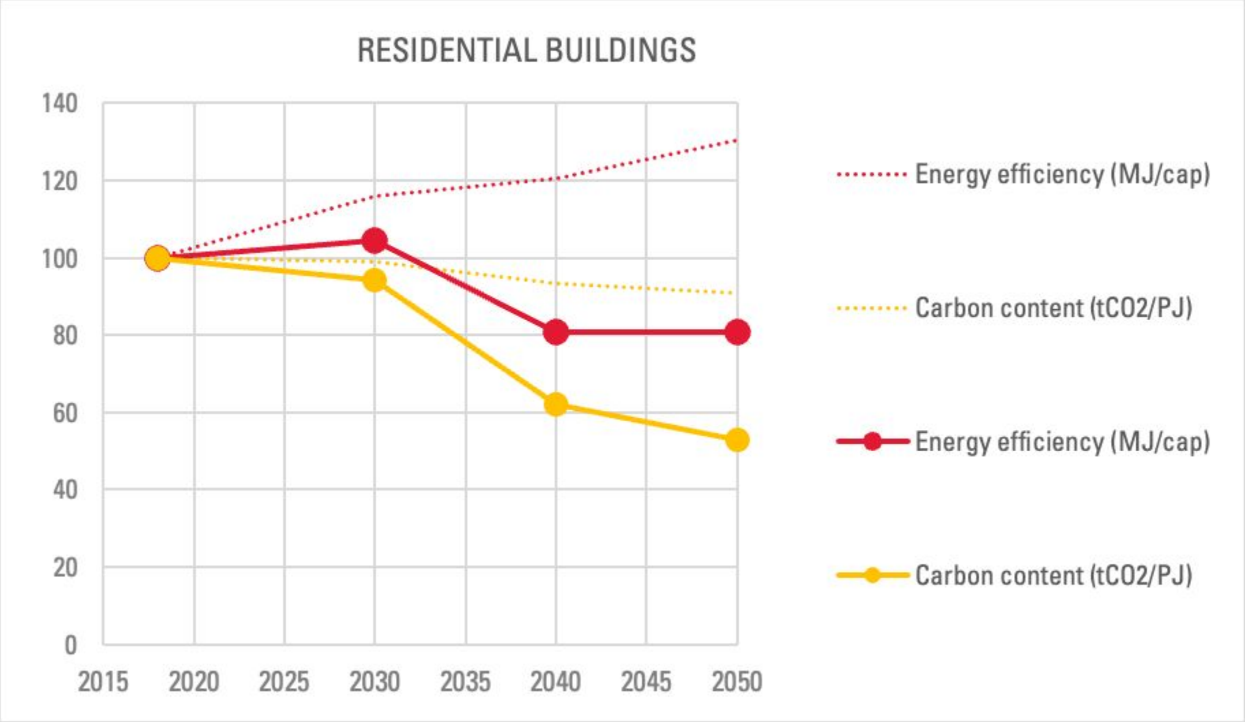
Total light industries' emissions in the DDS SCE4 stays quite stable are reduced by 50% in comparison to the BAU in 2050. SMEs are the main emitter considered in the sector, representing 75% to 67% of the CO2eq (2018-2050). Energy consumption increase in the two scenarios, reaching approximately 800PJ in 2050 due to the increase of the industry's value added. The decarbonization strategies rely essentially on the reduction of the carbon content of fuel used, coupled with energy-efficiency measures. The carbon content drops until 21g CO2/MJ by 2050.

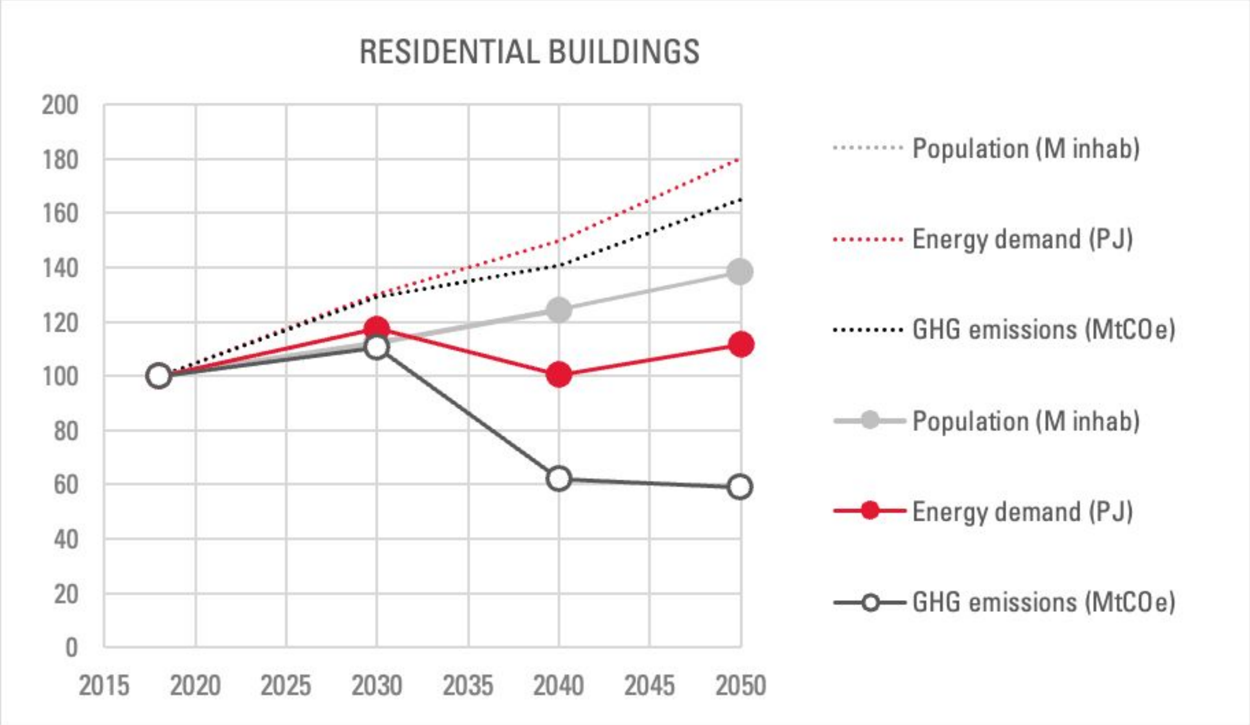
The main drivers are:

- Energy efficiency measures included in the plans of the Secretariat of Energy, and the extension of Energy Management Systems (EMS) to high percentage of SMEs. EMS reduce both electricity and NG consumption.
- Fuels substitution, particularly a significant increase in electricity, accompanied by a slight increase in firewood, biomass residues, and bagasse.

Developing Paris-compatible RESIDENTIAL BUILDINGS

Figure 15. Sectoral emission drivers and main aggregates (Index, 2018 base year)





- In the BAU, surface heating is the main emission source and will make up to 55% of the sector's emission by 2050 if nothing changes, followed by water heating and cooking. The SCE4 decarbonization strategy rely therefore on a reduction of both carbon content and energy consumption of these uses starting in 2030 (strategy close to the SCE3).

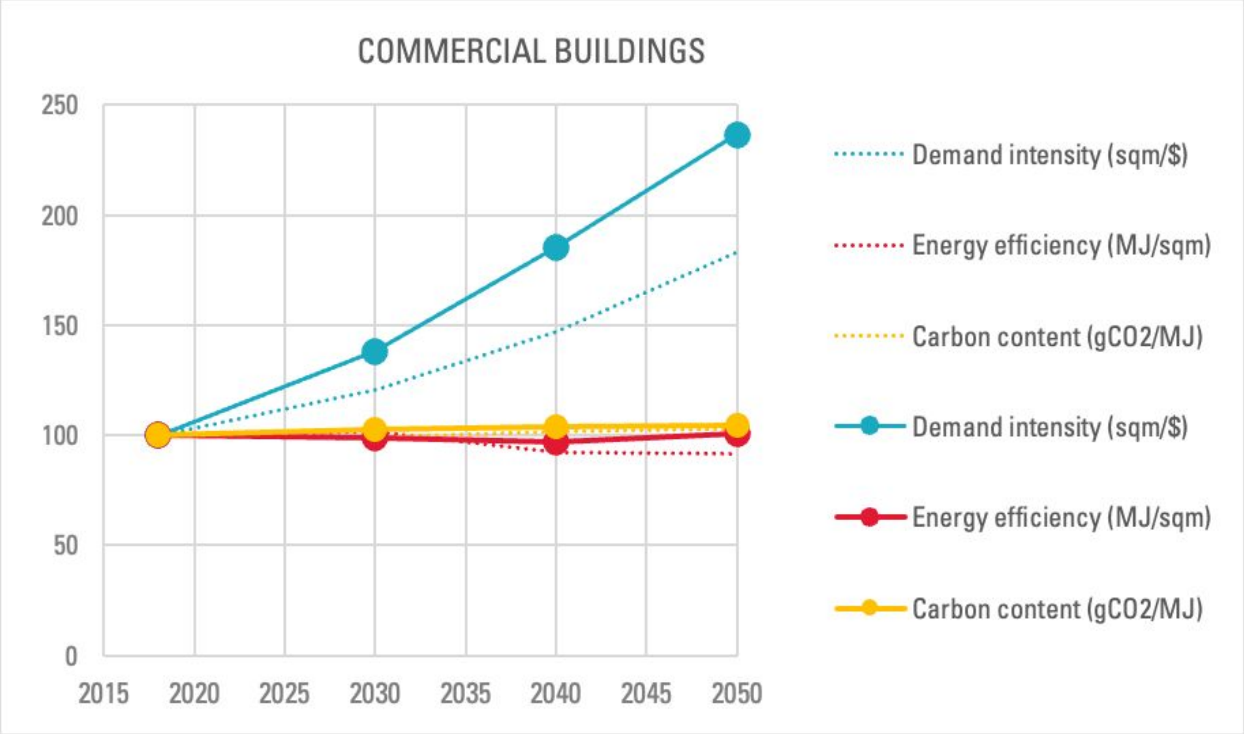
The main drivers of decarbonization are:

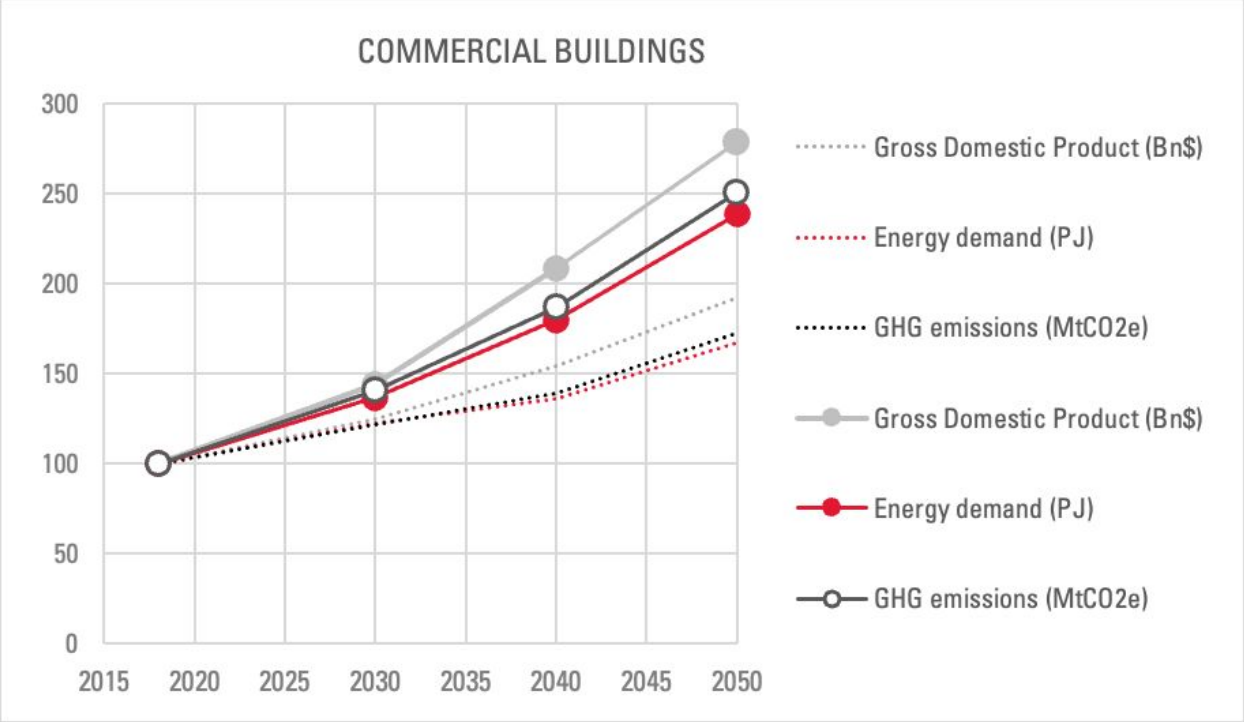
- the decreasing use of gas and increasing electrification: switch from NG heaters and boilers to split and heat pumps, respectively. Heating technology substitution follows a logistic curve, saturating towards 2050. Split technologies also substitutes conventional air conditioners and conventional electric stoves.
- In SCE4, wealth increase of the population, increasing number of middle- and high-income households, will enable the uptake of these new energy efficient systems.
- For surface heating, energy use intensity is reduced of 40% compared to BAU thanks to building investments with skin improvements.
- For water heating, there is a 45% decrease in useful energy intensity thanks to water heater economizer implementation.

The key additional policies compared to the BAU should focus on reducing energy consumption and increase the electrification for the main emitting residential usages.

Developing Paris-compatible COMMERCIAL BUILDINGS

Figure 16. Sectoral emission drivers and main aggregates (Index, 2018 base year)





- This sector covers emissions from commercial activity and commercial buildings, and Public Lighting.
- Commercial final energy demand follows a stronger growth path in the SCE4 compared to historical growth for this sector (3% vs 1.9%) and is also higher than in the BAU, driven by a higher value added of this sector in the SCE4.
- The DDS SCE4 decarbonization strategies rely essentially on a drastic shift of fuel in Commercial and on efficient technologies in Public Lighting
- The carbon content drops until 10g CO_2/MJ by 2050.

The main drivers are :

- the decreasing carbon content due to the decreasing use of gas coupled with an increasing electrification in Commercial sector.
- In Public Lighting the decrease of the energy use intensity by 50% by 2050, thanks to the substitution of lamps by LED technologies.
- the decrease of the demand intensity, by 6% in 2050 in comparison to the BAU, related to the implementation of energy efficiency actions.

Part 2.2

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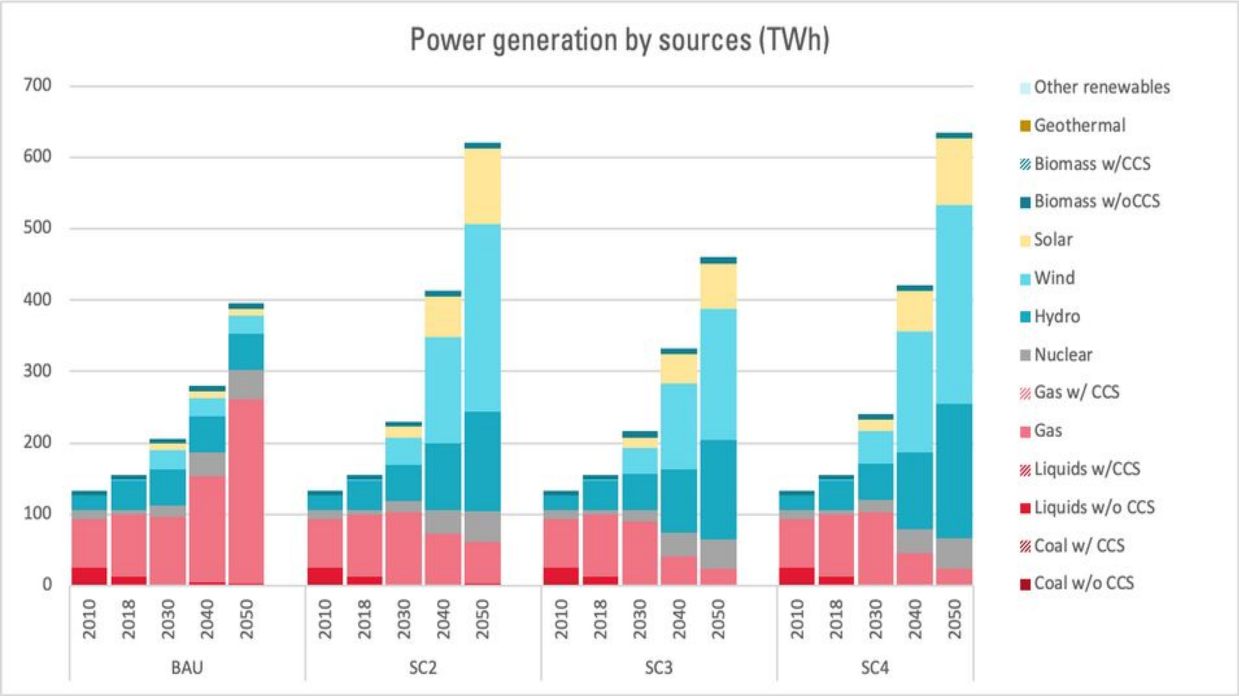
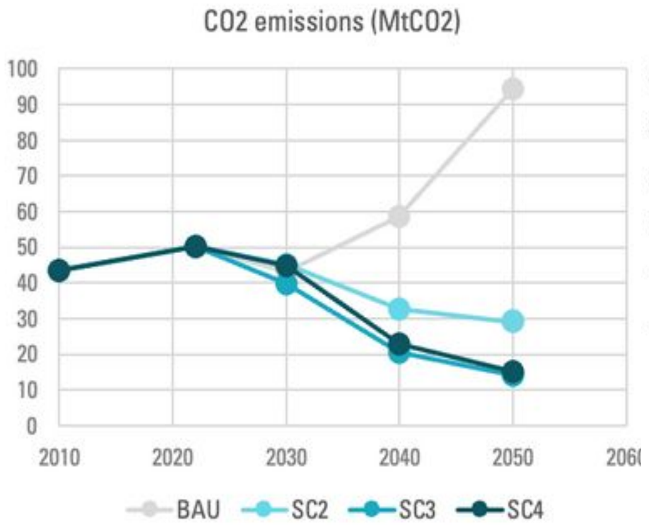
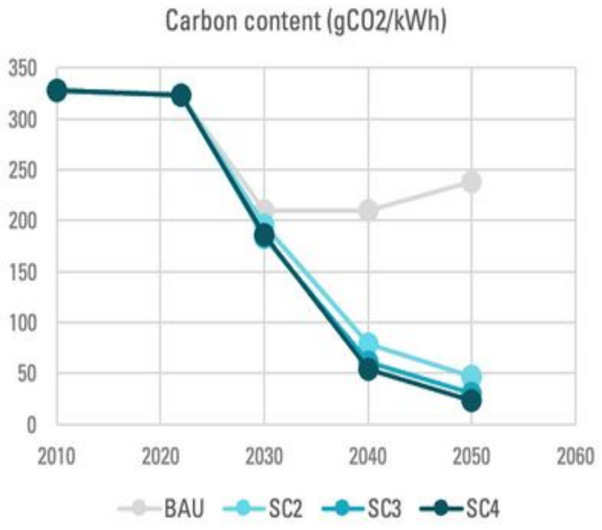
Transition of energy-related emission sectors:
Power generation, Extractive energy industries, Other energy production industries

Decarbonizing POWER GENERATION

Figure 17. Power generation by sources (Top, in TWh) and production emissions / electricity carbon content (Bottom, in MtCO2 & gCO2/kWh) .







Power demand is expected to increase in all scenarios, mostly in industry and residential sectors. Power demand is similar in SCE2 & SCE4, even though electrification of the end-use sectors is more profound in the later. This is because of efficiency gains.

The average electricity cost for SCE4 is the lowest between the four Scenarios (because of the effect of discount rate used to model international cooperation and its impact in CAPEX). The average electricity cost in SCE4 is 60% of SCE3 in 2050.

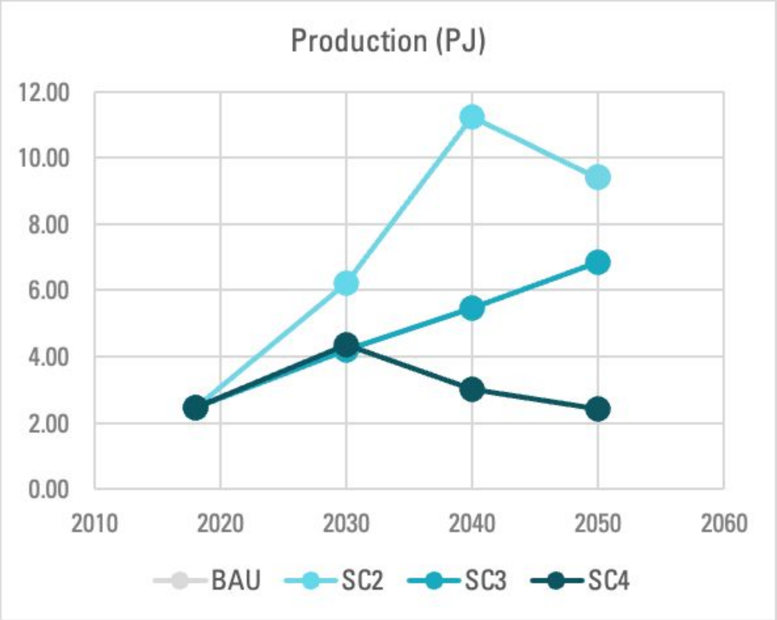
The main drivers of decarbonization are :

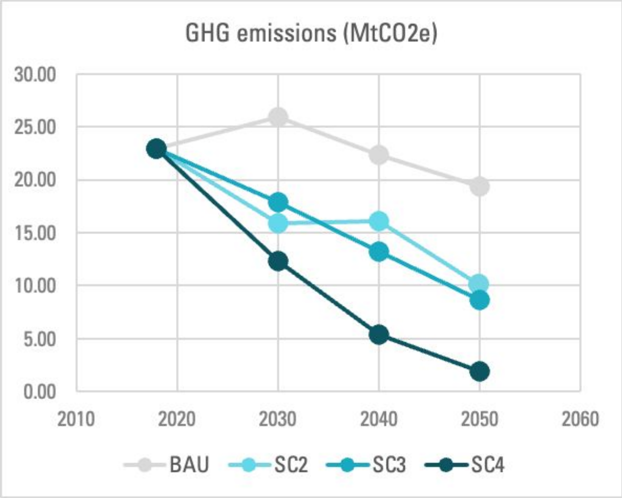
- a massive electrification, as show the augmentation of final power delivered per capita (LEV, heat pumps…). Electricity consumption increases from 3,5 TWh/capita in 2018 to 10 TWh/capita by 2050. The carbon content decrease to net-zero in 2030.
- the decarbonization of electricity production. This can be achieved with large-scale deployment of renewables (solar, hydro, nuclear, geothermal) and without the utilization of CCS technologies.
- the augmentation of electricity sector investments for the interconnected system and investments from green power/hydrogen/ammonia.

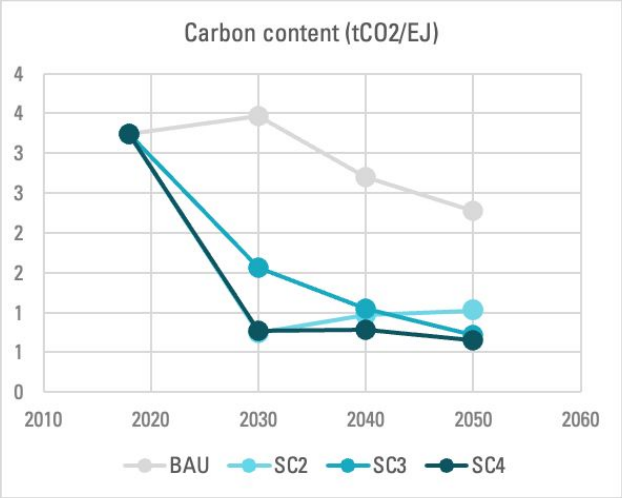
The key additional transformations compared to the BAU should focus on the large-scale deployment of renewables and the augmentation of electricity sector investments for power infrastructures & decarbonization. Electricity system requires, at least, 15 BN USD additional to the BAU to follow the electrification requirements proposed for SCE4.

Decarbonizing EXTRACTIVE ENERGY INDUSTRIES

Figure 18. Coal, Oil and Gas production (Top, in PJ) and production emissions / carbon content (Bottom, in MtCO2e & MtCO2/MJ) .





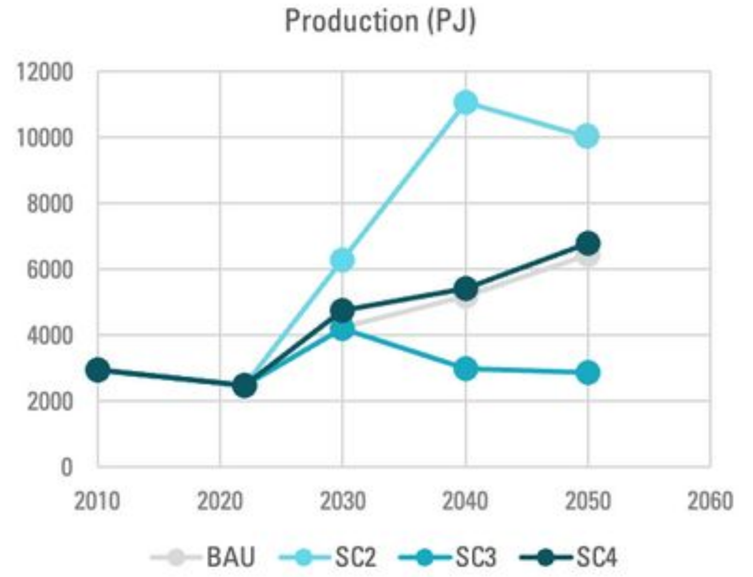


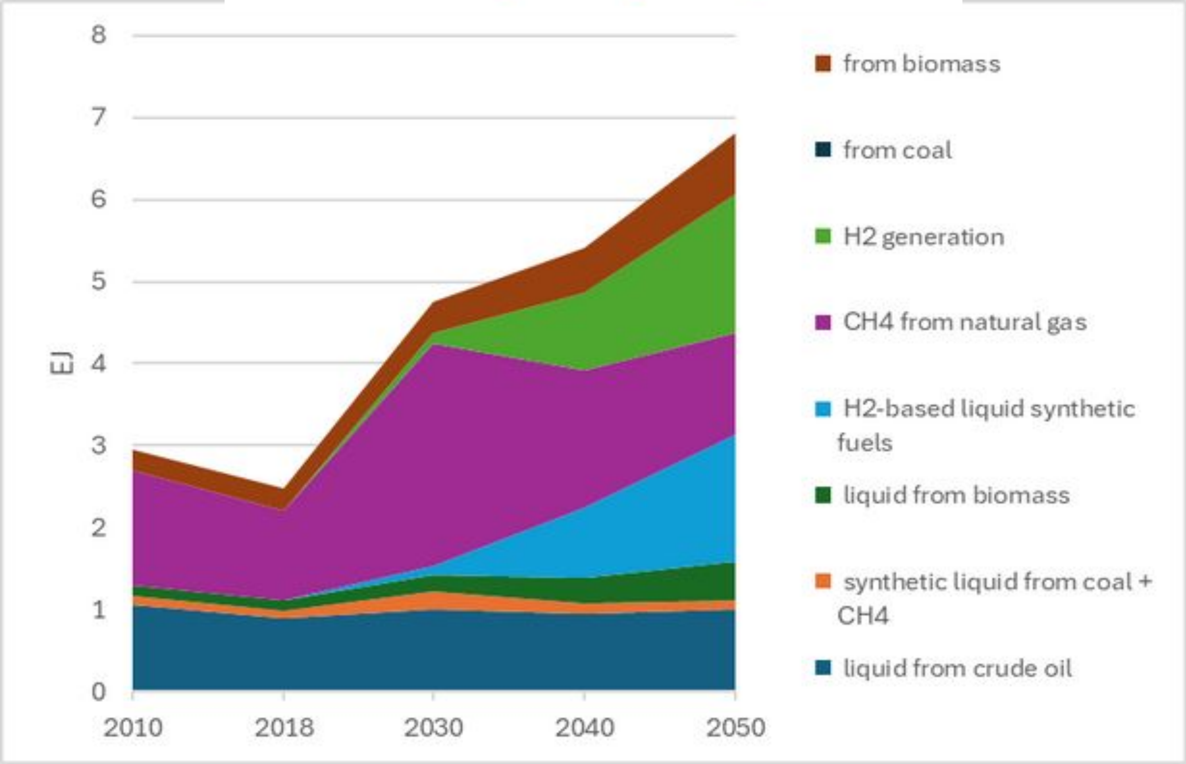
- In all scenarios, there is a reduction of the emissions from the extractive industries across time, with a stronger decrease in the SCE4 scenario. Emissions peak nowadays (2018) in all scenarios.
- NG demand increases in this short and medium terms, primarily driven by power sector up to 2026, and reduces continuously afterwards.
- Natural gas extraction reduces after 2030/35 in the SCE4 due to ambitious climate targets. NG production in the SCE4 reduces by 70% in comparison to the BAU in 2050, mainly for domestic purposes (exports of NG strongly reduce).
- For natural gas, the international prices come from NZE (Scenarios 3 and 4) scenarios and from SPES (SCE 2). The local costs come from the local lifting costs on non-conventional natural gas and the resulting costs from the projected expansion of LNG infrastructure.
- Argentinean NG production is mature and profitable; therefore, the current lifting cost are relatively low and convenient for the short/medium term development of the industry.

- Coal demand is mainly driven by industrial demand. Coal used in the transformation sector disappears as the power sector is retired. Its demand finally reduced with energy-efficient measures.
- Oil production reduces by 50% by 2050 in the SCE4. This leads to a stop of the oil exports by 2050 in this context. The production is used for domestic purposes.

Decarbonizing OTHER ENERGY PRODUCTION INDUSTRIES

Figure 19. All other final fuel production* (Top, in PJ) and production emissions / carbon content of energy produced (Bottom, in MtCO2e & MtCO2e/MJ)





*All other solid, liquid, gaseous final fuel production activities (e.g. refineries, H2 generation, ...)

- Energy production increases in the SCE4 in comparison to the BAU. Green ammonia & green hydrogen production start in 2030;to reach respectively 1,4 and 1,69EJ in 2050, mostly for exports uses.

- The SCE4 has a lower production of natural gas than the BAU: it decreases by 71% in 2050. This is due to the fact that natural gas it not exploited following current production trends, due to more ambitious mitigation policies. In the short-term, natural gas production is higher in the SCE4 than in the BAU in 2030 by 7%, driven by the electrification; it reduces with time as the carbon content of power decreases.
- Oil production is at the destination of agriculture and transports, the share of oil used for transport decreases by 2050 due to a substitution with power for passenger and to LNG for freight.

- Additionally international cooperation is modeled via access to soft loans and NH3 quotas which leads to cost-effective values for H2 and Ammonia production enabling the narrative for green exports.

The key additional transformations to compared to the BAU should focus on soft financing directed to energy industries (VRE + green H2 + Ammonia among others), new international trade commitments/rules on green products for developing regions; annual investment requirements of around 10 BN USD annually that would be cost-effective with interest rates of 4% (rate for which integrated benefits overpasses the economic projected costs compared to BAU) for the Ammonia value chain.

Part 2.3

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Transition of non-energy related emission sectors:
Agriculture, Forestry and Land use change, Waste

Developing a Paris-compatible AGRICULTURE, FORESTRY AND LAND-USE sector

- The main emission sectors in Argentina are currently Energy and AFOLU, the latter due to the significance of agriculture and cattle raising activities.
- Mitigation strategies for the AFOLU sector are much less developed than the energy sector.
- Our decarbonization scenarios, which focus on energy sector mitigation, show a BAU scenario for AFOLU sector (see above drivers) which translates into an increase in the relative weight of AFOLU emissions in total emissions towards 2050. This is because AFOLU sector emissions are mainly what remains after the steep reduction in energy sector emissions, since these two sectors are dominant in total emissions.
- According to previous estimations, the mitigation of the remaining emissions through afforestation would require devoting several millions of hectares of land and, according to some studies, would have uncertain negative impacts and cannot guarantee an effective mitigation strategy.
- Thus, mitigation strategies within the livestock/agriculture system are key to achieve deep decarbonization targets.

Figure 20. Non-energy sector drivers for emissions of this study are the following:

IPCC Category	Main driver	Scenario
3Ai	Cattle heads by subcategory (bovine dairy, etc.)	Static, except for bovine for meat (Growth(0,2%))
3B1	Land area corresponding to category	Static
3B2	Land area corresponding to category	Static
3B3	Land area corresponding to category	Static
3C4	Cattle heads by subcategory	Static, except for bovine for meat (Growth rate 0,2%)
3C5	Cattle heads (bovine for meat)	(Growth rate 0,2%)
4A1	Population, Per capita MSW production, Population, fraction MSW managed	Static, except for population (1,02% growth rate 2019-2050)
4A3	Populations, Per capita MSW production, fraction MSW not managed	Static, except for population (1,02% growth rate 2019-2050)
4D1	Population	1,02% growth rate 2019-2050
4D2	Volume BOD by type of industry (refineries, iron & steel, Chemical products, Cellulose & paper, Food & Beverages	Growth as refinery capacity: growth as iron & steel production; Growth as GDP with 0,7 elasticity; Growth as pulp and paper production; Growth as GDP with 0,7 elasticity respectively.
2A1	Cement production	Growth rate 2019-2050: 2,82%
2C1	Iron & Steel production	Growth rate 2019-2050: 2,46%
Rest of categories	Grow as GDP with 0,5 elasticity	

Conclusions

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Key lessons for national & international climate and development decision processes

Lesson 1 - NG could play a strategic role on medium term global energy transition, and could be key for Argentinean JET

- Global energy transition will require NG to replace carbon intensive options in the short/medium term. However, it will be necessary to close the gap between PA compatible NG demand and country´s NG producing plans.
- A new Paris compatible fossil-fuels global market should be based on CBDR principle: this could be achieved by aggressive quotas on NG, oil and derivatives in the short term (2025/30), including a total ban, for high-income exporting countries, while for the developing countries this total ban can be set to 2050/60.
- Argentina has significant Non-conventional NG resources, which can be extracted in a cost-effective way.
- The investment/recovery timeframe for the exploitation of these resources would be compatible with a phase-out by 2050-2060
- The high recovering rates of the invested capital (due to low cost + steep production curves and rapid depletion) in the medium term make feasible a scenario of increasing production without the stranded assets problem.
- It would not be fair to penalize growth (SCE2 vs BAU) by neglecting a very cost-effective energy source.
- Abandonment of all NG and fossil resource exploitation is seen as unrealistic (and patronizing) if it is not backed by a feasible plan for export substitution to compensate for the loss of foreign currency inflows from fuel exports.

Lesson 2 - Key areas/sectors which require additional transformations to reach net-zero GHG & development objectives

To move from BAU (e.g. current policy trends) & current NDCs scenarios to Paris-compatible pathways:

- Further electrification in buildings (Households & Commercial) actions are needed.
- Industry & Transport demand for important transformations. Efforts should start no longer than 2040.
- Freight transport is a huge challenge for Argentinean decarbonization, both because of its dependence on fossil fuels and for its economic relevance in relation to productive sectors (e.g. agriculture sector).
- Electrification of passenger transport sector also demands for huge private investments in technologies & infrastructure, which will probably require time.

- Electrification of final demands are crucial but additionally demands huge investments in both RE power generation, and transmission & distribution. This is particularly important considering the current transmission and distribution situation in Argentina.

- Mitigation strategies within the livestock/agriculture system (not modeled here) are crucial to achieve carbon neutrality, because of the relevance of this sector in GHG.
- Energy mitigation actions alone are far from achieving PA commitments, even with huge efforts.

Lesson 3 - Key international conditions to implement them

- Increasing the long-term environmental ambition as a national policy with sectorial and socio-economic specificity.
- CBDR should frame international cooperation and environmental trade negotiations.
- Design a long-term strategy (route map) which includes a medium-term exploitation of NG for exports (using public revenues for energy mitigation strategies) and a long-term low-carbon H2 and ammonia (or other green products) development.
- Setting a reasonable, equitable and efficient system of energy prices (tariffs) to incentivize the efficient use of energy & help energy access.
- Designing strategies to finance private investments in low-carbon technologies. This requires a deep evaluation of the financial sources for these strategies.
- Support specific agreements (like joint ventures) to produce H2 or other energy related vectors and batteries.

Lesson 4 - Fair national contributions/enablers to the GST outcome

- PA compatible transformations are difficult to implement and have strong impacts on development if they are not accompanied by international cooperation (SCE4 vs SCE3)
- The opportunity cost of non exploitation of Argentinean large NG resources should be considered in international funding schemes (CBDR) (SCE2 vs BAU).
- Many of the green energy alternatives (e.g. low-carbon H2 or green ammonia) are not yet feasible under market conditions (esp. in developing countries). Long-standing priorities based on profitability are still very true (e.g. GN recently after Ukrainian-Russian war).
- International cooperation channels will be required in different manners. CBDR & SDGs should frame all the environmental discussions and, therefore, should be considered in the cooperation mechanisms.
- Cooperation with Argentina (and other developing countries) can be either addressed by:
  - Financial Resources. It may be required different alternatives of Blended Finance (based on the recent experience of JET-P) specially directed to energy industries (VRE + green H +Ammonia among others), which includes soft loans (convenient rates & timeframes) and guarantees funds (help overcome reluctance amongst private sector lenders or equity investors).
  - Low interest loans with specific use implemented by state owned companies could create a virtuous development cycle of production/research/development. Y-Tec or INVAP* could be excellent recipients with H2 or other VRE initiative.
- Special international trade commitments/rules for the products that they produce and export, including green exports.

* Both technology state owned companies

Lesson 4 - Fair national contributions/enablers to the GST outcome

d) Transitioning away from fossil fuels in energy systems, in a just, orderly and equitable manner….

This orderly transition away from fossil fuels must also be developed in a fair manner and under the concept of the CBDR, which could include a modification of the current structure for the international oil and gas market, based on the development stage of each supplier (region/country) and considering the macroeconomic and development impact.

This can be addressed by aggressive quotas on natural gas, oil and derivatives in the short term (2025/30), including a total ban, for high-income exporting countries, while for the developing countries this total ban can be set to 2050/60. In the near term this can be addressed by establishing schemes of some purchasing quotas from developing countries, as well as tariffs (maybe a carbon border tax to explicit carbon). This aspect has twofold benefits: on the one hand, encouraging production in developing countries which may require the fuel revenue to develop, and, on the other hand, as a reduction of energy supply prices will increase, which may encourage fuel substitution in developed countries.

Regarding the Argentinean low-cost NG resources, the country can contribute to this goal by providing the world with NG to substitute other high emission fossil fuels in the short/medium term.

e) Accelerating zero – and low-emissions technologies, including …, and low carbon hydrogen production.

In this condition is important to highlight the need for clear consensus on which are the technologies included, and the need for given an impulse to the development of the value chains in developing region (in where natural resources are located).

Argentina can contribute to this global goal in the production of low carbon H2 based on its existing RE potential but probably based on the conditions mentioned in previous slides (SCE4). In this regard it is important to include the conditions mentioned above for the accelerated deployment of low emissions technologies

Annex 1 : DECARBONIZATION PATHWAY FOR ARGENTINA - values

ARG	2018	2030	2040	2050
Total GHG emissions (MtCO2e)	356	386	301	274
Total CO2 emissions (MtCO2)	213	231	145	111
Total energy-related CO2 emissions (MtCO2)	159	168	98	79
Total final energy consumption (PJ)	2220	2827	2813	3260
Total Pop (Million)	44	50	55	61
Total GDP (Billion USD (2015))	583	832	1134	1448