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The Energy Transition in Colombia

Current situation, projections, challenges, narratives and public policies – in relation to the energy transition in Germany

Johannes Thema
María Cecilia Roa García

Universidad de los Andes

Wuppertal Institut

Publisher:
Wuppertal Institute for Climate, Environment and Energy
Döppersberg 19
42103 Wuppertal, Germany
www.wupperinst.org

Authors:
Johannes Thema
E-mail: johannes.thema@wupperinst.org
María Cecilia Roa García
E-mail: mc.roag@uniandes.edu.co

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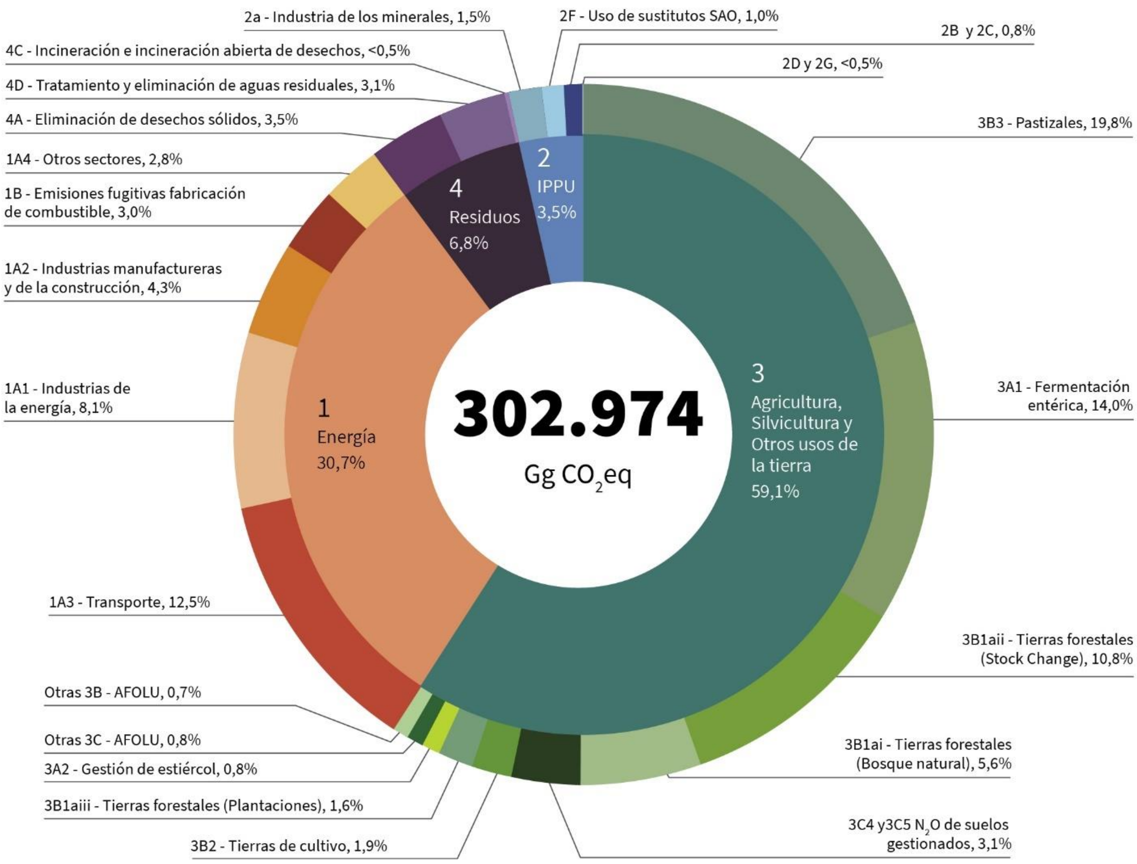
Content

Executive summary

This paper analyses the energy transition models of two countries with ecologically unequal trade-offs (Infante-Amate et al., 2020) and which are currently collaborating in the exploration of energy alternatives for decarbonisation. The emphasis of the exercise is on an analysis of options for the complete decarbonisation of the Colombian energy system. To this end, it analyses the current situation, public policy debates and the decarbonisation route taken by Global North countries, taking Germany as example country with which Colombia has historically maintained energy trade relations and that currently embarks in financial and technical support for renewable energy rollout in Colombia. Each country has particular conditions, therefore a generalisation for countries in the Global South and North is not possible, however, the analysis raises some reflections on a just energy transition on a global scale.

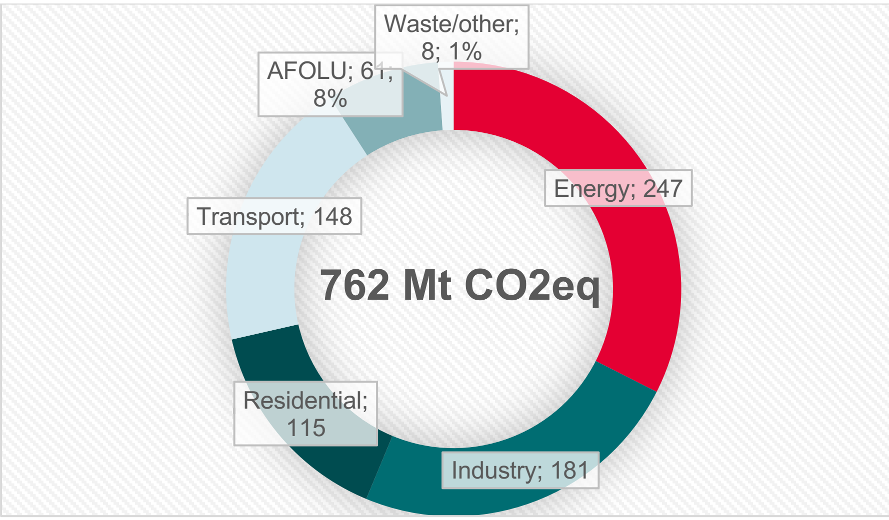
The composition of greenhouse gas (GHG) emissions in the two countries shows large differences. In Colombia, only 31% of GHG emissions are from the energy sector (including sub-sectors), and 59% from the AFOLU sector (Exec. fig. 1). This highlights the importance of this sector in GHG mitigation, especially its sub-sectors land use change (grassland, forest land in the graph) and livestock (enteric fermentation - Exec. fig. 1). Unsuccessful efforts over the last 20 years to control deforestation as a major source of GHG emissions indicate that it is necessary to refocus efforts in the AFOLU sector and diversify the strategy to include other sectors.

Exec. fig. 1: GHG emissions by sector Colombia (2018)



Source: IDEAM et al. (2022, p. 95)

Exec. fig. 2: GHG emissions by sector Germany (2021)



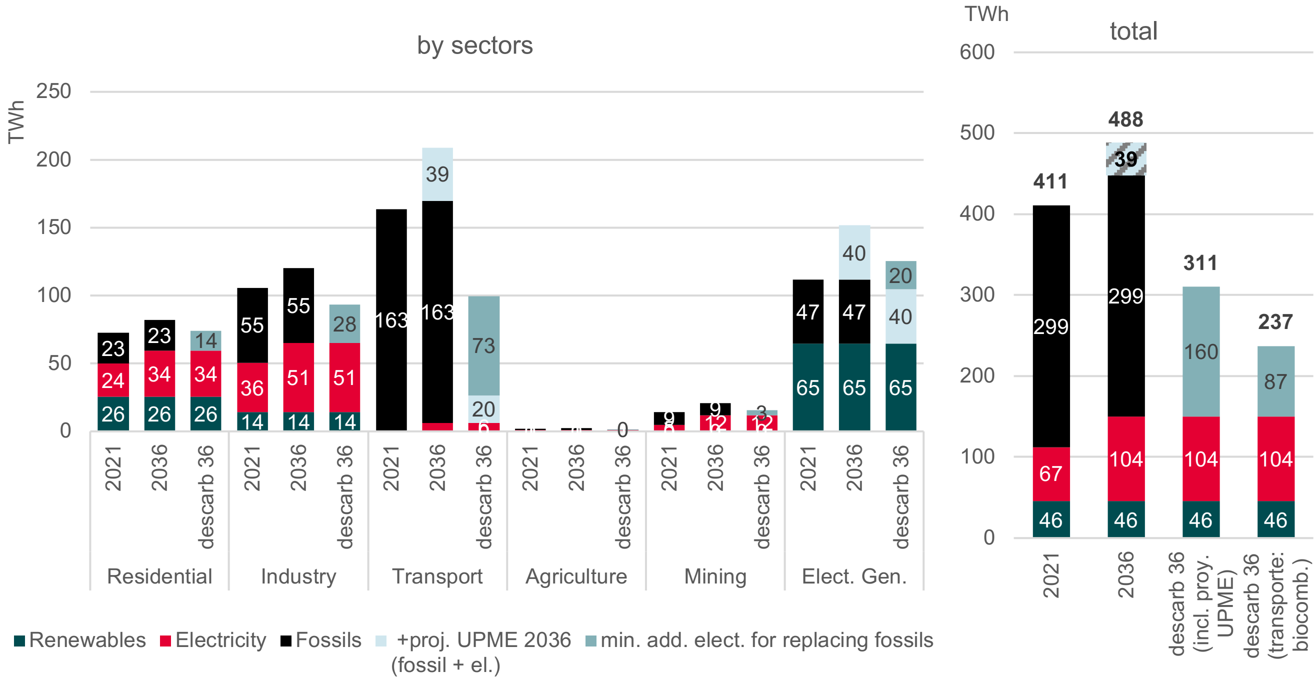
Source: based on data from UBA (2022), graph adapted by author

In Germany as a country of the Global North, with both high industrialisation and consumption levels, the energy, industry, residential and transport sectors account for 91%, AFOLU for 8% of emissions. For this reason, decarbonisation in Germany is mainly focused on energy transition and less on AFOLU. The comparison of emissions per capita shows 6t/cap/yr in Colombia and 9.1t/cap/yr in Germany, a surprisingly small difference given the difference in economies, and highlights the importance of the land-use related emissions in Colombia.

This paper analyses the current situation in each economy sector, existing projections and options for decarbonisation. Detailed analysis of sectoral energy consumption in Colombia shows the sectors with the highest fossil energy consumption (in this order): transport (fuels), industry (gas, coal), electricity generation (gas, coal) and residential (gas). We show how the Colombian Mining and Energy Planning Unit UPME projects an increase in demand for fuels and electricity, and calculate the amount of electricity theoretically needed to substitute fossil sources in each sector (see Exec. fig. 3 left).

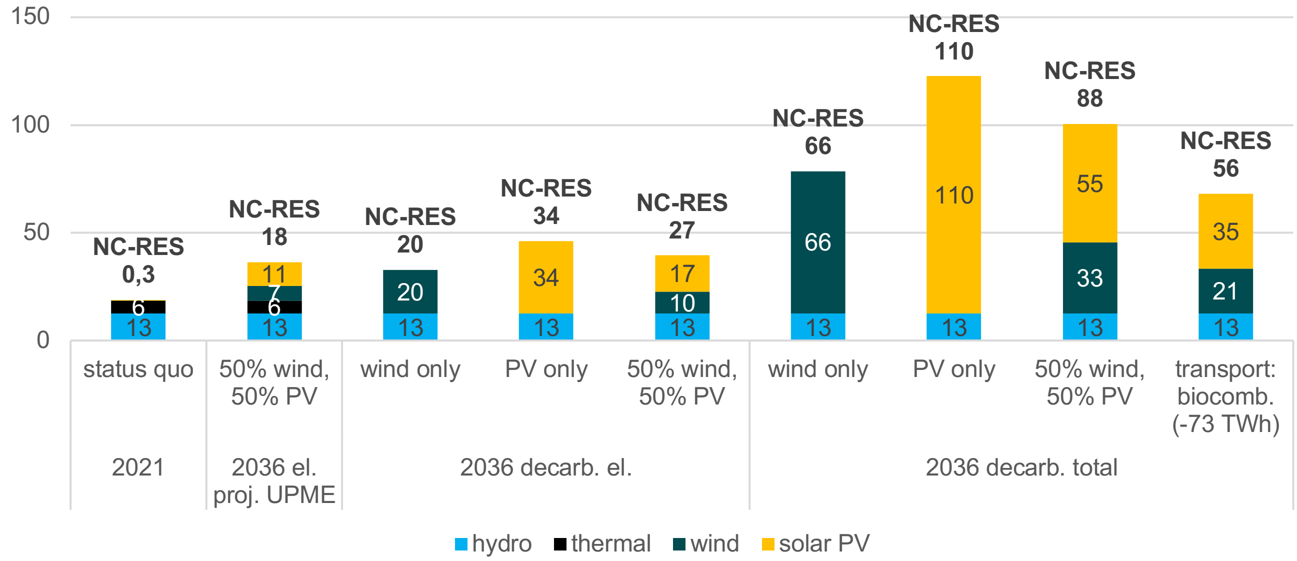
In two hypothetical scenarios we estimate the total electricity required for a decarbonisation: 1) completely by electrification and 2) assuming that the transport sector decarbonises by another source (biofuels) (Exec. fig. 3 right). We estimate the capacity (GW_p) required to supply demand in four hypothetical scenarios of 1) wind only, 2) solar PV only, 3) 50% both technologies and 4) 50% wind and solar (for simplicity reasons, we do not analyse other sources like geothermal or tidal), but with transport not supplied by electricity but by biofuels (which reduces electricity demand by 73 TWh). The results can be understood as the minimum capacity required, under optimistic assumptions on efficiency increases through electrification and high wind and solar yields per installed capacity.

Exec. fig. 3: National demand 2021/2036 and minimum additional electricity generation required by fossil fuel substitution, by sector (left) and total (right)



Data source: UPME (2023a), calculations by the author
Note: 2036 includes increase in demand (UPME, 2022), descarb 36 includes projected increase in electricity demand up to 2036 (UPME, 2022) and additional electricity demand for fossil demand replacement in 2036. In the electricity sector, "renewables" includes hydro and bagasse.
In total figure, excl. hydropower. Descarb 36 includes incremental electricity demand and substituted fossil fuels. Descarb 36 (biomass transport) assumes decarbonisation of transport by other non-electricity sources and thus a 73 TWh lower electricity demand.

Exec. fig. 4: Estimated installed capacity needed (GW_p) for decarbonisation, assuming electrification by wind/PV/mixed/biofuel transport



Source: own calculations based on UPME data (2022, 2023b, 2023a), for calculation contact author.

UPME regularly publishes demand projections for the upcoming 15 years. The latest projection estimates an increase in energy demand until 2036 to be supplied, in our scenario, by 50% wind and PV. Compared to the current fleet of hydro and thermal (fossil) power plants with a combined capacity of 19 GW (XM, 2023), 10-14 GW of non-conventional renewable energy sources (NC-RES, i.e. RES excl. hydro) would be needed to replace the current thermal plants. With the increase in consumption, between 20 GW (wind only) and 34 GW (PV only) would be needed to decarbonise the electricity sector alone.

If all fossil fuel consumption in all sectors projected by the UPME (2022) by 2036 were to be replaced by electricity, the additional NC-RES fleet would have to reach 66-110 GW. If the transport sector (e.g.) was instead supplied by sources other than electricity (e.g. biofuels), this would reduce additional electricity consumption, and consequently the additional capacity needed to about 56 GW, but on the other hand would require to substitute previous 163+39 TWh/a of fossil transport fuels with biofuels. Without using a detailed electricity system model, this first estimation of requirements demonstrates the challenges of decarbonising the entire Colombian energy system. It also shows that decarbonisation through electricity alone will be complicated for Colombia in the short to medium term, as the best wind potential areas are located in indigenous territories with a complex social, environmental and governance situation, and that Colombia probably needs to complement wind and solar strategies with other renewables such as biomass and geothermal. If the goal is the complete decarbonisation of the Colombian economy, the total NC-RES potentials need to be evaluated before significant amounts of energy can be exported to other countries. Current estimations of the total potential amount roughly to total requirements to substitute domestic fossil fuel consumption.

Our analysis of the energy transition narratives shows that in both countries a discourse based on technological solutions of replacing fossil sources with "green" ones dominates, in Colombia sometimes simply based on the addition of renewable sources. We find additional niche narratives in both countries, pursued by NGOs or academia, that focus more on natural resources, global justice and limiting consumption levels.

We give an overview of public policies for the transition in Colombia and Germany. Colombia has first roadmaps for a few sectors (wind, hydrogen) and is working on others, but sectoral policies are still disjointed, do not have full decarbonisation targets and lack a systemic vision. In Germany, systemic visions and sectoral strategies exist, but consistent implementation is lacking, and plans for a national energy transition involve imports of large amounts of energy without analysing what this means for the energy transition in respective exporting countries.

In order for a global energy transition to be successful, we conclude that an understanding as technology-based decarbonisation is insufficient and that structural fundamentals need to be changed. A systemic analysis of energy systems is required that informs sectoral strategies and policy action with clear pathways to full decarbonisation of all sectors. But sectoral and national strategies need global articulation to avoid flawed developments: if the Global North bases its decarbonisation on renewable energy import structures from the South, it puts the transition there at risk. And if the structures of international trade relations remain unchanged, an energy transition will remain difficult in many countries of the Global South. Energy and technological sovereignty will be key to a just transition.

It is necessary to establish a dialogue between all actors of the energy transition, and especially to ensure the participation of local communities at energy generation project sites – not only in consultations but also in decision-making, ownership and benefits.

Finally, reducing high emissions from the AFOLU sector requires an understanding of deforestation and land use changes not as local or national phenomena, but in the global contexts of the illicit drugs market, land grabbing and speculation, growth in demand for meat and timber trade. This would allow for the development of solutions that address structural causes.

Finally, the challenges analysed in this paper are large and require profound political and infrastructural changes that will take time. This indicates a need for immediate political action.

List of abbreviations, units and symbols

Abbreviations

Abr.	ES	EN
ACPM	Aceite combustible para motores	Diesel
AFOLU	Agricultura, forestales y cambios en uso de tierra	Agriculture, forestry and land-use change
BEV	Vehículo eléctrico de batería (EN)	Battery electric vehicle
FNCER (NC-RES)	Fuentes no convencionales de energía renovable (excl. Hidroeléctrica)	Non-conventional renewable energy sources (excl. hydropower)
GEI	Gases a efecto invernadero	Greenhouse gas emissions
GLP	Gas liquado de petróleo	Liquefied petroleum gas (LPG)
ICE	Motor de combustible	Internal Combustion Engine
PM	Materia particulada	Particulate matter
PND	Plan Nacional de Desarrollo	National Development Plan
NAMA	Acción de Mitigación Apropiada Nacional	National Appropriate Mitigation Action
SIN	Sistema integrado nacional (de electricidad)	Integrated national system of electricity
UPME	Unidad de Planeación Minero Energética	Mining and Energy Planning Unit Colombia

Units and symbols

Abr.	ES	EN
a	Año	Annum (year)
USD	US dólar	US dollar
%	Por ciento	Per cent
€	Euro	Euro
°C	Grados Celsius	Degrees Celsius
Cap	cabeza	capita
CO_2	Dióxido de carbono	Carbon dioxide
CO_2 eq	Equivalentes de CO2	Carbon dioxide equivalents
g	Gramos	Gram
Gg	Giga gramos = mega kilo = kilo tonelada	Giga gram
GJ	Giga julios (1000 MJ)	Giga joule
Gt	Giga tonelada	Giga tonne
GWh	Hora gigavatio	Gigawatt hour
h	Hora	Hour
H_2	Hidrógeno	Hydrogen
kg	Kilogramo	Kilogram
km	Kilometro	Kilometre
kt	Kilotonelada	Kilotonne
kW	Kilovatio	Kilowatt
kWh	Hora kilovatio	Kilowatt hour
l	Litro	Litre
m	Millón	Million
MBL	Millones de barriles	Million barrels
MJ	Mega (millones de) julios	Megajoule
Mt	Mega tonelada	Mega tonne
p.a.	Por año	per annum
pkm	Kilómetros de pasajero	Passenger kilometres
PJ	Peta julios (1000 TJ)	Peta joule
PV	Fotovoltaica	Photovoltaic
t	Tonelada	tons
TJ	Tera julios (1000 GJ)	Terajoule
Tkm	Kilómetros de tonelada (carga)	Ton kilometres (freight)
TWh	Hora Tera vatio	Terawatt hour

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1 Introduction: Background and Greenhouse Gas Emissions (GHG) in Colombia and Germany

Background

Colombia, like many countries in Latin America and the Global South, faces a multitude of crises and political challenges, including social, ecological, economic, public finance, security and internal public order issues. Climate change with its impacts and needs for adaptation and mitigation adds to these problems. All these crises, which are common to many of the countries of the Global South, converge in what is perhaps the greatest global challenge in human history: the energy transition as a response to the climate crisis resulting from the historical project of modernity/coloniality (Escobar, 2022). Colombia, being part of the 2015 Paris agreement and subsequent Conferences of the Parties (COP), committed itself to decarbonisation and thus to an energy transition by the middle of this century at the latest.

However, this is not the only reason to undertake an energy transition. Beyond complying with international climate agreements, reducing significant emissions or reducing the adverse environmental and social impacts of fossil fuel extraction (which are not discussed in this paper), an energy transition is linked to many of the other issues mentioned above. Among others, Colombia in the near future risks becoming an importer of fossil fuels and losing export revenues, losing competitiveness of its industry if it does not decarbonise, and missing out on the advantages of decarbonised transport. More systemically, the energy transition from the Global South is an opportunity to question the historical geopolitics of North-South trade relations and the very development model based on infinite growth (Nirmal & Rocheleau, 2019).

This paper analyses the energy transition models of two countries that maintain an ecologically unequal exchange (Infante-Amate et al., 2020) and are currently collaborating in the exploration of energy alternatives for decarbonisation. The emphasis of the exercise is on an analysis of options for the complete decarbonisation of the Colombian energy system. To this end, it analyses the current situation, the debates on public policies and the decarbonisation route undertaken by the global North, taking as an example Germany as one of the countries with which Colombia has historically maintained energy trade relations and which is currently financing renewable energy projects. Each country has particular conditions, therefore, a generalisation for the countries of the Global South and North is not possible, however, the analysis raises some reflections on a just energy transition on a global scale.

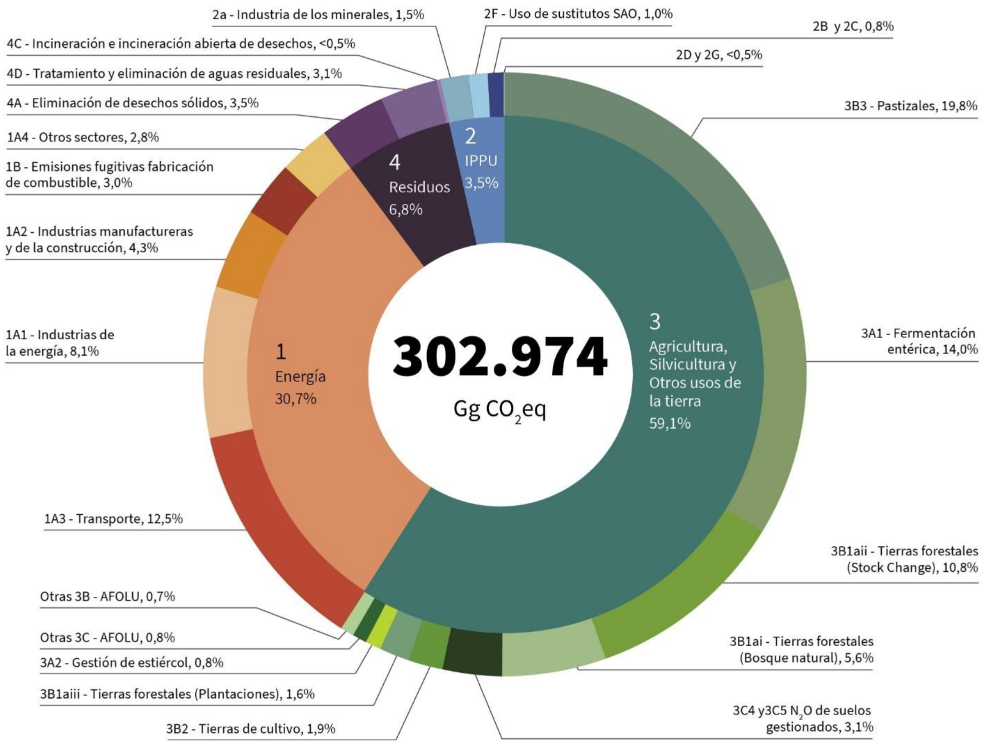
We mainly use two analytical frameworks. On the one hand, from a technical and quantitative perspective, we show the energy balances between supply and demand from various sources, technologies and forms of use, considering the needs and constraints for energy transport and storage. Under this framework, the analysis starts from the available national information especially on secondary energy sources and the official statistical information of the two countries to offer a look at the needs of decarbonisation at the national scale.

On the other hand, from the perspective of Latin American political ecology, we analyse the global dynamics that allow us to understand the systemic obstacles to achieving an energy transition on a global scale. This perspective allows us to analyse the different interpretations of energy transition and the scope of each of them. For example, an energy transition that effectively reduces greenhouse gas emissions on a global scale (for all countries) requires an understanding of how the international financial and trading system impacts the ability of countries in the global South to finance the transformation of their energy matrices. That is, energy transition efforts focused exclusively on the decarbonisation strategy of economies may work for certain countries with technological and financial capacity. But in the global sum, effective energy transition, i.e. one that significantly reduces the greenhouse gas emissions of *all* countries, requires taking on shared but differentiated responsibilities, based also on the recognition of the historical emissions that have caused global warming. This is the basis for undertaking a just energy transition that will also maintain the conditions for the reproduction of a good life on the entire planet. A just energy transition implies questioning and stopping the expansion of sacrifice zones in peasant and indigenous territories for the extraction of transition minerals or for the production of renewable energies. For these reasons, the energy transition is multi-scale and implies a transformation of the energy system starting from a change in social relations with food, transport, leisure, the immediate environment and the entire planet. Rather than a comparison between two countries in the global North and South, we focus on Colombia to analyse how large and achievable the goal of internal decarbonisation of countries in the global South is and the feasibility of a strategy of exporting renewable energy sources to the Global North, in order to replace oil and coal revenues. The comparison between the energy sectors of Colombia and Germany allows us to highlight the differences in the capacity of the countries to undertake their transition processes and the convergences, synergies and frictions between North and South to jointly move towards a transformation of energy relations.

Greenhouse gas (GHG) emissions in Colombia and Germany

Globally, 79% of GHGs are (2019) from the energy sector (energy, transport, buildings) and 22% from agriculture, forestry and land use change (AFOLU) (IPCC, 2023, p. 4). The countries analysed in this report diverge substantially from this distribution. In Colombia, according to Colombia's national greenhouse gas (GHG) inventory report to the IPCC (IDEAM et al., 2022, p. 4) only 31% comes from the energy sector, and 59% from the AFOLU sector (Fig. 1). This highlights the key importance that this sector must play in GHG mitigation, with its sub-sectors land use change (related to grassland and forest land in the graph) and livestock (enteric fermentation in the graph).

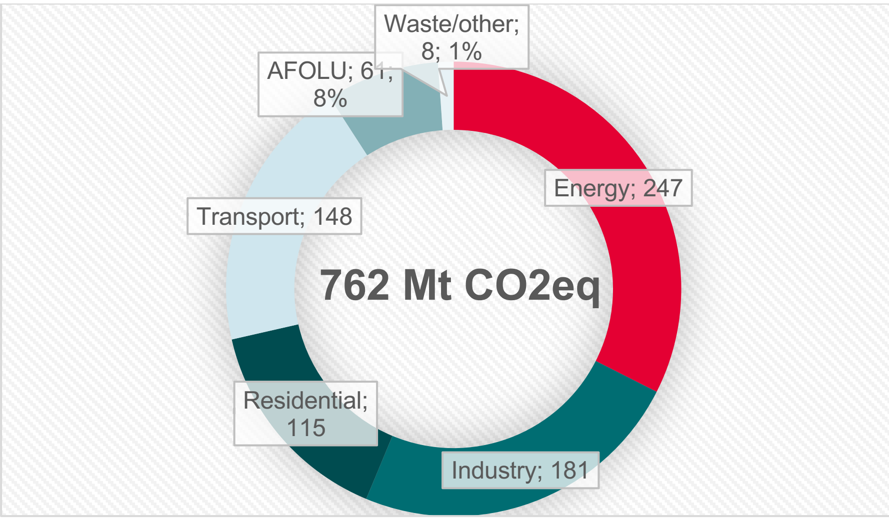
Fig. 1: GHG emissions by sector Colombia (2018)



Source: IDEAM et al. (2022, p. 95)

In Germany as a representative of the Global North and a country with high industrialisation and consumption levels, the energy, industry, residential and transport sectors account for 91%, while AFOLU barely 8% of emissions. The key focus for decarbonisation in Germany is therefore on energy transition and less on AFOLU.
The comparison of absolute emissions also reveals, that in 2018 Colombia emitted 303 Mt CO2eq (2018), while Germany emitted 762 Mt CO2eq (2021), with a population of 50 (COL) and 83 million (DE). While energy emissions per capita are relatively small in Colombia (1.8t/cap/yr) and large in Germany (8.3t/cap/yr), the total increases to 6t/cap/yr in Colombia and 9.1t/cap/yr in Germany when AFOLU is included. The difference between the two countries is surprisingly small given the difference in the economies, and highlights the importance of the AFOLU sector in Colombia.

Fig. 2: GHG emissions by sector Germany (2021)



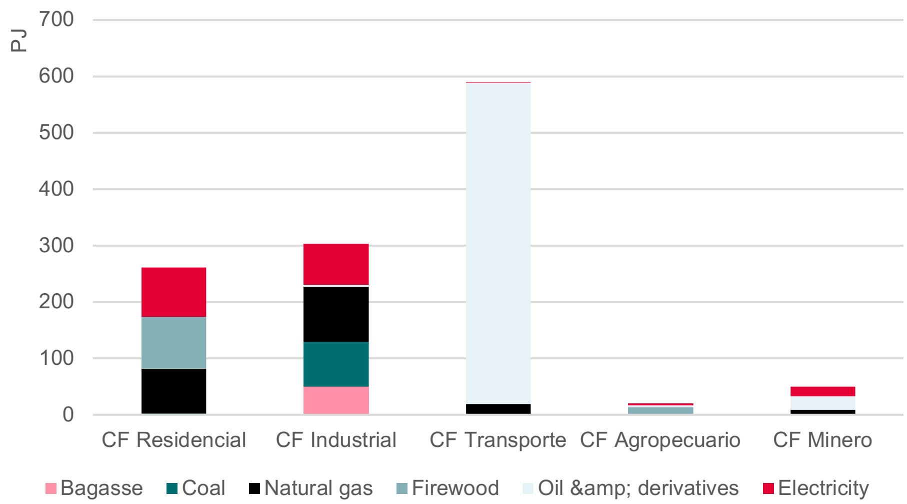
Source: based on UBA data (2022) graph adapted by author

For Germany, sectoral decarbonisation strategies are key to the energy transition, and are being elaborated. Although in Colombia the AFOLU sector is of major importance, the energy sector also requires decarbonisation to implement the goals of the Paris agreement (UNFCCC, 2020). Substitution of fossil sources in the AFOLU, transport, industry, residential and electricity sectors is a challenge in both countries.
This report analyses the current situation and existing projections in each sector comparing Colombia and Germany (chapter 2 and 3), and then presents the existing narratives (chapter 4). It analyses the renewable generation capacities needed for electrification (chapter 5) and how the energy transition projects envisaged in the two countries as representatives of the Global South and North are interconnected (chapter 6) through import/export of energy sources, goods and technology and concludes with requirements for a just transition and some reflections on the need to think and design an energy transition beyond decarbonisation (chapter 7). Public policies (chapter 0) aiming at an energy transition in both countries are listed in the annex.

2 Sectoral analysis Colombia: current situation and challenges for decarbonisation

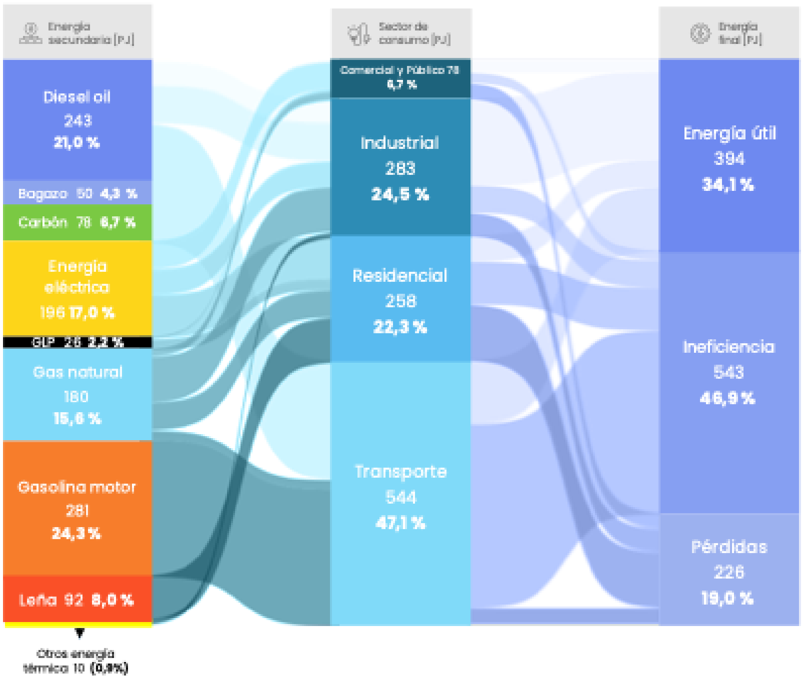
This report focuses on the energy transition as a strategy for GHG emissions mitigation. After a brief summary of recent efforts to reduce emissions from the AFOLU sector, the section concentrates on emissions from energy uses rather than other emissions. It discusses energy consumption and supply by sectors, projections and sectoral plans in Colombia, and in the following section, in Germany. Behind the GHG emissions from the "energy" sector depicted in the Fig. 1 is the use (combustion) of fossil fuels in Colombia. These come mainly from the transport sector (600 EJ, gasoline, diesel and paraffin), the industrial sector (300 EJ, natural gas, coal and firewood), and the residential sector (260 EJ, natural gas and firewood) (Fig. 3). The agricultural and mining sectors consume a smaller share. Electricity generation and export of energy sources is not included in this graph, but is discussed separately in the chapters below.
Fig. 4 shows how energy sources (secondary energy only, no primary sources) are distributed across sectors. It also shows that only 34% of secondary energy is converted into useful energy. This is mainly a consequence of inefficient combustion processes in industrial plants, residential uses and diesel and gasoline engines.

Fig. 3: Consumption of energy sources by sector (2020)



Data source: UPME (UPME, 2023a)

Fig. 4: Energy consumption by source and use by sector (2020)



Source: UPME (2022a, p. 11)

2.1 AFOLU: Agriculture, Forestry, Land Use

In Colombia, emissions come mainly from the land use and land use change sector, as follows: Grasslands (Grasslands remaining as such and Forest land converted to grasslands) with 20% of the national total; Forest land remaining as such (stock change), corresponding to emissions from the change from natural forest to another type of cover or use, with 11%; and 3 Forest land remaining as such (natural forest), corresponding to emissions associated with forest degradation due to the consumption of firewood by the rural population, with 6%. These three (3) subcategories together with enteric fermentation (subcategory 3A1), which contributes 14% of the total, account for 51% of the country's total emissions.

With the sectoral composition of Colombia's greenhouse gas (GHG) emissions, deforestation is considered the main contributor to climate change in the country, generated by factors such as land grabbing, extensive cattle ranching, road construction, illegal mining and the planting of illicit crops (CCAP & FCDS, 2023).

The concomitant strategies over the last twenty years have shifted from the militaristic and policing approach of the two Uribe governments (2002 to 2010) focused on combating illicit crops as the cause of deforestation, to the institutionalist strategy of Santos (2010 to 2018). This strategy, despite including Payments for Environmental Services (PES; PAS in Spanish) schemes and the signing of the Paris Agreement in 2015, saw deforestation rates rise, which were associated with the end of territorial control by the FARC as a result of the signing of the Peace Agreement. Subsequently, the Duque government (2018-2022) returned to a military approach with the so-called “Operation Artemisa”, which, at a high cost in terms of human rights violations (Bautista, 2022) aimed to recover areas of natural parks, but failed to lower deforestation rates. In the Petro government since 2022, the military strategy was replaced by a community strategy based on social agreements and educational action, with some precedents in the country, whose main obstacle has been a lack of funding. Its effectiveness cannot be assessed yet.

The global strategy to reduce emissions from deforestation and forest degradation (REDD+) has served as a framework for several Colombian government strategies. Two main groups of initiatives stand out: multilateral agreements such as the Joint Declaration of Intent (DCI in Spanish) and voluntary carbon markets. The Joint Declaration of Intent was initially signed at COP21 in 2015 and has been extended until 2025, as a mechanism for payment for results in GHG reduction by Germany, Norway and Great Britain (UK Government et al., 2023), Sweden and Switzerland have joined them. These countries pay the Colombian government for results achieved based on policy or implementation milestones up to USD 106 million, and for verified emission reductions up to USD 260 million. One of the initiatives implemented under the DCI was Visión Amazonía, which combined the objectives of deforestation control (reducing net deforestation to zero by 2020) and peacebuilding, as it focuses on a territory with a long history of armed conflict. As monitoring shows, the deforestation reduction target has not been met and the objectives have been diluted into less specific achievements (UK Government et al., 2023). The shortcomings of Amazon Vision are attributed to the fact that its actions have been disconnected from the structural drivers of deforestation (Rodríguez-de-Francisco et al., 2021). The lack of attention to indigenous peoples' rights and the consequent unequal distribution of benefits has also been criticised (Andoke Andoke et al., 2023).

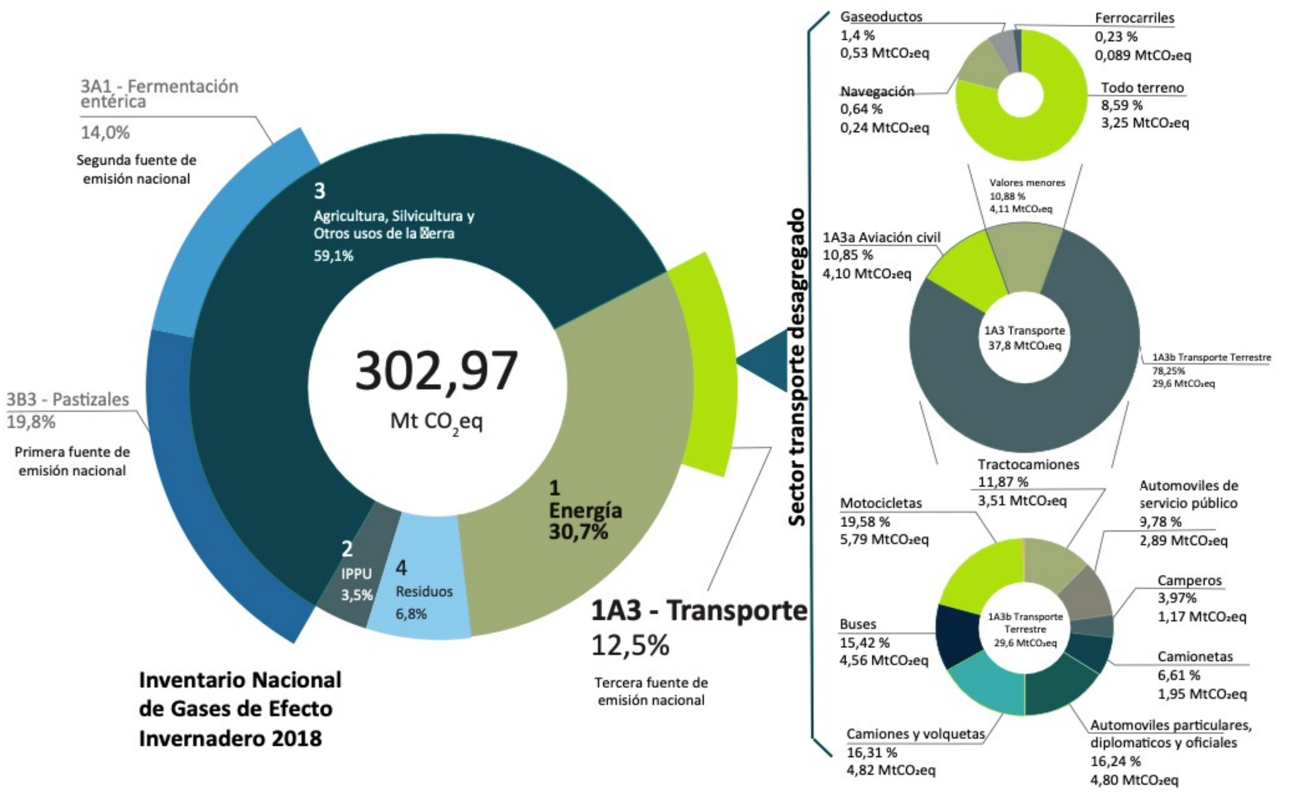
On the other hand, voluntary schemes that trade emissions from companies or countries for the potential of carbon sequestration in tropical vegetation or soils, also called "nature-based solutions", have operated for about twenty years under the assumption of equivalence between emissions from fossil fuel burning and sequestration in vegetation and soils. The former are part of the slow carbon cycle and the latter are part of the biological cycle, which is unstable and takes a long time to effectively sequester the carbon emitted by burning fossil fuels. In addition to the equivalence problem, it has been shown that avoided deforestation offset projects have not actually avoided deforestation, and if they have, it has been far less than claimed (West et al., 2023).

The difficulties demonstrated in reducing emissions from deforestation in Colombia underline for the country to consider adjustments to the AFOLU sector strategies, seeking to address the structural causes of changes in land use, and also to address the decarbonisation of the other sectors responsible for GHG emissions.

2.2 Transport

The passenger and freight transport system in Colombia is mainly based on road transport, which generates 78% of the sector's GHG emissions (Fig. 5). Although air transport volumes are lower, annual emissions from this mode amount to 10%, due to the high intensity of energy consumption.

Fig. 5: GHG emissions from the transport sector (2018)

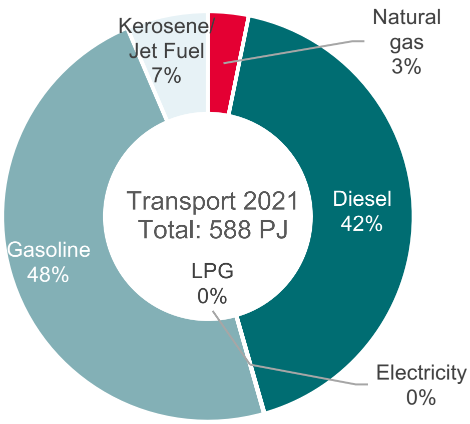


Source: Mintransporte (2022, p. 53)

The fuels used in the sector are mostly diesel (trucks, tractors, buses), gasoline and in limited quantities natural gas (private cars and motorbikes) and kerosene (aircraft), totalling 588 PJ/a (2021) (Fig. 6). With 0.3 PJ, electricity still plays a marginal role, including the Medellín metro and few electric cars (BEV).

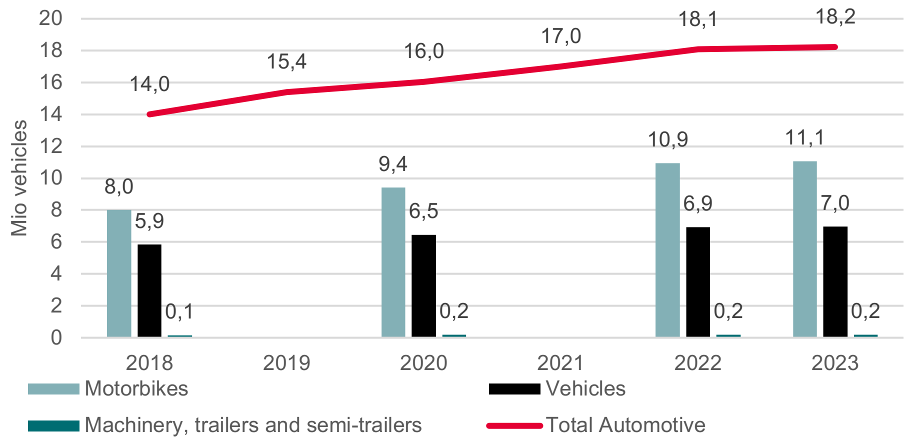
The number of cars, motorbikes and heavy-duty vehicles is growing, as is the global trend (Fig. 7). There are currently 135 vehicles per 1000 Colombian inhabitants. This trend is maintained in the projections. UPME projects an increase in demand until 2035 for all fossil fuels: 14% diesel (ACPM), 19% gasoline, 34% LPG and 80% kerosene (Fig. 8). This projection is completely incompatible with GHG emission mitigation targets.

Fig. 6: Primary and secondary energy in the transport sector



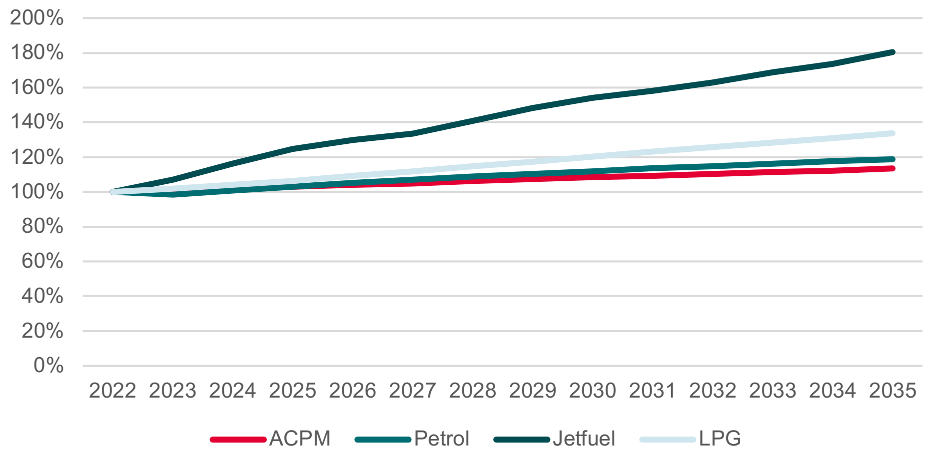
Data source: UPME (2023a)

Fig. 7: Vehicle fleet registered in the single national traffic register (RUNT)



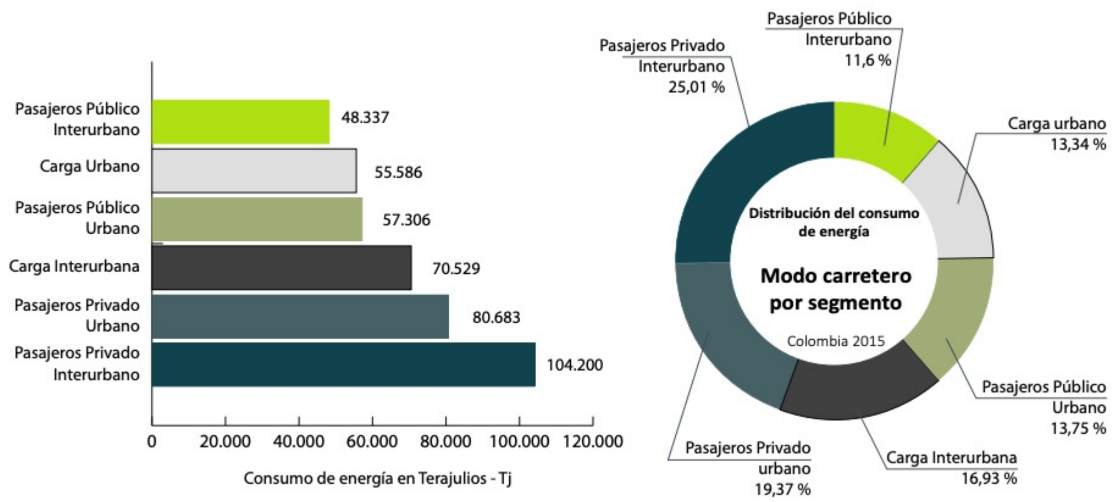
Data source: compiled from RUNT (2023) graph by author

Fig. 8: Fuel demand projection



Data source: UPME (2022), calculations and graph by author

Fig. 9: Energy consumption by road transport



Source: Mintransporte (2022, p. 56)

The decarbonisation of transport as the third largest source of GHG emissions is key to an energy transition in Colombia. And as the sector is currently entirely concentrated on roads and combustion engines, it will require an adequate policy strategy that achieves a forceful transformation for all major sub-sectors: urban and inter-urban passenger transport (both individual and public) and urban and inter-urban freight. It requires an improvement of public transport infrastructure (including a focus on the most efficient mode: trains), and the elaboration of a strategy to replace fossil fuels by electric engines (battery or hydrogen) or by biomass (biodiesel or bioethanol).

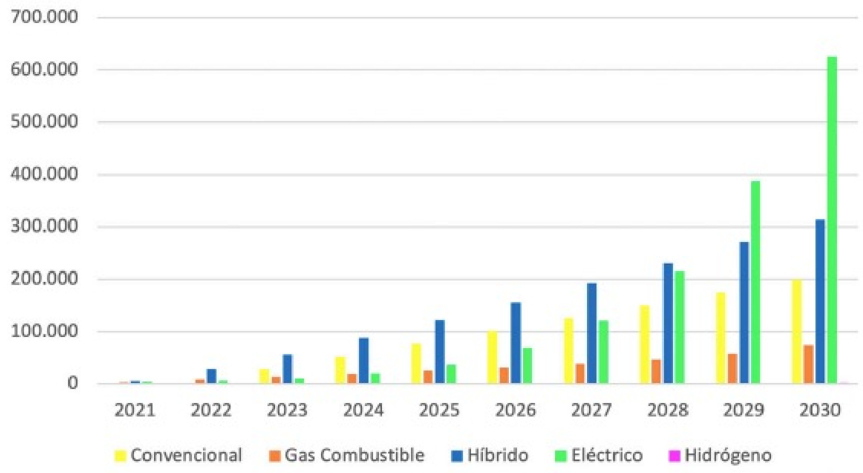
The final version of the National Development Plan (PND in Spanish, Plan Nacional de Desarrollo) is not specific about steps in the transport sector. Mention is made of the possibility for the national government to finance more than 70% of rail passenger transport systems (Article 172) and the promotion of electric school mobility (Article 221). Green and white hydrogen are defined, but no concrete plan for the development of this industry is included, nor any plan for the progressive transition of mobility through tax incentives, technical assistance and electric power supply, as promised in the election campaign (Petro & Márquez, 2022). The PND lacks concrete measures to be taken for a transformation of the mobility and freight sector.

Transport fuel prices in Colombia have been protected from the volatility of international oil prices through the Fuel Price Stabilisation Fund (FEPC) that was created in 2007. Compensating Ecopetrol for the difference between the domestic and international price has generated a growing deficit especially after the pandemic, becoming a fiscal risk. The Petro government has initiated a gradual increase in the price of gasoline and plans to increase the price of diesel. The political risk of this increase relates to a possible impact on inflation, especially in food. However, the goal is to raise domestic prices to the level of international prices in order to discourage the use of private vehicles (cars and motorbikes) with the dismantling of a regressive subsidy.

The national transport strategy of the former Duque government (Mintransporte, 2022) contains a detailed diagnosis of the transport sector with a disaggregation by vehicle type (light and heavy/cargo, individual and public), by emission standard, etc. In contrast, the current NDP refers superficially to rail, with little vision and no concrete measures. The few railway lines in operation (Mintransporte, 2022, p. 71) are mainly used for the transport of coal and other cargo, mostly for export. The strategy names several Nationally Appropriate Mitigation Actions (NAMAs) in the transport sector (incl. issues of freight efficiency, cycling/rationalisation of private modes, digitalisation and electric mobility). It seems unlikely that these pilot projects will fundamentally change the sector.

The national strategy postulates as objectives to mitigate GHG emissions, increase efficiency and diversify the energy mix, improve transport security and encourage energy transition. The "action plan" chapter focuses on electromobility, but in the sense of expanding rather than replacing existing vehicles.

Fig. 10: Projections of cumulative growth by technology 2022-2030



Source: Mintransporte (2022, p. 56)

The projections include the growth of new technologies (vehicle fleet), where especially electric and hybrid vehicles show the highest growth in the current decade, but with a growth of fossil technologies that remain in the market. It is not clear how this scenario could be compatible with the goals of the Paris agreement, nor how a decarbonisation of the[1] sector will be achieved with such an increase in vehicles (even if they are electric: indicative target 1.2 M, 7% by 2030) (Mintransporte, 2022, p. 97), nor how these vehicles will be able to circulate on the country's roads.
In the automotive markets of the Global North, where the car per capita rate is already much higher than in Colombia (DE: 0.59/cap vs. COL: 0.135/cap), the planned decarbonisation strategy (see chapter 3.2) mainly follows two measures:

- Technological change: replacement of combustion engines by electric motorisation (battery or fuel cell/hydrogen).
- Mode shift: substitution of kilometres by individual vehicle to public transport (electric train/bus), or non-motorised means of transport

For Colombia there are additional options:

- Biofuels (oil-based)
- Biogas (based on agricultural residues or dedicated crops)
- Bioethanol (e.g. sugar-based)

The latter options are not feasible in many countries of the Global North (esp. Europe), where agricultural areas are already very limited and the expansion of sustainable bioenergy production is hardly viable. For Colombia, the potential and the sustainability of these options are to be studied in detail. Bioethanol is already used as a main strategy in Brazil and could be implemented in the short term. The technology is mature and ethanol can be blended with gasoline to gradually replace it, using the same engine fuels (Sydney et al., 2019). However, it may have limits due to the social conditions of sugar cane production in Colombia. In addition, engines are less efficient than BEV, with losses >70%.

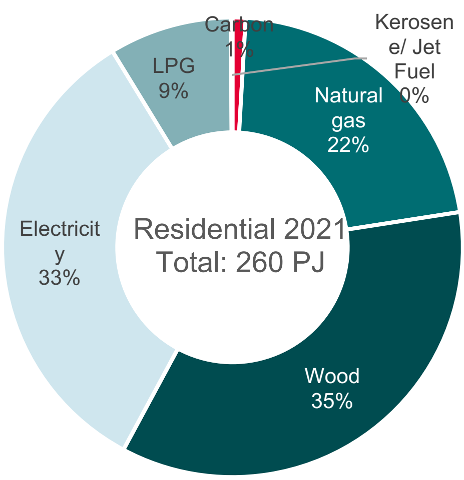
[1] A study by the National University (Valencia Hernandez, 2022) evaluates transport scenarios for Colombia by means of a system dynamics model, with a focus on propulsion technologies (without alternatives such as rail), along similar lines to the Government's narrative (Mintransporte, 2022). The 4 scenarios evaluated do not lead to a decarbonisation of the sector (emissions variation between± 20% (p. 108) compared to *business as usual*).

The Global North strategy on the other hand aims at electrification (direct: BEV with higher efficiency >90%, or indirect via hydrogen), which would reduce the primary energy consumption of the transport sector, because the direct use of electricity is more efficient and has fewer losses. BEV technology is still more expensive than internal combustion engines (ICE), which makes it inaccessible for a large part of the Colombian population. Given the high number of motorcycles, their decarbonisation is equally important. With technological advances, low electricity costs (compared to other countries), and possibly state subsidies, especially small BEVs and probably also motorcycles can already be cheaper in the long run than ICEs (Liu et al., 2021), and could become the preferred decarbonisation technology. In the current strategies for articulated bus systems, natural gas vehicles are the preferred emission reduction technology. This is however not decarbonisation, and very little action on electrification can be observed.
The electrification strategy in turn relies on large amounts of additional electric power that has to be generated, distributed and a charging network. There are no projections for the additional electric power, nor the charging network in Colombia. A focus on less energy-intensive public transport is key to minimising total sector consumption.

2.3 Residential

Residential energy consumption is equally divided between electricity, firewood and gas (natural and liquefied) (Fig. 11). While electricity is used for all residential applications including e.g. lighting and refrigeration, wood and gas are mostly used for cooking.
Since natural gas is considered as a transitional energy source, there has been little discussion of a medium-term plan on how this fossil carrier could be substituted. Rather, it is projected as a strategy to replace open firewood, which has serious health effects due to particulate matter (PM) emissions. However, wood is a renewable energy source. The strategy to replace open-fire cooking should rather frog-leap the fossil source, and focus on clean, health-friendly and sustainable sources such as biogas, electricity or wood in closed stoves that can be lower-cost solutions with local and renewable energy in rural areas that currently use wood.

Fig. 11: Energy consumption in the residential sector 2021



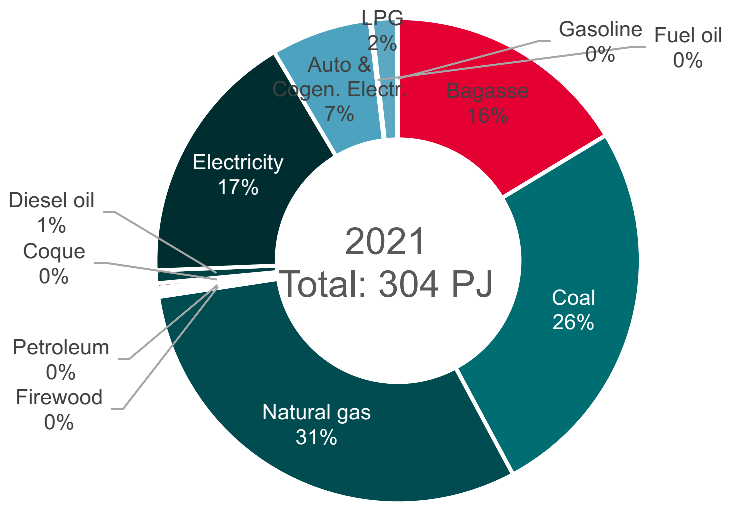
Data source: UPME (2023a)

The substitution of natural gas in urban areas can work in one of two main ways: by biogas or electricity. Both options have implications for the supply sectors: the advantage of biogas is the continued use of domestic appliances (stoves) and the existing distribution network. On the other hand, a whole new biogas industry would have to be built, capable of supplying these large quantities of biogas from organic waste or crops dedicated to gasification. Production capacities of biogas are limited and probably insufficient to serve entire cities. The other option of electrifying cooking would mean on the one hand a production and diffusion of electric stoves and on the other hand a corresponding increase in electricity demand and generation needs.

2.4 Industry

The Colombian industry is the second largest consuming sector in the country, with main energy sources being natural gas, coal, electricity and bagasse (Fig. 12).

Fig. 12: Energy consumption in the industrial sector 2021



Data source: UPME (2023a)

As industrial energy applications are typically very diverse, a description of energy sources and transformation options is superficial in this report and requires further study. Natural gas is used in a variety of furnaces for high and medium temperature processes (e.g. chemical, metallurgical, plastics etc.). As in the other sectors, there are several substitution options, the main ones being direct electrification or biomass. A detailed study of the uses in Colombia and the most favourable substitution options is needed.

The situation for coal and decarbonisation options is similar. Coal is mainly used in the metallurgical industry and for furnaces in the Colombian coal zones. For the steel and high-temperature industry, the technological route is the use of green hydrogen or direct electrification. To organise a decarbonisation process and maintain the competitiveness of the industry, Colombia needs a thorough analysis of current technologies, options for change and an industrial and investment policy strategy.

Bagasse is mostly used in the sugar industry as furnace fuel. It is a renewable source and does not require substitution. Rather, increases in the efficiency of its use could generate surpluses and supply other industries.

There is not yet a governmental roadmap for decarbonising the industrial sector in Colombia. The main challenges will be the substitution of the current use of natural gas and coal. Manufactura Latam (2022) recommends the following "pathway to decarbonise major industries" in Latin America (translated from Spanish):

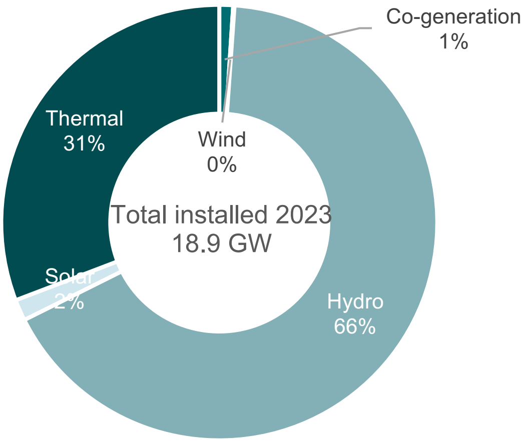
- “In the cement industry, replace fossil fuels with biomass; in the future, transition to hydrogen or electricity. [capture and storage/CCS for process emissions].

- In steel production, it is proposed to use charcoal instead of coal. Although charcoal is less efficient because it requires smaller furnaces, there are already plants in Brazil that have made the transition and are profitable [+H2, CCS for process emissions].
- Ammonia producers can replace urea with nitrate-based fertilisers, produced from ammonia rather than carbon dioxide [...]
- In ethylene production, recycled plastics would reduce the carbon emissions associated with the cracking process. Plastic manufacturers could use zero-carbon hydrogen or biomass to heat pyrolysis furnaces, a modification that would require minimal alterations to furnace design. [...]"(Latam, 2022).

2.5 Electricity generation

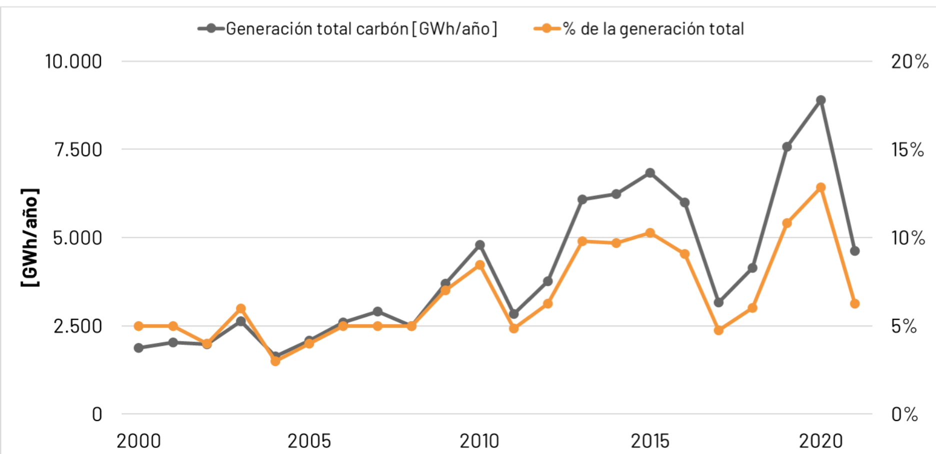
The installed fleet of electricity generation plants in Colombia currently amounts to almost 20 GW, of which 2/3 are hydro and 1/3 are thermal (Fig. 13). The plants generate around 70 TWh/a (Fig. 15), of which approx. 60 TWh are hydro and the remainder are coal-fired thermal (Fig. 14) and natural gas, with a small share of Diesel (Spanish: ACPM), especially in the Caribbean region.

Fig. 13: Installed capacity by type of generation



Data source: XM (2023)

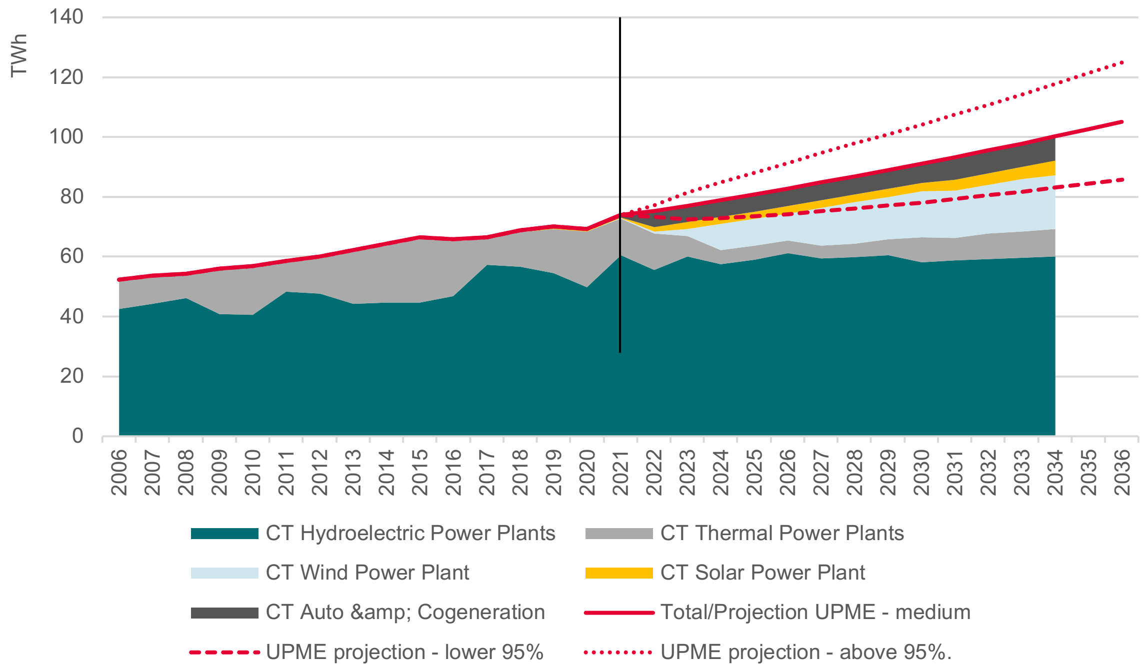
Fig. 14: GWh_{el} generated by coal source



Data source: XM (2022), cited in Flechas Mejía et al. (2022, p. 5)

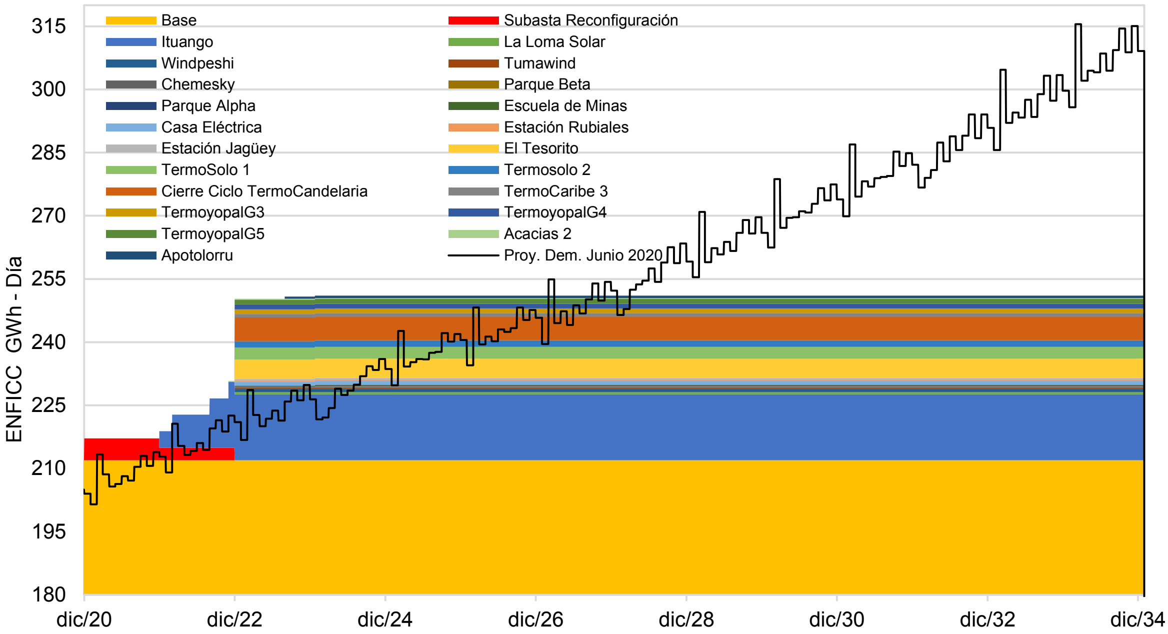
Key to the decarbonisation of the electricity sector will be the elimination of fossil fuels (coal and gas) and the expansion of "non-conventional renewable energy sources" (NC-RES) to replace them and to meet future demand growth.
Variations in coal use over the last decade (Fig. 14) are related to water shortages in reservoirs especially during *El Niño* events. The trend in coal use is increasing, given the construction of new thermal plants in the last decade. In 2022, there were 19 active plants with a capacity of 1.7 GW.
The organisation Transforma proposed a roadmap for phasing out coal-fired plants (Flechas Mejía et al., 2022). It proposes a possible closure of the oldest and most inefficient facilities first, in two scenarios until 2030 or 2035, and a replacement by NC-RES. A similar analysis is to be done with respect to natural gas plants. Fig. 15 shows how the projected growing demand is met by new generation capacity coming on stream, mainly Ituango, thermal plants and planned new wind farms.
UPME regularly projects the demand for energy sources including electricity, taking into account trends and new expected uses (e.g. from major industrial activities, BEV or the Bogotá metro). The projection (UPME, 2022) estimates an increase in demand from 75 TWh/y in 2022 to 85-117 TWh/y in 2036 (Fig. 15). This does not include a longer-term projection and especially does not include the massive electrification of sectors that currently use substantial amounts of fossil energy (transport, industry, residential).

Fig. 15: Electricity generation energy matrix 2006-2021



Data source: Historical data up to 2021 UPME (2023a)percentage generation projection from 2022 UPME (2020, p. 49 scenario 1) (2020, p. 49 scenario 1)demand projection UPME (2022, p. 49) (2022). Calculations and graph: author.

Fig. 16: "Firm energy" and demand projection 2020-2034



Source: UPME (2020, p. 23)

In the list of fixed expansion projects (projects under management), Tab. 2 includes, next to Hidroituango, the vast majority of NC-RES (2.7 GW), and the thermal projects (0.9 GW) that could be the last to come on stream in Colombia (UPME, 2020).
In its "baseline expansion plan" (UPME, 2020) UPME uses a simulation model to evaluate the future expansion and utilisation of technologies in the electricity generation fleet. Given that NC-RES (wind, solar) are already lower cost than coal plants (Tab. 1), much less than the 1800-2400 USD/kW calculated by the World Bank in 2010 (World Bank, 2010) and with gas expected to be of limited scope and increasing cost, the simulation finds that new capacity would be solely NC-RES. This is also reflected in the contribution of the source to the projected electricity generation (Fig. 15). In the different sensitivity scenarios (delayed entry into operation of Hidroituango, El Niño, carbon tax of USD 5/tCO2, or application of the Environmental Flow Guide for hydropower) of the UPME, the changes lead to an increased need for construction of solar and wind plants. Long-term scenarios (2050) foresee a 150% increase in installed capacity, with main expansion of solar and wind, but still including thermal plants in 2035-2050 which is not compatible with the goals of the Paris agreement.

Tab. 1: CAPEX of electricity generation facilities by technology (2020)

Tecnología	Mínimo [$/kW]	Promedio [$/kW]	Máximo [$/kW]
Carbón	1,300	1,900	2,500
Gas	1086	1,150	1,213
Crudo	1,613	1,613	1,613
Hidro Mayor	1,704	1,792	1,880
Hidro Menor	2,542	2,542	2,542
Eólico	1,108	1,454	1,800
Solar	710	1,105	1,500
Biomasa-Cog	2,141	2,141	2,141
Geotermia	4,500	4,500	4,500

Source: UPME (2020, p. 28)

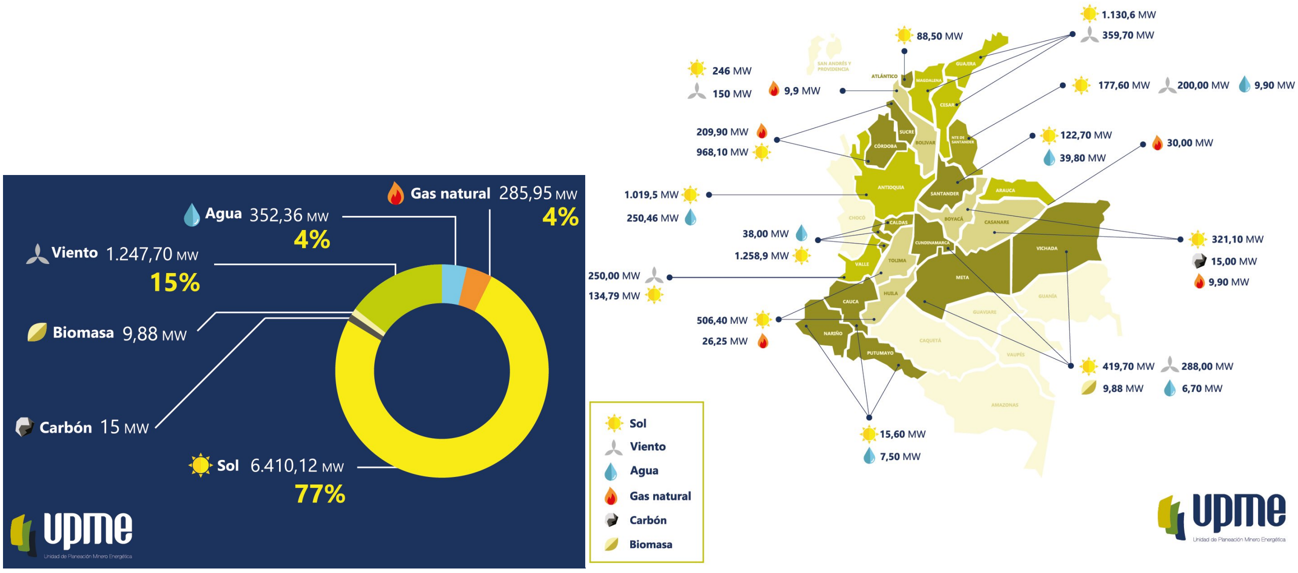
Tab. 2: Fixed expansion projects (2020)

Technology	MW (total sum)	Planned connection (last unit)
Solar	702	1/24
Wind	2072	11/23
Hydro (Ituango)	1200	6/22
Thermal	909	12/23

Data source: UPME (2020, p. 28), aggregation of complete list of projects

Expansion in generation capacity has continued in 2022-2023 along these lines, but with more emphasis on solar (6410 MW), wind (1247 MW) and other marginal plants. The largest capacity additions are concentrated in the north and centre of the country (UPME, 2023b).

Fig. 17: Capacity 2022-2023 (29 March 2023) allocated by resource



Source: UPME (on twitter 2023b)

2.6 Fossil energy exploitation and exploration

Among the three main fossil energy sources (coal, natural gas and oil) there are significant differences in exploitation/exploration and use amounts (Fig. 18) according to energy balance figures (UPME, 2023a):

- Of the coal mined in the country's main mines (esp. Cesar, Guajira), almost all is exported. Only a minimal percentage is used for electricity generation, coke oven processing and industrial consumption (and marginally for residential heating).
- Colombia is (still) self-sufficient in natural gas supply. A certain percentage of the exploitation is lost to categories such as "untapped", self-consumption or treatment (energy used for exploitation/processing), but the majority is used for final consumption (residential, industry) and in power plants. A significant portion (about 30%) of the extracted gas is re-injected into oil wells to maintain well pressure, which can also be considered as a loss due to inefficient fossil extraction.
- Oil exploitation is not only sufficient to supply domestic consumption (in the graph refinery utilisation), but more than half of domestic exploitation is exported.

Fig. 18: Extraction and use of fossil fuels 2021 (MJ)

Data source: UPME (2023a), graph by author. Note: gas reinjection = injecting into oil fields to maintain pressure.

As a consequence, Colombia is an exporter of coal and oil (chapter 2.7). For a global energy transition, the exploitation, exploration and commercialisation of these three fossil fuel sources must necessarily end in the medium term. Colombia, like any other economy, depends fundamentally on the use of these sources, and additionally on export revenues. This complicates a gradual phase-out, and endangers plans put forward during the election campaign of the Petro government as shown by current policy developments (translations from Spanish sources):

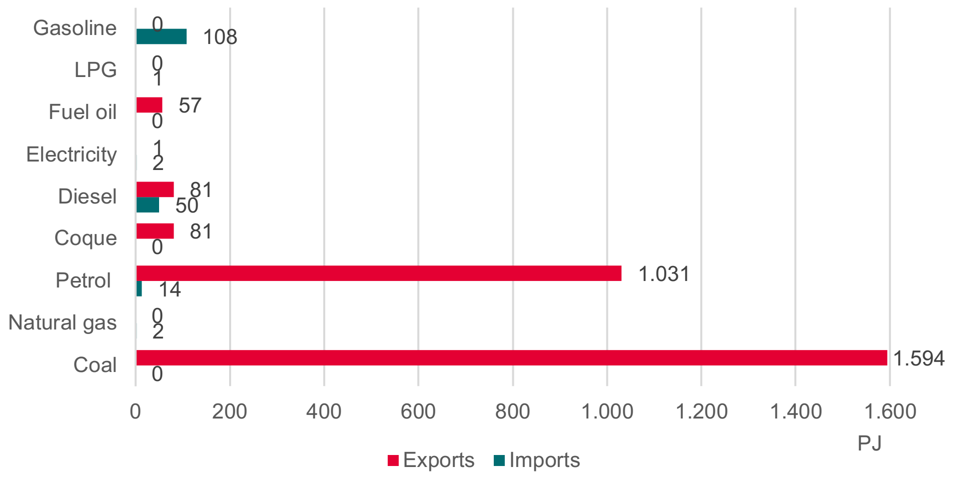
- ***Campaign*** (Petro & Márquez, 2022): "We will promote within Colombia's international policy agenda [...] the obtaining of compensation for leaving coal and oil reserves in the ground and the imposition of taxes on the commercialisation of products highly intensive in carbon dioxide" (P. 16) "In our government, the **exploration and exploitation of unconventional deposits will be prohibited, fracking pilot projects and the development of offshore deposits will be stopped. No new licences will be granted for hydrocarbon exploration, nor will large-scale open-pit mining be allowed.**" (p. 17)
- ***PND*** p. 129: "The country's energy and economic dependence on fossil fuels represents low competitiveness and accentuates vulnerability. An urgent response is required, leading progressively to substantive changes in modes of production and consumption. In a forceful manner, the financial surpluses from coal and oil will be used to make an energy transition that will lead us to a green economy" (Government of Colombia, 2022, p. 129) - no longer explicitly phasing out oil.
- ***PND coal*** (p. 148): "the development of new mining projects for the extraction of open-pit thermal coal classified as large-scale mining will be prohibited, specifying that the holders who are carrying out activities for the exploitation of this energy source will be able to continue carrying out their activities in accordance with the rights and obligations derived from their contracts; likewise, strategies will be established for agreement between the beneficiaries of the titles of contracts that are terminated or terminate, with the mining and environmental authorities, in order to provide a correct management of the closure of their operations". (Government of Colombia, 2022, p. 148)
- ***Ministry of energy on oil and gas*** (15.3.23): "In the comprehensive strategy, the National Government includes, among other instruments: [...] Continue with the exploration and exploitation of liquid fuels and gas, promoting the self-sufficiency of the energy matrix" (Minenergia, 2023)
- ***Decision of the Congress of the Republic on coal*** (17.3.2023) to eliminate article 186 of the PND that sought to prohibit the development of new mining projects for the extraction of open-pit thermal coal classified as large-scale (Quiroga Rubio, 2023).

In the presidential campaign, the government's plan called for a gradual phase-out of fossil fuels, starting with coal and no further exploration of oil and gas, accompanied by an expansion of NC-RES. Recent discussions and communiqués listed above indicate the collapse of political plans to phase out fossil fuels. The decisions that will remain in the final version of the PND and the roadmap for the energy transition scheduled for May 2023 have not yet been finalised.

2.7 Imports/exports: energy sources and other goods

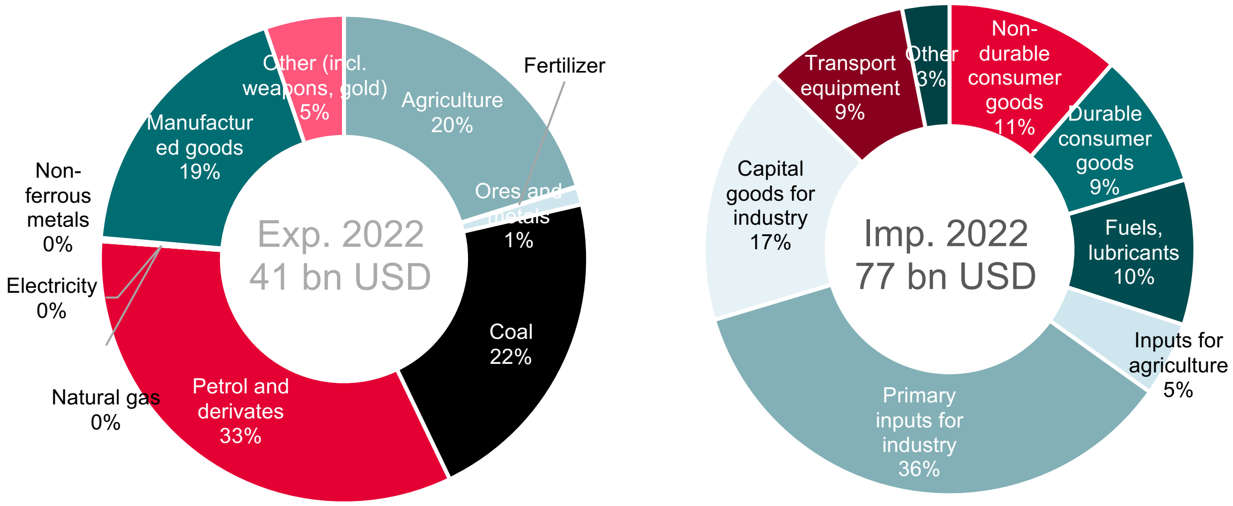
As mentioned in the previous chapter, Colombia is self-sufficient in natural gas and does not import or export significant quantities. In larger quantities, almost 1600 PJ (55 Mt) of coal and 1000 PJ (169 MBL) of oil are exported, and smaller quantities of their derivatives (import of 20 MBL of gasoline, import of 8 MBL of diesel and export of 14 MBL), Fig. 19 provides a summary.
For the balance of international payments and trade balance, the monetary value and share in international trade is key. In 2022, fossil fuels constituted 55% of Colombia's exports in value, followed by agricultural and manufacturing products. Fifty percent of imports were raw materials and capital goods for industry, followed by 20% consumer products and another 20% products for the transportation sector (Fig. 20).

Fig. 19: Energy imports/exports (PJ)



Data source: UPME (2023a)

Fig. 20: Exports (left) and imports (right) 2022, value in bn USD

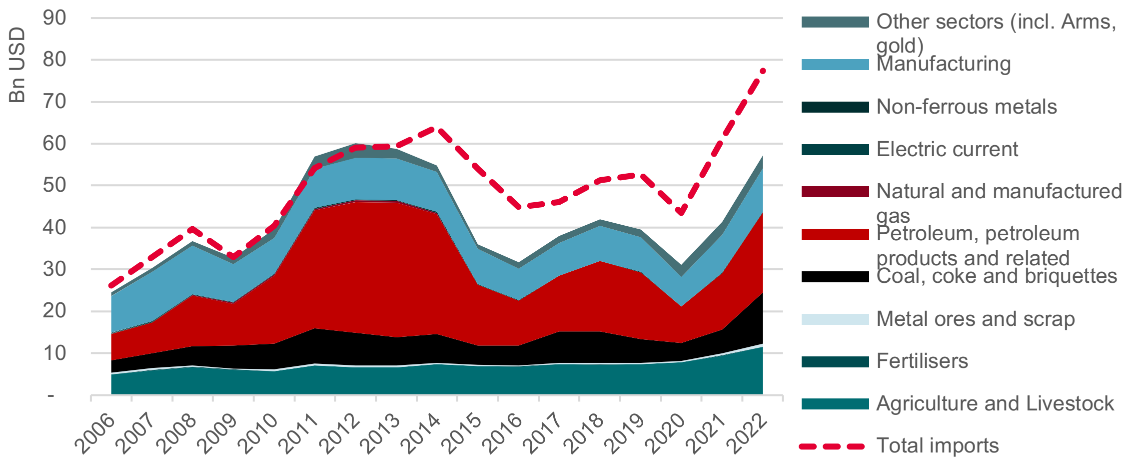


Data source: DANE (2023)

The evolution of exports and imports (Fig. 21) shows a deficit in foreign trade since 2014, when the value of oil exports fell and imports remained high. The increase in fossil energy prices and export volumes since 2021 generated an increase in the value of exports. However, despite an optimistic view of natural gas and oil exploitation by the Ministry of Mines and Energy (Minminas & ANH, 2022) the medium-term scenario requires preparation and planning by Colombia due to a number of challenges:

- Colombian gas exploitation is set to decline gradually (Minminas & ANH, 2022). From 2025 onwards, Colombia could become a natural gas importer (Moncado, 2022; UA & WTW, 2022).
- Oil exploitation is declining at 8% p.a.; without significant investment in exploration and enhanced recovery, Colombia could be an oil importer from 2028 (Moncado, 2022; UA & WTW, 2022).
- Demand (and prices) for coal and oil will decline with the transition in importing countries advancing, and shift to other (probably Global South) importing countries
- Global demand for hydrogen and derivatives is set to grow massively

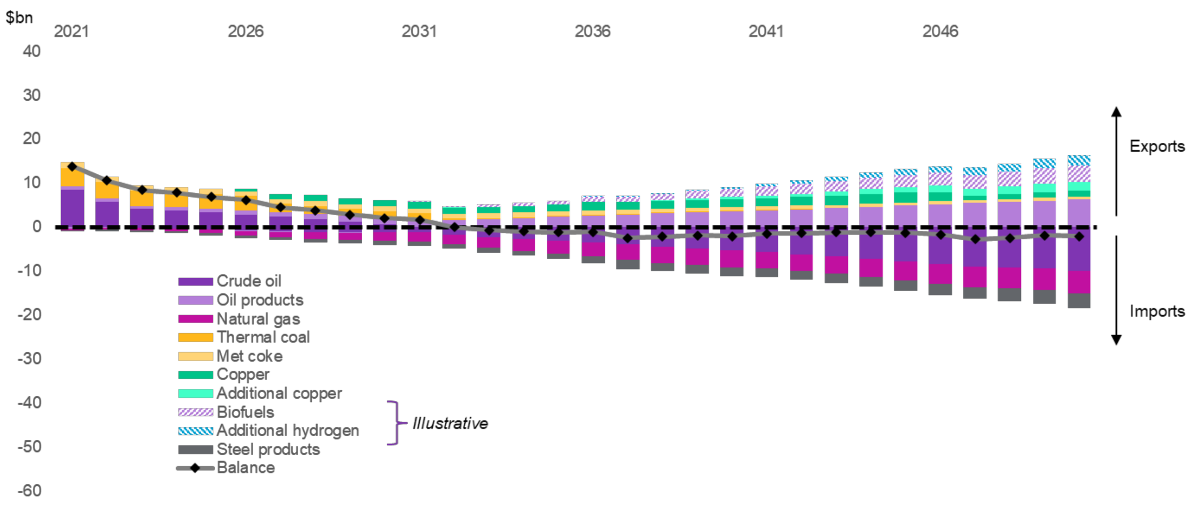
Fig. 21: Exports and imports 2006-2022



Data source: DANE (2023)

UA & WTW (2022) recently studied a scenario in which Colombia evolves from a fossil exporter to an importing and dependent country (Fig. 22). In the scenario, the authors find new exports of biofuels and hydrogen as well as metals (copper) as additional replacements to counterbalance future imports of oil, natural gas and steel products.

Fig. 22: Colombia's potential future trade balance in transition-exposed sectors (WB2C) including a growth in transition-related exports and the impact of lower domestic oil and gas consumption



Source: UA & WTW (UA & WTW, 2022, p. 19)

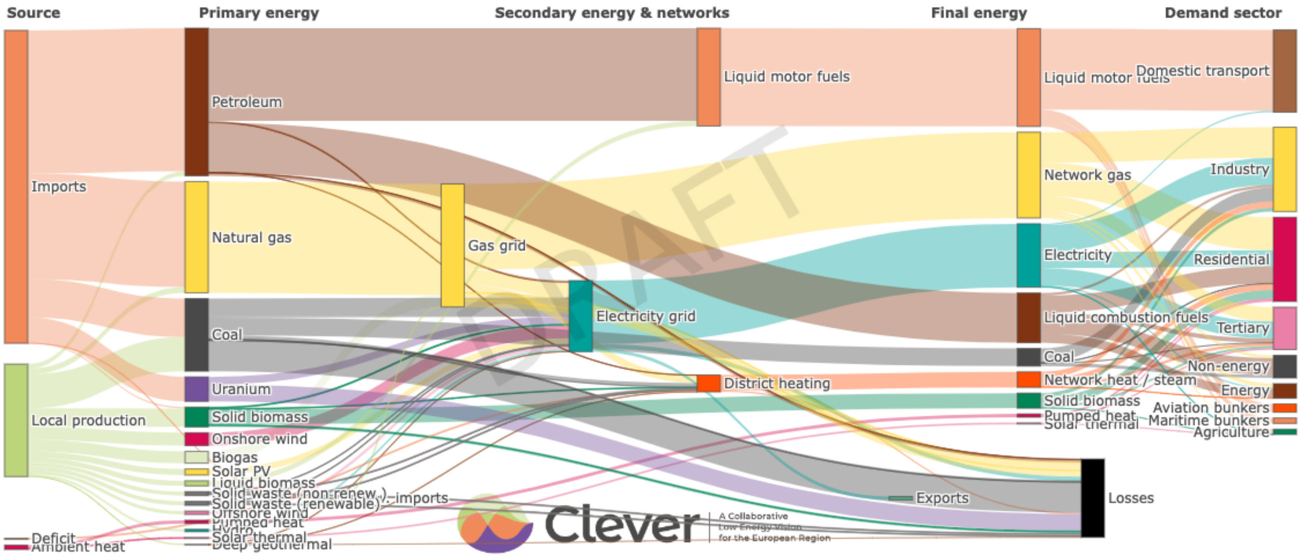
Against this backdrop, it seems even more important to replace fossil fuel consumption in all Colombian sectors in order to avoid future fossil fuel imports and rather to self-supply the Colombian economy with clean domestic sources.

Consequently, the 2022 version of the PND (Government of Colombia, 2022) formulates: "The National Government will promote the incorporation of new sources of electricity generation from NC-RES, adjusting and implementing the roadmaps for hydrogen and offshore wind energy." (P.144) and "This will allow the decarbonisation of multiple sectors and the strengthening of the export basket to gradually decrease dependence on fossil fuels" (p. 147).

The success of this strategy will be key to avoiding a serious future deficit in the external trade balance and associated currency and economic turbulence.

3 Sectoral analysis Germany: current situation and challenges for decarbonisation

Fig. 23: Sankey diagram Germany 2020



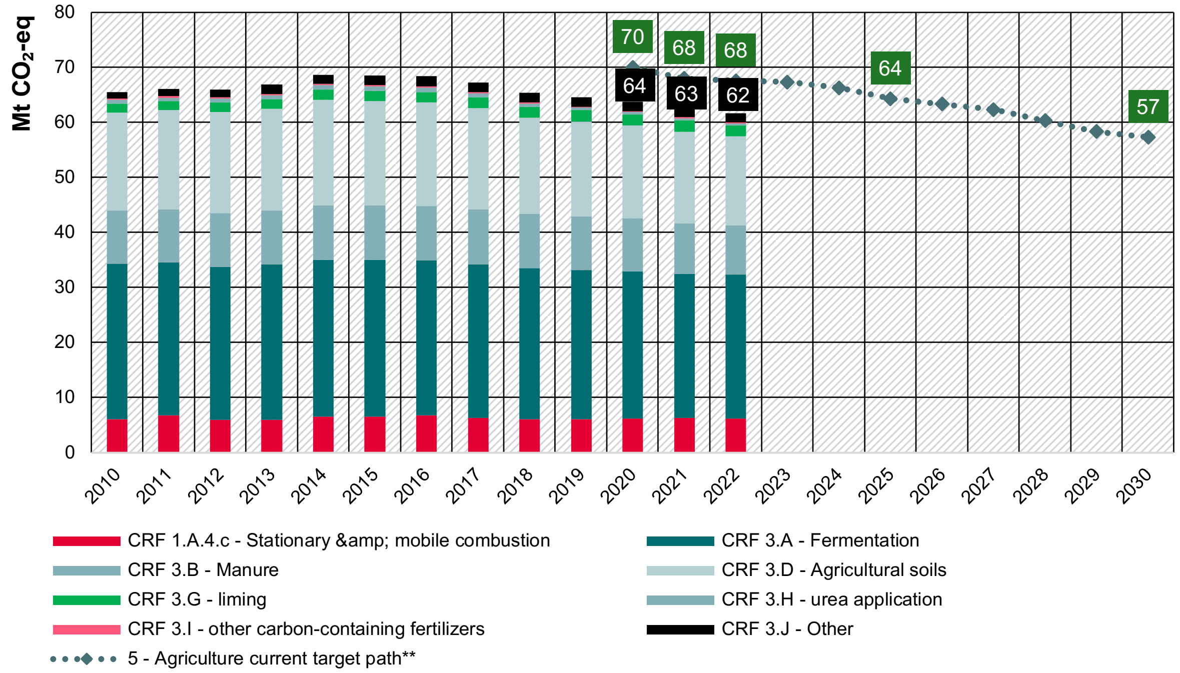
Source: CLEVER (2023)

3.1 AFOLU: Agriculture, Forestry, Land use

In Germany, the AFOLU sector accounts for only 8% or 62 of the total 762 Mt CO2eq of GHG emissions (Fig. 2), compared to 59% or 179 Mt CO2eq in Colombia. The main difference is that in Germany there are no significant land use changes, which constitute a large part of the emissions in Colombia. Fig. 24 shows the AFOLU emissions by CRF categories (UNFCCC). The highest emissions are 26 Mt from enteric fermentation (vs. 42 Mt in Colombia), followed by soils (16 Mt). For this reason, the energy transition efforts in Germany focus more on the energy sector. However, emissions in the AFOLU sector require political strategies. The Ministry of Nutrition and Agriculture focuses on 10 axes: Reduction of nitrogen and ammonia emissions, promotion of manure and agricultural waste fermentation and eco-agriculture, reduction of emissions from animal husbandry, energy efficiency, soil improvement and wetland conservation, sustainable forestry management, and sustainable nutrition (BMEL, 2022).

The main challenges are high meat consumption and consequent emissions from enteric fermentation animal livestock and manure, and soil emissions including the need for wetland protection and restoration.

Fig. 24: AFOLU emissions according to CRF category and climate mitigation law targets

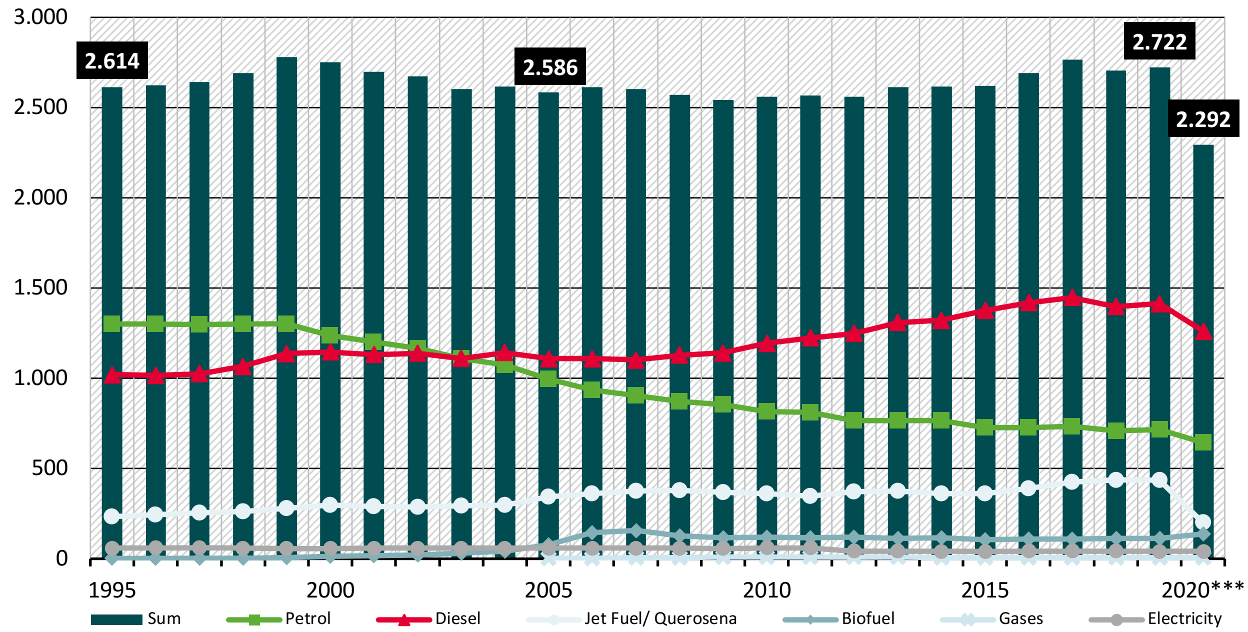


Data source: Umweltbundesamt (2023a, p. Daten Sektorgrafik)
*** sectoral target path of the law for climate mitigation (Klimaschutzgesetz)*

3.2 Transport

The transport sector contributes 19% of GHG emissions, 148 Mt CO2eq - 4 times more than the 37 Mt in Colombia. Emissions come as in Colombia mostly from the combustion of fossil liquids (tax incentives have favoured the use of diesel over petrol since 2000), with electricity playing a smaller role, especially used for railways (Fig. 25).

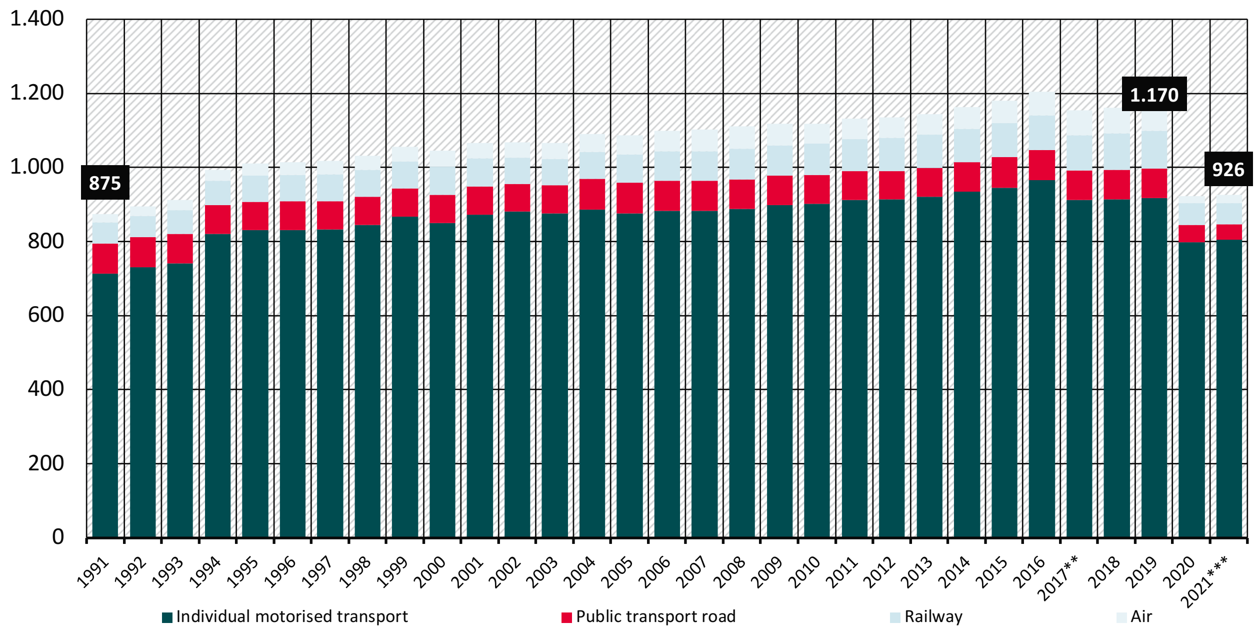
Fig. 25: Energy consumption in the transport sector by energy source (PJ)



Source: Umweltbundesamt (2023b)

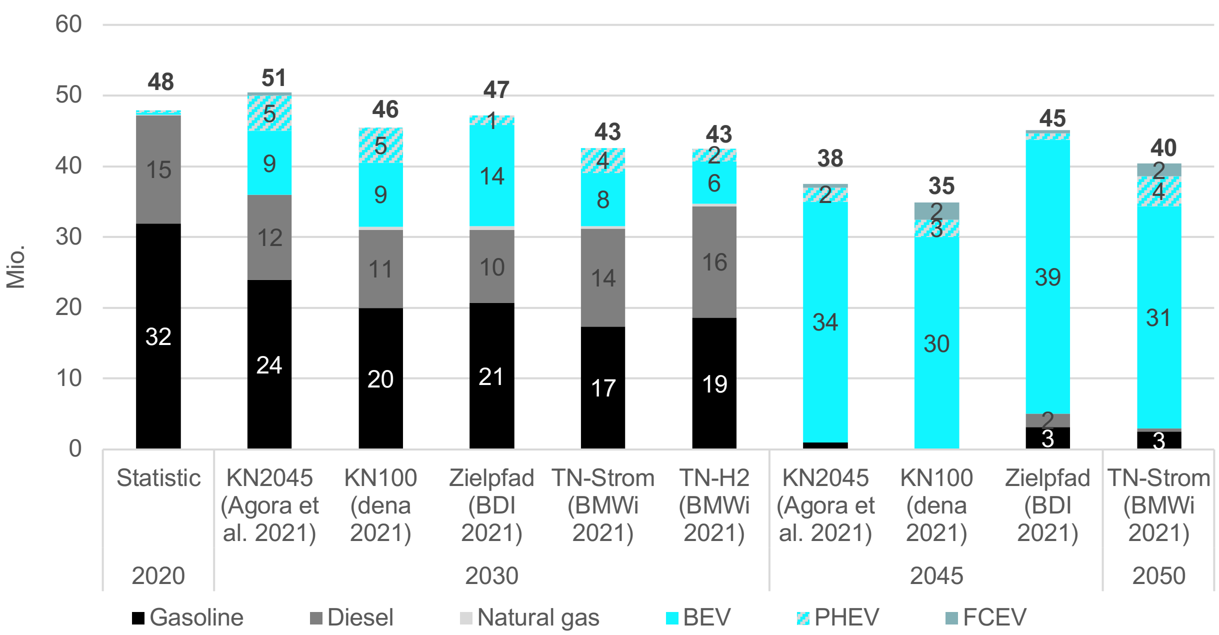
As in Colombia, the decarbonisation of the transport sector is a challenge, as 80% of the km (PKM) are travelled by individual vehicles and the remaining 20% are distributed between road, rail and air public transport (Fig. 26). Policy strategies focus on the one hand on boosting public transport and on the other hand on shifting the car sector towards electric motors.

Fig. 26: Km travelled (persons) by mode of transport (bn PKM)



Data source: Umweltbundesamt (2023c)

Fig. 27: Vehicle fleet by engine type in main scenarios



Data source: SCI4climate.NRW (2022)

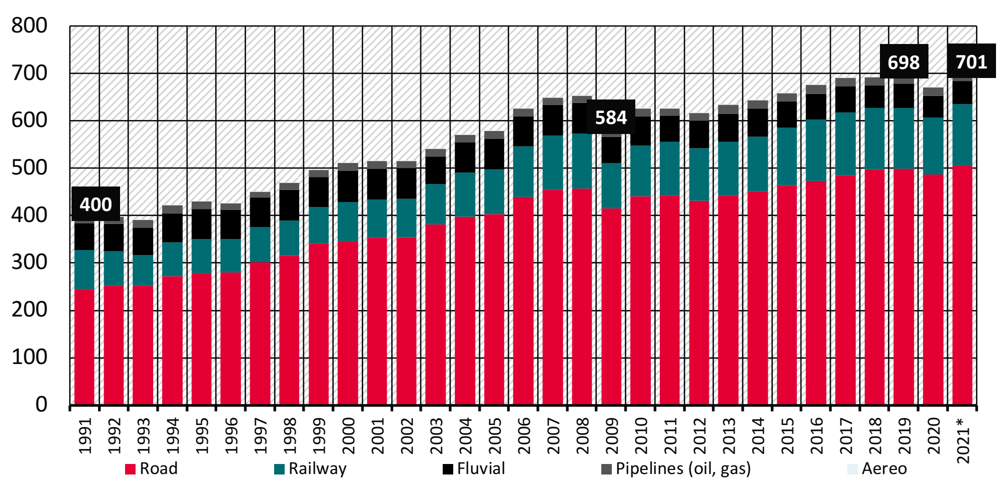
The German automotive industry as the main national industry is already preparing for this fundamental technological change. All brands, while keeping fossil cars on sale, are turning towards battery-electric products (BEVs). At the same time there is a trend towards heavier and larger vehicles. According to current European Union (EU) directives (EU 2019/631), new fossil fuel vehicles may not be sold in the EU after 2035. This means that from 2035 at the latest, the remaining fuel vehicles will be rapidly reduced and replaced by electric vehicles (possibly with a smaller share of hydrogen, biogas or synfuels, Fig. 27), which implies a shift in energy sources starting in the 2020s and ending in the 2040s. The main scenarios for Germany towards GHG neutrality project a stabilisation or even slight reduction in the volume of passenger transport (Fig. 28).

Fig. 28: Projections of transport demand (PKM passengers left and TKM freight right) in main scenarios

Data source: SCI4climate.NRW (2022)

With a growing economy, freight volumes have almost doubled since 1990. This increase has been almost entirely met by road transport, and in 2021, 66% of freight was transported by road and fossil fuels (Fig. 29). By 2050, the scenarios project with a growing economy, an additional freight volume of 20 to 35% (Fig. 28) depending on the scenario with a slight shift towards efficient modes (*modal split* rail and waterborne) and a shift towards battery, hydrogen or overhead contact line electrification technologies. Some scenarios also project the use of *biofuels* or *PtX/synfuels*.

Fig. 29: Cargo transported by mode of transport (bn TKM)

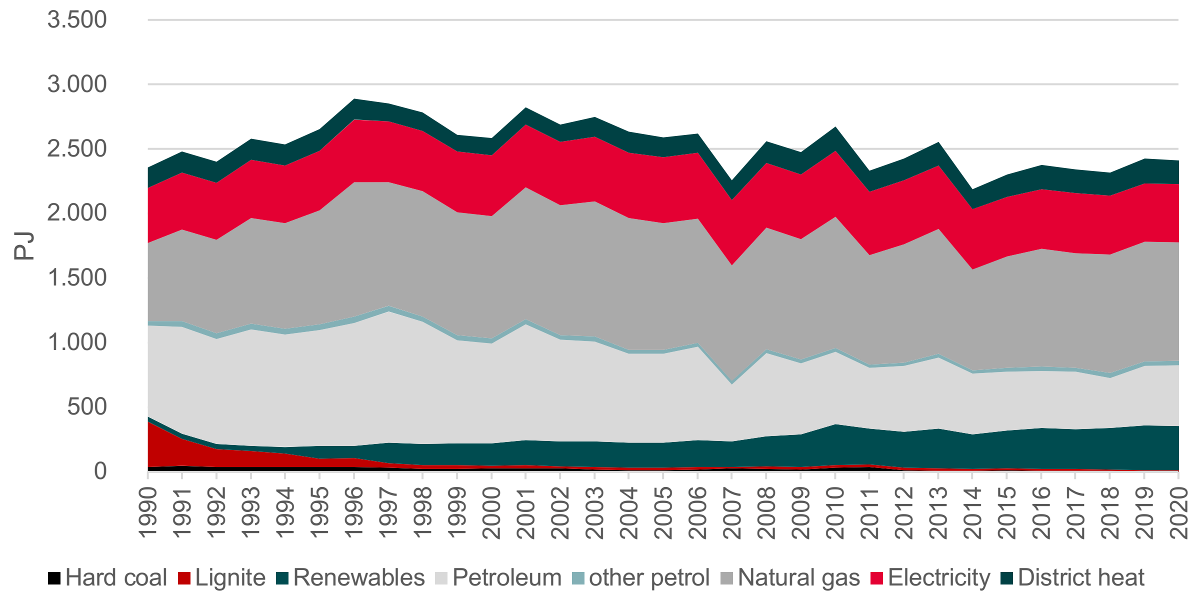


Data source: Umweltbundesamt (2023c)

3.3 Residential

In the residential sector, there has been some progress in reducing GHG emissions through efficiency gains: the use of coal as a source for heating was virtually eliminated, and there was some shift from oil to natural gas (Fig. 30). Total consumption in return has not decreased significantly despite significant efficiency gains through insulation to high standards. This is a consequence of the increase in heated floor area per capita which continues to rise. An important reason is that older people continue to live in large houses after the moving-out of children, and families build additional houses, which increases the total heated area (Bayern Labo, 2020).

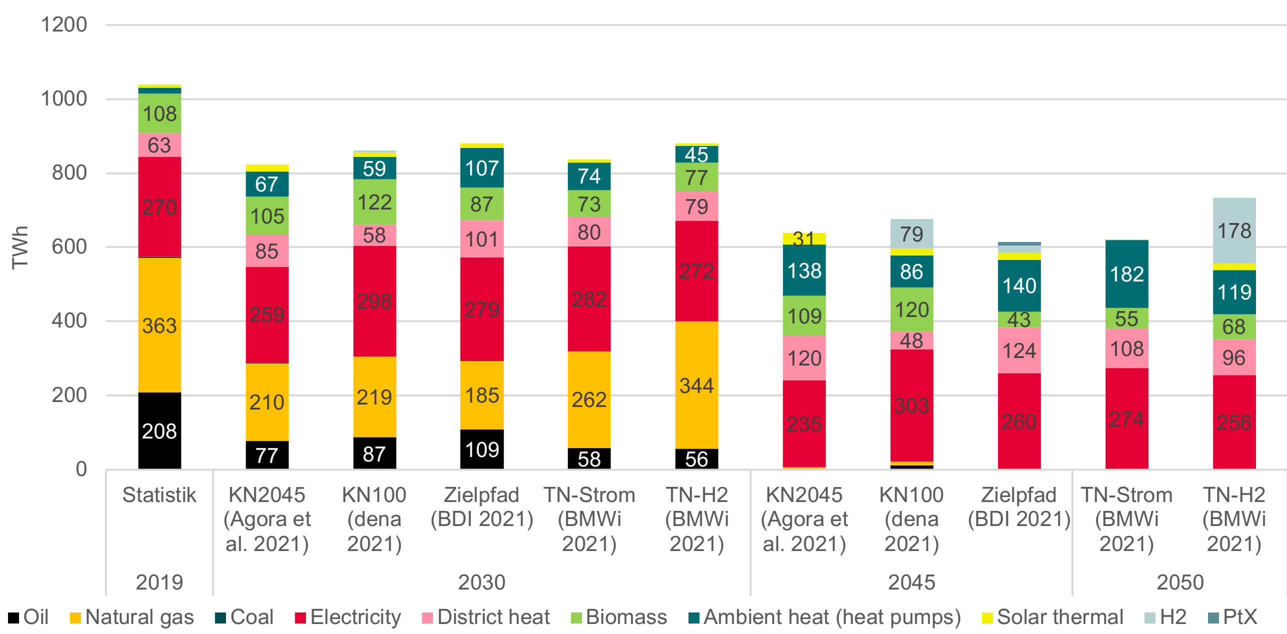
Fig. 30: Residential energy consumption by source



Data source: BMWK (2023c)

Current policy strategies concentrate on increasing the renovation/insulation rate (important EU directive: Energy Performance of Buildings Directive; currently in affiliation: COM(2021) 802 final) and changing heating technologies. In this line, the aim is to replace first oil heating and then natural gas heating. According to the update of the building law (Gebäudeenergiegesetz, GEG (BMWK, 2023a)), every heating system has to use >65% renewable energy. This reduces the role of gas or oil heating to a subsidiary part. Thus, the scenarios also project an increased use of electricity for heating by heat pumps using ambient heat, while other electricity uses are reduced (Fig. 31).

Fig. 31: Projections of residential consumption by source in main scenarios (final energy)

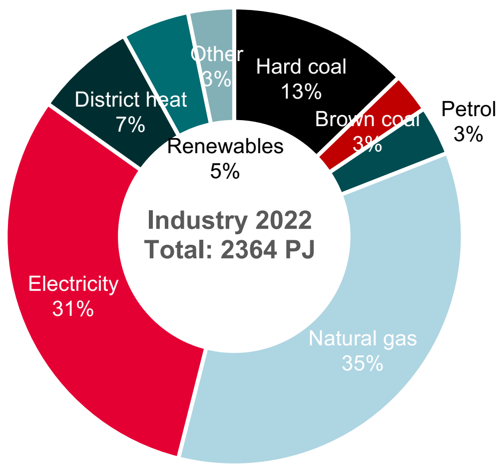


Data source: SCI4climate.NRW (2022)

3.4 Industry

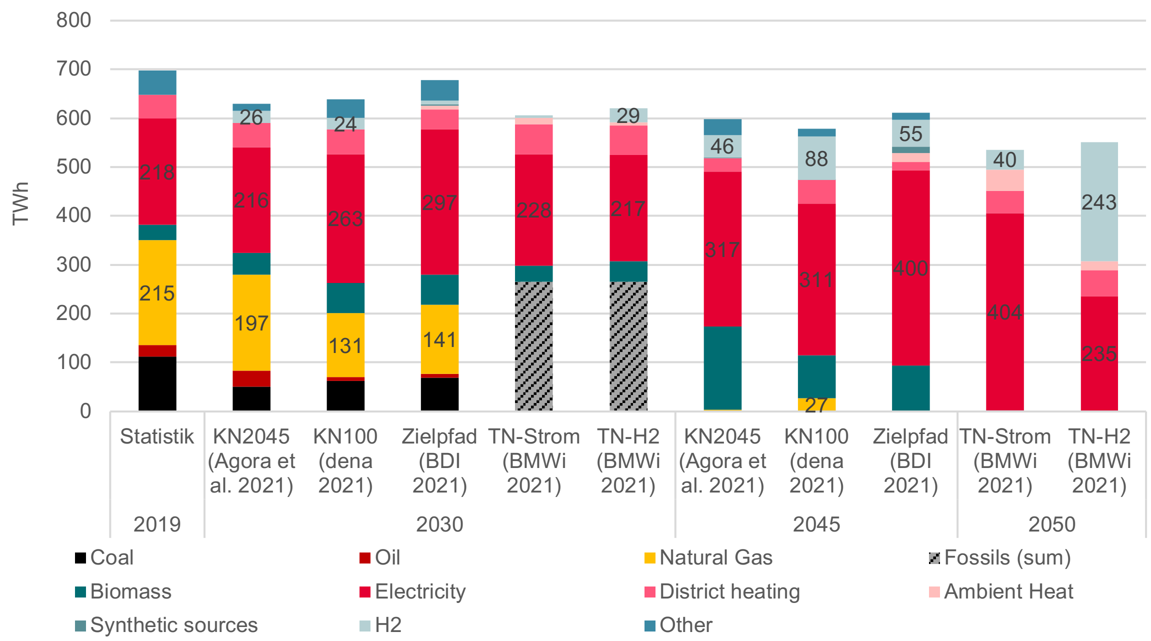
Industry is the second largest emitting sector in Germany (181 Mt CO2eq vs. 26 Mt in Colombia) after electricity generation. Emissions come mostly from the combustion of natural gas in multiple industrial uses (especially high, medium and low temperature furnaces) and from coal, which is used especially in the metallurgical industry. Decarbonisation of this sector will be key to the energy transition in Germany, as it plays a central role in the economy, employment and society.
Policy strategies and integrative processes are already underway with the main industrial associations around the implementation of actions to decarbonise industrial processes. The main pathways studied include direct electrification of processes where possible, and where not a shift towards the use of hydrogen or biomass (Fig. 33).

Fig. 32: Energy consumption by source in the industrial sector



Data source: BMWK (2023c)

Fig. 33: Projected final energy consumption in main scenarios



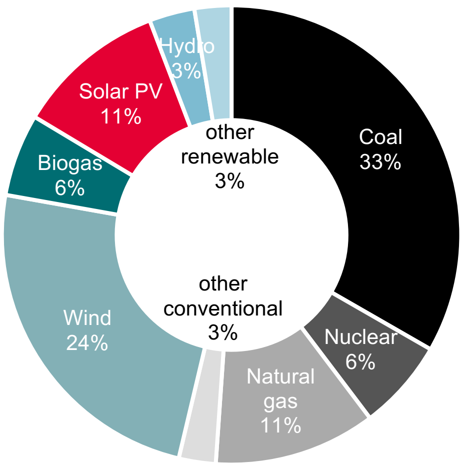
Data source: SCI4climate.NRW (2022)

3.5 Electricity generation

As the main difference to the Colombian energy system, electricity generation is the main GHG emitting sector in Germany with 33% or 247 Mt CO2eq, almost reaching Colombia's total levels. The German electricity system has already made a profound transition from a system with >35% nuclear power to its replacement by renewables. In April 2023, the last 3 nuclear plants were shut down, after decades of political discussion and a cross-party agreement with the industry. As a result, in 2022 electricity generation was half from fossil sources (coal and natural gas) and half from renewables (wind, solar, biogas and hydropower) (Fig. 34). In contrast to Colombia, hydropower has no significant potential for expansion.

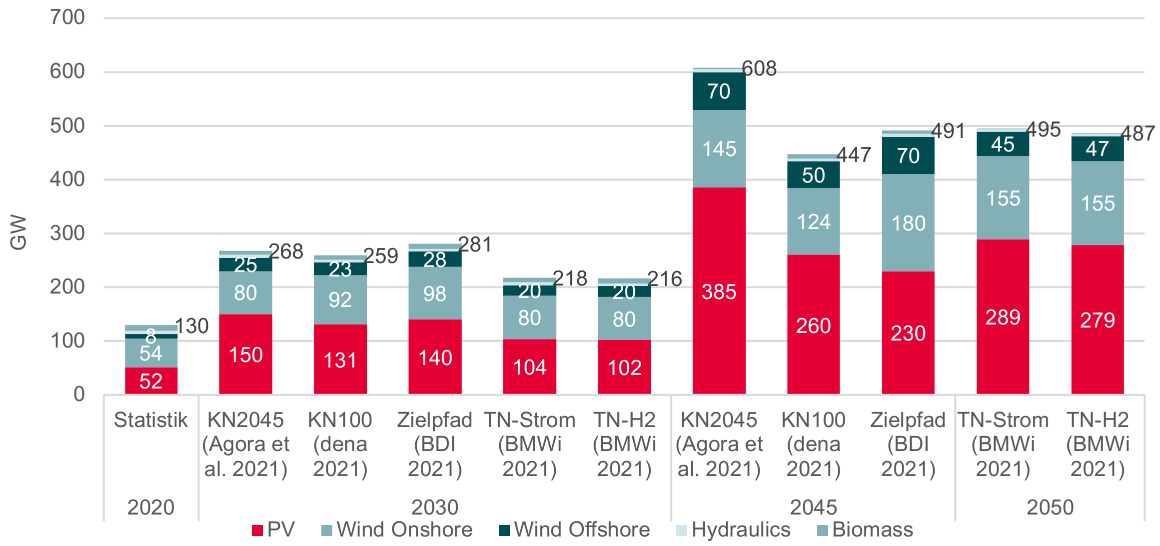
The main challenge is the rapid decarbonisation of the remaining fossil sectors. The government's principal focus is on a phase-out of coal, starting with the most inefficient plants, in the sense proposed by Flechas Mejía (2022) for Colombia. In Germany, this is law with the closure of the last coal-fired plant in 2038 (Kohleausstiegsgesetz, 2020) but the government advocates a closure possibly until 2030 (BMWK, 2022). The approach is subject to multiple revisions in the legal framework due to the rapid expansion of wind and solar energy. This is reflected in the projections of installed renewable capacities in the main scenarios (Fig. 35) and the projected electricity generation (Fig. 36).

Fig. 34: Electricity generation by technology/energy sources 2022



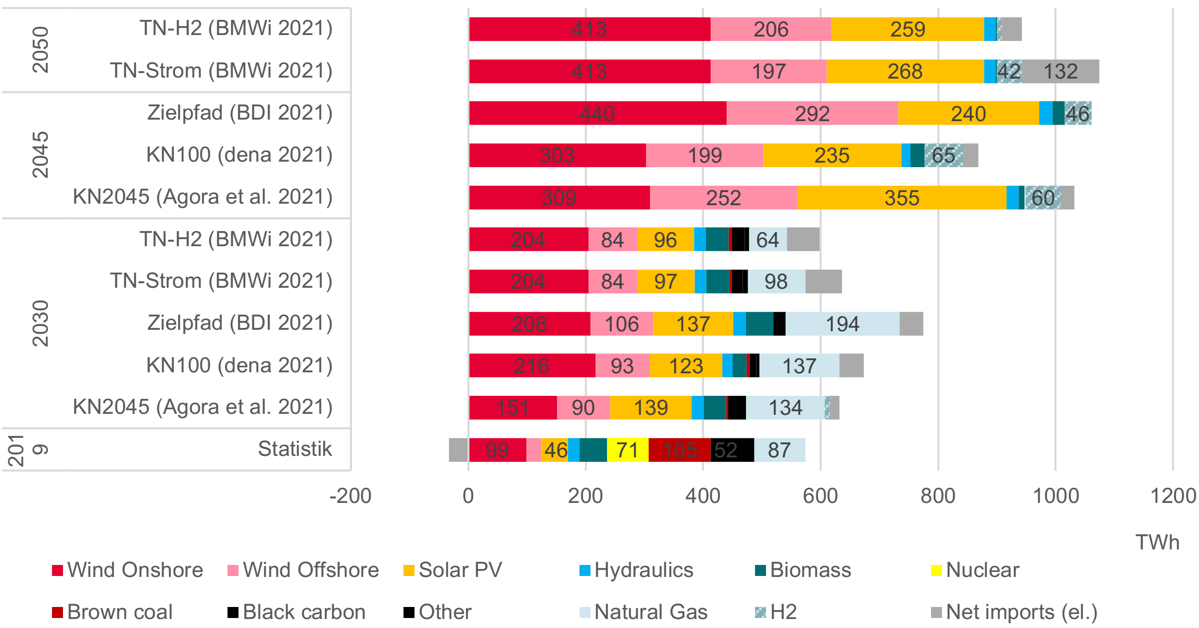
Data Source: Destatis (2023a)

Fig. 35: Projections of installed renewable energy capacities in main scenarios



Data source: SCI4climate.NRW (2022)

Fig. 36: Projections of electricity generation by energy sources in main scenarios

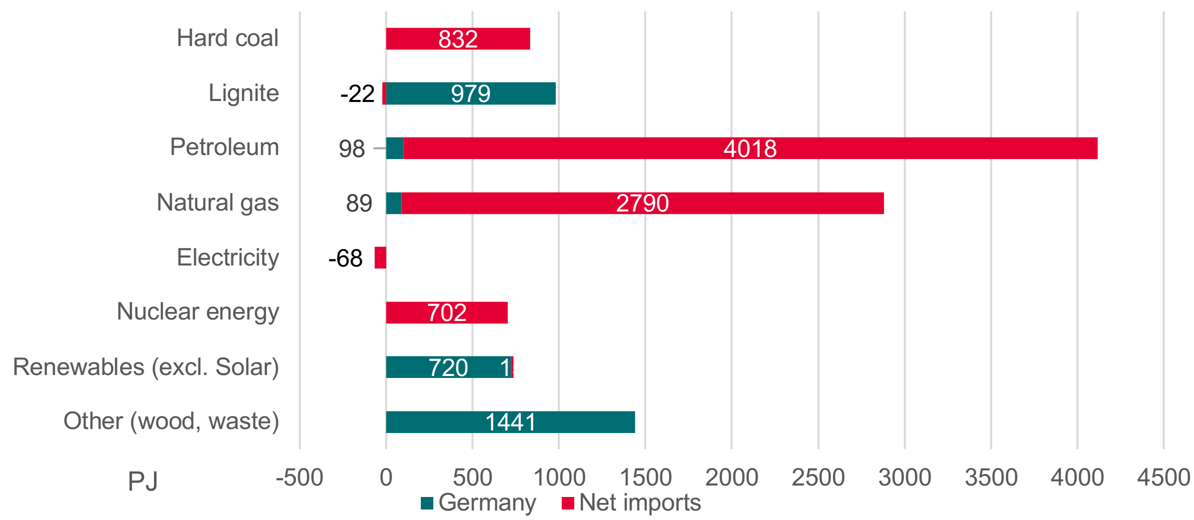


Data source: SCI4climate.NRW (2022)

3.6 Import/export of energy sources

Germany, with a population of 80 million (Colombia: 51.5 million), high vehicle numbers (48 Mio. vs. 7 in Colombia), an energy-intensive residential sector for heating, an energy-intensive industry and an electricity system still based 50% on fossil energies, has only significant fossil resources in brown coal (the last underground black coal mines were closed in 2018 for reasons of low competitiveness). Other domestic sources are exclusively renewable (incl. wood, waste, wind, solar). With the total energy demand high, and the restricted supply, self-sufficiency is not possible, especially not with oil, gas and hard coal (Fig. 37) today, and for the next two decades, in the long term uncertain.

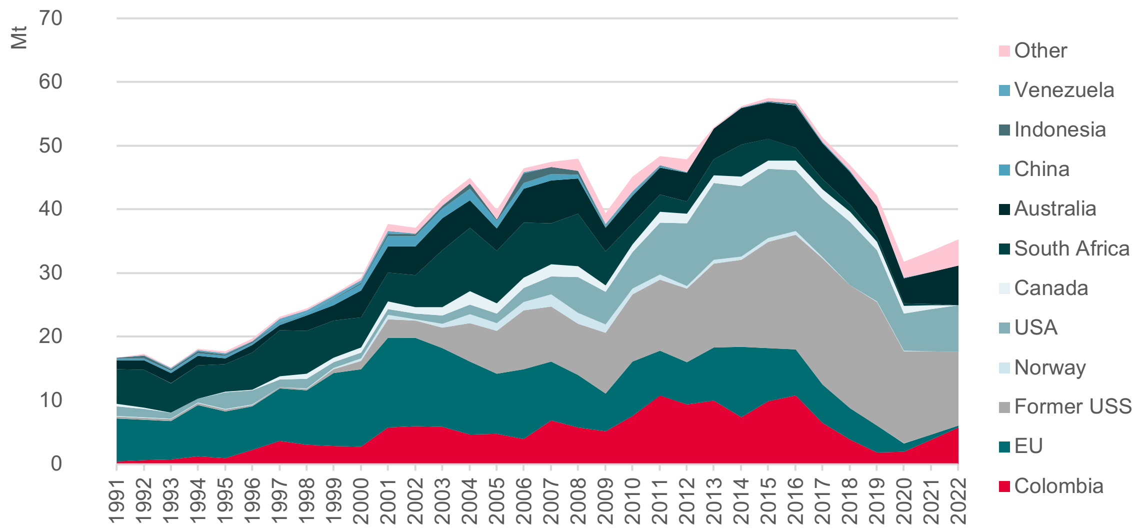
Fig. 37: Primary energy generation in Germany and net imports (PJ)



Data source: BMWK (2023c)

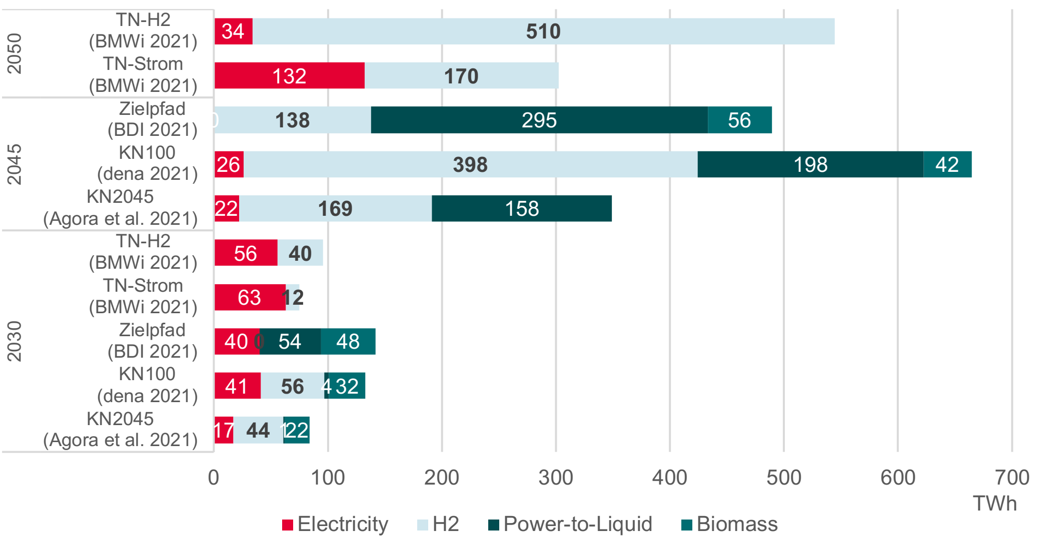
Germany is one of the main destinations for Colombian coal exports. Coal imports to Germany have increased with the closure of hard coal mines in Germany, with Russia and the US being the main suppliers. Colombia was always on the list of supplier countries, and especially with the war against Ukraine, Colombian coal served to replace significant amounts of Russian coal (Fig. 38). With the phasing out of coal for electricity generation by possibly already 2030 and 2038 at the latest, import demand will decrease dramatically. Industrial use will decrease as well, but probably ending in the 2040s. A similar trend is foreseen for natural gas and oil imports.
Notwithstanding the massive expansion of renewable sources in Germany, generation/production is projected to be unable to meet the high demand. Thus, the country would require energy imports also in a decarbonised future. The main scenarios project large amounts between 300 and >600 TWh of imports in 2050 for a fully decarbonised system. The amounts and sources of energy in the scenarios diverge according to the approach: hydrogen is likely to play an important role, possibly also derivatives and biomass (Fig. 39).

Fig. 38: Coal imports to Germany by country of origin



Data source: BMWK (2023c)Destatis (2023b)

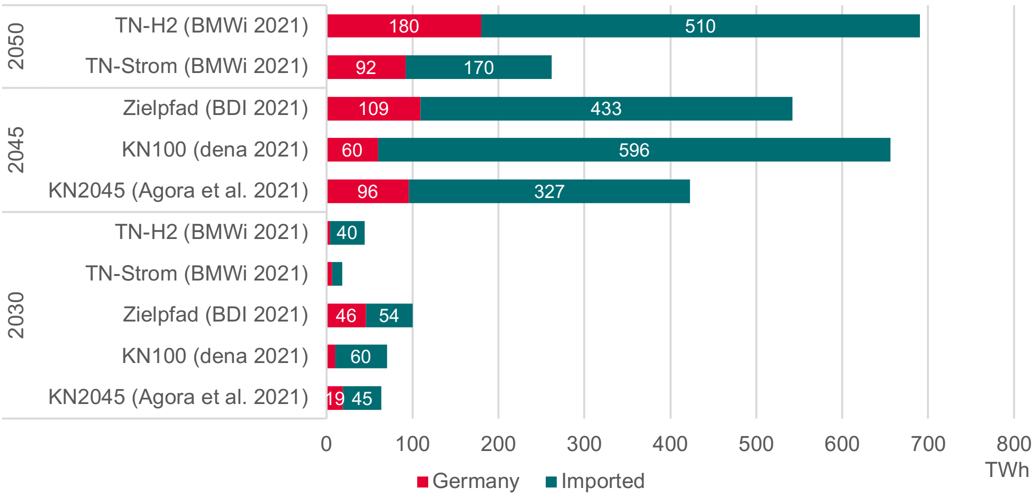
Fig. 39: Projected net energy imports under main scenarios 2021-2050



Data source: SCI4climate.NRW (2022)

Looking in more detail at the use and sourcing of hydrogen and its derivatives in the decarbonised German system, the scenarios show that significant amounts will be produced domestically, but in a decarbonised future, possibly between 170 and 600 TWh/a would have to be imported (Fig. 40).

Fig. 40: PtX vectors by origin (domestic/imported)



Data source: SCI4climate.NRW (2022)

This overview of just one EU country demonstrates the enormous demand potential for hydrogen and its derivatives that may evolve by the middle of the century. Faced with these scenarios and with the implementation of the German government as other countries are doing, German development cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ) promotes knowledge, projects, state and industrial cooperation worldwide (in Latin America e.g. H2LAC or *Hidrógeno Colombia*), the H2Global initiative of the GIZ has 900 M€ available to bridge the gap between generation costs and revenues, with the aim to kickstart the hydrogen market that is still in the implementation phase. Development banks are investing dedicated credit lines.

4 Narratives of the energy transition

4.1 Colombia

The strategies described in section 2 for the energy transition in Colombia reflect the confluence of two dominant energy transition narratives: the narrative of decarbonisation and that of the economic imperative, which are added to the strategy of reducing deforestation as the main source of GHG emissions. The entry of the Petro 2022 government sought to position the just energy transition narrative, which has lost steam as the roadmaps are consolidated (i-deals & Montoya & Asociados, 2021; World Bank et al., 2022) and the National Development Plan (Government of Colombia, 2022). Among social movements and civil society organisations there is a counter-hegemonic narrative that seeks to broaden and deepen the meaning of just energy transition, and outlines proposals for systemic transformation of food, transport, care, but also of public policies and democracy.

4.1.1 Decarbonisation by addition of renewable energy sources

The decarbonisation narrative is based on the assumption that it is feasible to replace high-emission technologies with low-carbon technologies for the entire world and that this replacement alone will serve to halt global warming. This narrative, associated with the scientific narrative of the

Anthropocene, does not consider the physical limits of the minerals required for low-carbon technologies, nor does it question the socio-political macro-structures of extraction, production and consumption of the global capitalist system that are at the root of environmental and climate injustices. Even so, it has been adopted without much questioning by the Colombian state and the productive sectors. The main vehicle for disseminating the decarbonisation narrative has been the United Nations' system of sustainable development goals, which posits the viability of maintaining economic growth of 3% per year (goal 8), providing affordable, reliable, sustainable and modern energy sources for all (goal 7), and adopting urgent measures to combat climate change and its effects (goal 13). This narrative is evidenced by plans for the development of new energy sources that do not replace existing sources, but add to the energy mix, as evidenced in the section 2. In the scenarios proposed for Colombia, decarbonisation will occur gradually but not completely, as significant growth in the use of both renewable and conventional energy is projected at least until the first half of this century. In other words, decarbonisation is interpreted as the expansion of energy sources to include renewables, but without there being any type of substitution of conventional energies by renewables. Decarbonisation has also been interpreted as the abandonment of thermal coal, but this is not a serious aim either, as national projections maintain coal exploitation for up to another five decades (Monsalve, 2022). The ban on the expansion of the coal frontier, which had been a campaign promise of the Petro government and was incorporated in the PND draft, was eliminated in the first debate in Congress (section 2.6). Thus, the narrative of energy transition as decarbonisation in Colombia is clear in its rationale, but has not been incorporated into public policy or the intention of the extractive sector. Not even the prospect of being left with infrastructure built for the exploitation and commercialisation of coal seems to dissuade either the state or the private sector from the need to abandon the most polluting sources of energy. Stranded assets may be a fear for countries in the Global North, but the coal market is shifting to countries that are not energy self-sufficient or, like Colombia, do not project a near-abandonment of fossil fuels. Since 2016, Turkey has been the main importer of Colombian coal (Cardoso & Ethemcan, 2018). Plans to build new thermal plants until 2050 reflect that the decarbonisation narrative has a rather loose interpretation.

4.1.2 The extractivist economic imperative

Under this premise, countries like Colombia that have a strong dependence on fossil energy exports (section 2.7) and which have not been responsible for most historical GHG emissions, should continue to take advantage of international markets, especially in times of high prices such as those generated by the conflict in Ukraine. This has been the position of several analysts who favour new exploration on the grounds of high fiscal and foreign exchange dependence on fossil fuel exports.

In addition, the mining sector perceives the energy transition as a new extractivist frontier, this time dressed up as the decarbonisation of the world's economies and climate change mitigation. President Petro, in several presentations and meetings at international stages in 2023, has mentioned the great opportunities that Latin America has to become the source of clean energy for the world, based on its mining, solar and wind energy potential. The energy transition has been formulated as a new phase of mining for noble purposes associated with a sustainable future. The bad press that the mining sector has received for its social and environmental impacts and the violence it has left in the territories has found in the energy transition a way to atone for its faults, through the discourse of green, sustainable and responsible mining. The Caribbean region, with its wind and solar potential, is projected in the narratives of the state and companies as a promising region for offering energy to the world, leaving aside the environmental liabilities left by coal. In section 5 we analyse the potential for green energy exports and the challenges in more detail.

4.1.3 Just energy transition

This perspective is perhaps the one with broadest variety in interpretations. In Colombia, the roadmap for a just energy transition (Minenergia, 2022a) highlights the need to extend energy supply to populations that have historically been disconnected from the electricity grid or have precarious access to energy sources, and makes visible the historical impacts suffered by the peoples and territories from which energy is extracted in the country. Countries such as Chile, Bolivia and Argentina, with large reserves of lithium, are emerging as suppliers of the raw material for the world's electric vehicles, but at the same time as new environmental sacrifice zones (Zografos & Robbins, 2020). Countries such as Mexico and Colombia with their high solar and wind potential could be on the path to ethnocidal and ecocidal projects (Dunlap, 2018). In this way, the energy transition threatens to create a new wave of extractivism that is even more aggressive than previous ones (Alarcón et al., 2022), with the urgency to decarbonise and the scale at which transition minerals are extracted and huge clean energy parks are installed. A second perspective of great relevance for workers in the mining and energy sector concerns attention to the jobs and income that will disappear with the extraction of fossil fuels, especially in the Caribbean region.

At the global scale, a distinction is made between the countries of the Global North as historically responsible for warming because they emitted the largest proportion of GHGs, and countries with a small carbon footprint, which are generally also the most vulnerable to climate change impacts. Faced with this imbalance, one version of just transition is posited as Northern countries having to reduce their emissions so that countries with reserves can follow the path of fossil-based development (see the case of Guyana).

In addition, and as has been discussed at COPs leading to the creation of the Green Climate Fund at COP15 in Copenhagen in 2009, just transition from the perspective of the countries of the Global South implies that historically high-emitting countries (which are also the richest countries) contribute to financing adaptation and mitigation measures. The Green Climate Fund, however, has never reached the $100 billion annual target it set at its inception. It operates primarily under financial schemes that are conditional on Southern countries and that generate business opportunities for the funding countries (https://www.greenclimate.fund/). The narrative of just energy transition through financial mechanisms has also been used by President Petro in international arenas when he suggests trading debt for climate action, even without much clarity on how this would operate.

A version of just energy transition being promoted by energy communities and civil society organisations proposes a reconfiguration of the energy system to reduce dependencies on large centralised systems, which are vulnerable to disasters associated with climate change because of their size. This proposal is based on concepts such as autonomy, democracy and energy insurgency as a form of community self-management for energy self-sufficiency with cultural affirmation and ecological responsibility (Massol Deyá, 2018).

4.2 Germany

In the narratives of how an energy transition could be implemented in Germany, there are as many approaches and elements as there are authors. In a study of narratives, dozens of elements, sectoral narratives and other approaches have been analysed (Umweltbundesamt, 2021). This section synthesises three ideal-type narratives that include multiple (and sometimes contradictory) narratives. Each narrative includes a synthesis of the proposal, brief descriptions of protagonists and the implications it could have for the Global South.

4.2.1 The technological solution

The technology solution is the dominant narrative in Germany. This narrative focuses on technological solutions for all sectors. As described in the analysis sections, it envisages profound technological changes:

- *Transport*: a drastic shift towards electromobility in private vehicle engines (possibly complemented by hydrogen and *synfuels*), in road freight possibly with *fuel cells* and a deployment of overhead contact lines. It also includes an expansion of rail transport, which requires large investments in infrastructure.
- *Industry*: The decarbonisation of industry is described as profound changes in technologies towards electrification, for process heating complemented by biomass and hydrogen sources, both for the manufacturing industry and the metallurgical industry. For process emissions (cement etc.), the application of CCS is targeted.
- *Residential*: In the heating of buildings the technological strategy is a switch to heat pumps which would be achieved through regulations and incentives and will be complemented by improving energy efficiency with insulation.
- *Electricity*: A fundamental change of the power plant fleet is planned. First, coal plants would be phased out by 2030 or at the latest by 2038, in the following decade also the use of natural gas (possibly replacing gas in these plants by hydrogen). This is planned to be accompanied by a massive expansion of wind plants (*on-shore* and *off-shore*), and solar plants. The capacity expansion is a factor 3 to 7 of the 2020 level, depending on the level of reduction in consumption and import fraction.
- *Imports*: Demand that cannot be supplied by domestic generation in 2045/50 will be imported. Scenarios diverge significantly, with most estimating around 50% of final demand to be supplied by imports, according to scenarios up to 1000 TWh/a, in electricity sources, hydrogen or derivatives.

This narrative is reproduced in consultancy scenarios (Wiese et al., 2022), in the media and policy forums (BMWK, 2023b). As it is compatible with the economic model, and although it means investments estimated to billions of €, it has also taken root in industry. The industry demands favourable legal frameworks for the transition and each sector has specific requirements, but they are not (any more) generally opposed to the transition, as the main associations of the metalworking industry demonstrate (WVMetalle, 2023) automotive (VDA, 2023) or the industry as a whole (BDI, 2023). Agreements have been reached with the main electricity generating companies and the coal-fired power plant phase-out law (Kohleausstiegsgesetz, 2020) has been implemented. (Kohleausstiegsgesetz, 2020). An additional agreement to close brown coal mines in western Germany (NRW) was concluded in 2022.

The implementation of this narrative would mean technological changes and large investments in Germany. At the same time, it depends primarily on a) large quantities of raw materials needed for the technologies, most of which would come from the Global South, and b) large-scale imports of clean energy, also from countries in the Global South. This means a partial externalisation of the ecological and social impacts of natural resource exploitation and energy generation, referred to in the literature as "green sacrifice zones" (Zografos & Robbins, 2020).

4.2.2 Need for fundamental changes in economy and consumption

A second set of narratives starts from a focus on the adverse effects that the first narrative could have, both in the Global South and also in the countries of the Global North. These narratives see the technological pathway as incompatible with *planetary boundaries* and a just transition. They contain multiple fringes, with a focus on economic and social structures or a focus on individuals in society.

Structural narratives are joined by critics of economic growth, which, according to them, has always proved to lead to an increase in resources and energy demand. Therefore, a "post-growth" or "de-growth" in economy and consumption is promoted. Other narratives of fundamental structural change focus on decentralisation and welfare.
A multitude of narratives exist around changes in the vision and behaviour of individuals (bottom up), with different focuses: on modes of self-creation, -production, repair (incl. urban gardens, repair workshops, shared schemes), on voluntary reduction of consumption and refocusing on "time well-being" (less work, more community).
The protagonists of these narratives are mostly activists, often organised in NGOs. The narrative is also shared with an academic section that, for example, organises transdisciplinary conferences (degrowth conferences).
The implementation of such a restructuring of the economy and society would be fundamental and would be based on principles such as only sustainable use of local resources, no externalisation of adverse impacts to other communities or global regions, reduction of consumption to sustainable levels, ensuring the well-being of all. It would reduce or eliminate the demand for resources and energy from the Global North to the Global South. The realisation of these narratives seems unlikely and, in most cases, lacks concrete proposals for how they would be realised politically or in-depth studies that present realistic scenarios of implementation and impacts on the economy, society and state institutions.

4.2.3 Combining technology with reductions in consumption

A third set of narratives attempts to combine the first two. It builds on elements of the criticisms of the second set, such as the analysis of limited natural resources (in different global regions), the recognition of adverse impacts also of renewable energies, the approach of fair development (between and within countries), a focus on maximising energy self-sufficiency at the most subsidiary level possible (also but not only for energy security reasons). On the other hand, these narratives recognise the need to implement new technologies in all sectors. In many cases, these narratives are sceptical of the implementation of certain technologies, because they do not yet exist or at very uncertain costs or because they are considered high risk or negative impact (e.g. CCS, CCUS, DAC, nuclear fusion energy, nuclear power, wind power in sensitive areas, possibility of energy imports). These narratives are therefore more conservative and less optimistic about the availability of technological solutions, but nevertheless attempt to create realistic decarbonisation scenarios. For this, they include as many impacts as possible, include or discuss consumption reduction strategies (sufficiency) and their respective political strategies.
The protagonists of these narratives come mostly from academia. They are often inspired by NGO arguments and bring them into scientific analysis and scenario building. As the narratives include elements of reducing or limiting consumption and production, they are hardly connectable to dominant discourses in the political and industrial arenas. However, they have gained some visibility (CLEVER, 2023; Ragwitz et al., 2023).
While not as radical as the narratives of the second group, the realisation of a middle path could significantly reduce the resource and energy demands of the Global North in its energy transition strategy and limit the adverse effects on countries where provision is sought.

5 Colombia's need to substitute national demand for fossil fuels and estimate of required NC-RES capacity

5.1 Decarbonisation options

In order to decarbonise the energy matrix, fossil energy carriers need to be replaced by carriers with no net carbon emissions. Depending on the sector and type of source required, there are a variety of options. The potentials of each renewable source have to be evaluated in the national context, with respect to environmental, social, territorial and resource constraints. Potential substitutes include:

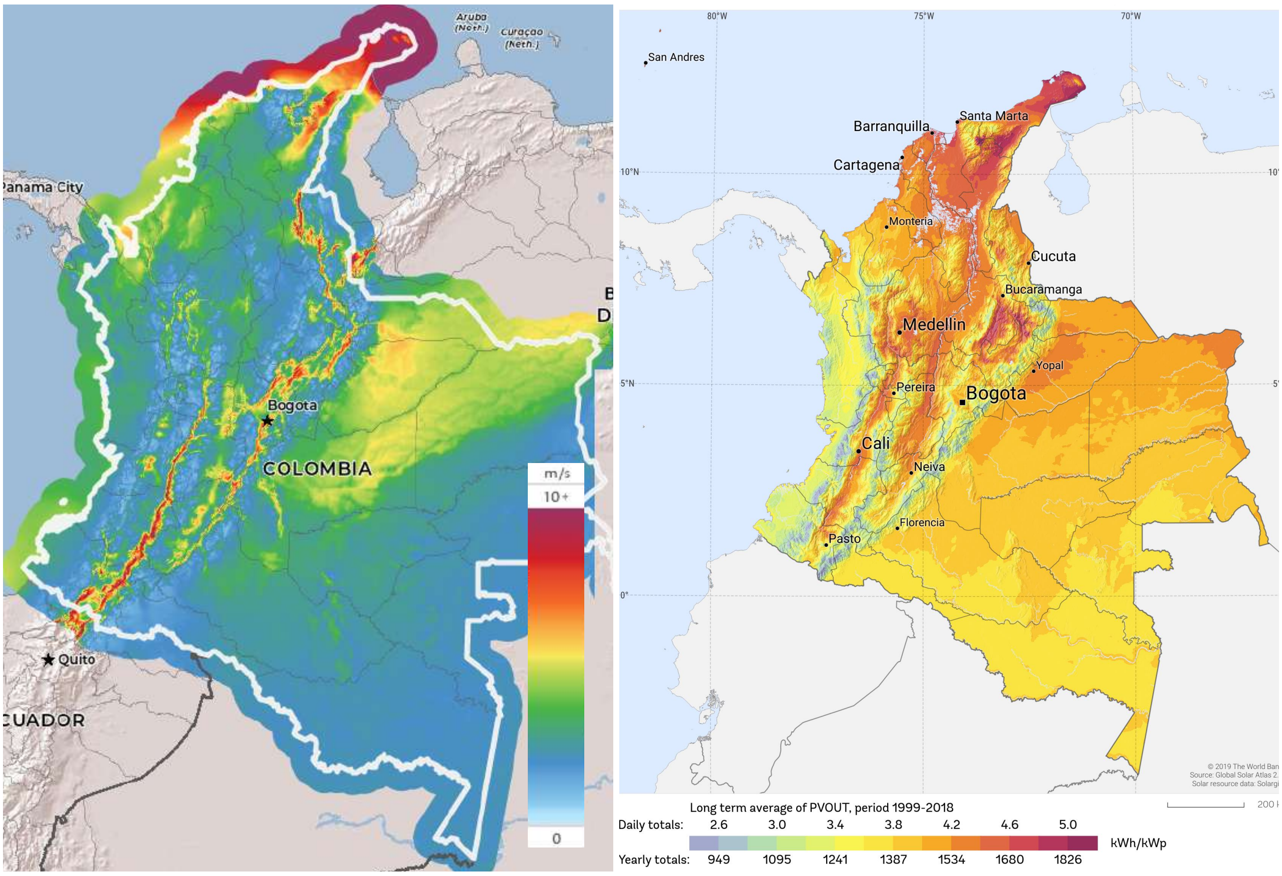
- Liquid fuels (esp. Transport):
  - Biofuels (oil-based)
  - Ethanol (e.g. based on sugar cane)
  - Electricity
  - synthetic fuels (electricity/hydrogen derivatives)
- Solid fuels and gas in industry:
  - Direct process electrification
  - Biomass/sustainable biofuels
  - Hydrogen (electricity/electrolysis derivatives)
- Gas in the residential sector (cookers):
  - Electrification
  - Biogas
  - Biomass (firewood) in stoves
- Fossil fuels in thermal power plants for electricity generation:
  - Solar
  - Wind
  - Geothermal
  - Biomass

In Europe, where there is not much potential to expand sustainable biomass production (especially for energy use), the main option remains direct electrification of most energy uses, or, as a last resort, imports via hydrogen or derivatives. Electrification has the advantage over the substitution of fossil fuels by bioenergy that it is more efficient than incineration processes (e.g. electric car vs. biofuel). Consequently, electrification avoids much of the energy inefficiency of burning fossil fuels. On the other hand, this strategy requires a massive expansion of renewable electricity generation.

5.2 Wind and solar energy sites, potentials and challenges in Colombia

The potentials for the expansion of wind or solar power plants are concentrated in certain areas. For wind power the wind speed counts, which is typically higher on the coasts. In Colombia, the most suitable areas are concentrated inland in the Guajira peninsula, Cesar department and the Andean mountain ranges. Offshore, the areas with the highest wind speeds (m/s) are along the entire Caribbean coast (Fig. 41 left). The effectiveness of solar PV depends on solar irradiation. The areas most suitable for generating most energy (kWh/kW$_p$) are also concentrated in the north, Guajira and Cesar, but include the Magdalena and Cauca river valleys, a large area north of the capital (Boyaca/Santander) and the north of the eastern plains (Fig. 41 right). Capacity expansions allocated by the UPME follow the distribution of these potentials (Fig. 17). Large wind projects under planning or implementation are located in the indicated area of Guajira and the offshore Caribbean.

Fig. 41: Wind (left) and solar (right) energy potentials in Colombia



Sources: DTU et al. (2023), Solargis et al. (2023)[2]

There is no comprehensive study of all national NC-REF potentials. In 2010, a first study estimated the wind potential in Guajira at 18 GW (World Bank, 2010), updated to 25 GW total onshore in the Hydrogen Roadmap, complemented by 45 GW photovoltaic (i-deals & Montoya & Asociados, 2021). Additionally, the Offshore Wind Roadmap estimates the potential of this technology at approximately 50 GW. The NC-REF sum thus amounts to a technical potential of 138 GW.

Onshore and offshore wind projects in many cases generate discussion, conflict and resistance for various reasons. A successful realisation of projects is only possible with consent of the local population and resolved local conflicts. In Colombia, the situation is especially delicate, because the area identified as having the highest potential is territory of the indigenous Wayúu community. NGOs such as Indepaz report "rigged and unfairly treated prior consultations" (Barney, 2021), fragmentation of communities and resulting inter-ethnic conflicts. They also report that the area that has historically been abandoned by the state, with a vulnerable population, does not benefit. The distribution and ownership of land according to Wayúu traditions does not coincide with the forms of distribution by

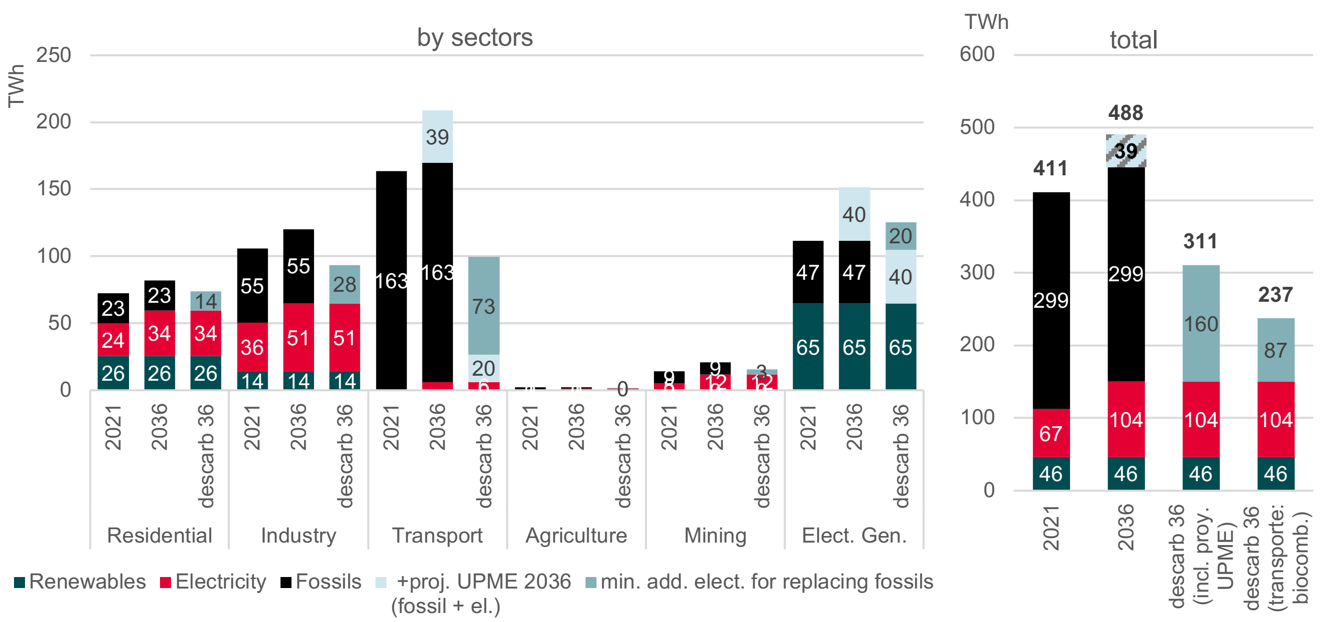
[2] Full citation as requested by authors:
Wind: map obtained from the Global Wind Atlas 3.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU). The Global Wind Atlas 3.0 is released in partnership with the World Bank Group, utilizing data provided by Vortex, using funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info
Solar: map obtained from the Global Solar Atlas 2.0, a free, web-based application is developed and operated by the company Solargis s.r.o. on behalf of the World Bank Group, using Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info

the state, which again generates conflicts (Barney, 2021). The complexity of project planning and implementation is compounded by the challenges of corruption, insecurity, risks of ecological and tourism impacts, and lack of opportunities for local communities. The implementation of projects in Guajira must find ways of prior consultation and agreements that are fair, orderly and reliable for all and in accordance with the rules of the communities. Otherwise, they run the risk of perpetuating and deepening the injustices that have existed for more than 30 years of coal exploitation in the territory. For the reasons listed above, it remains uncertain how much of the estimated technical potential could be realistically developed.

5.3 Estimated NC-RES capacity required for decarbonisation

Based on the energy balance for the year 2021 (UPME, 2023a) and the projections for electricity, gas and fuel demand growth, Fig. 42 (left) shows the demand by sectors and energy sources in 2021 (UPME, 2023a), and with the increases in demand for fuels and electricity projected up to 2036 by UPME (UPME, 2022). With very conservative assumptions regarding technological efficiencies, the additional amount of electricity required to replace fossil demand in 2036 was estimated. The figure (left) shows results by sector, with transport as the largest sector in terms of consumption and potential additional electricity demand (73 TWh). For total figures (right), two hypothetical scenarios were calculated: 1) substitution of all fossil fuels exclusively by electricity and 2) substitution of fossil fuels by biofuels (Government of Colombia, 2021, p. 59).

Fig. 42: National demand 2021/2036 and minimum additional electricity generation required for fossil fuel substitution, by sector (left) and total (right).

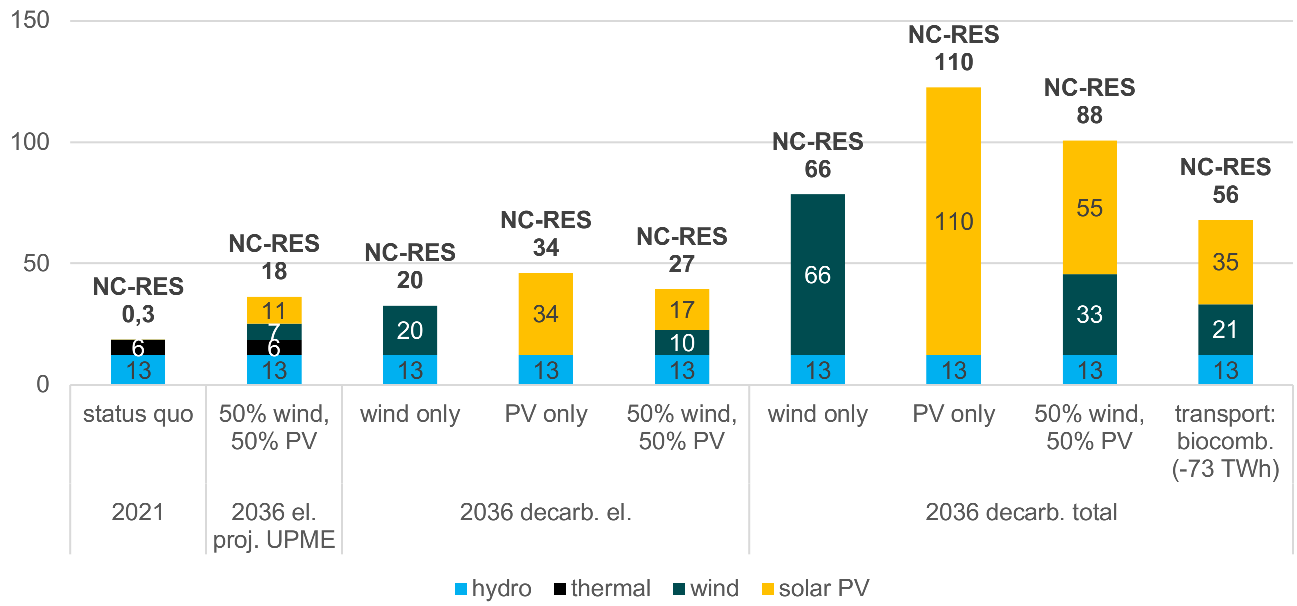


Data source: UPME (2023a), calculations by author.[3]
Note: 2036 includes increase in demand (UPME, 2022), discard 36 includes increase d e projected electricity demand up to 2036 (UPME, 2022) and additional electricity demand for fossil demand replacement in 2036. In the electricity sector, "renewables" includes hydropower and bagasse. In total figure, excl. hydropower. Descarb 36 includes increased electricity demand and substituted fossil fuels. Descarb 36 (biomass transport) assumes transport decarbonisation by non-electricity sources and a 73 TWh lower electricity demand.

[3] For the calculation that includes the data sources (UPME, 2022, 2023a) assumptions and calculations, contact author.

Total electricity demand in 2021 was 67 TWh, the UPME projection estimates it at 104 TWh until 2036 and an additional 39 TWh in fuels. If in 2036, all fossil fuels were replaced by electricity, this would increase electricity consumption by another 160 TWh. Total electricity demand would be a factor of 3.5 higher than in 2021. In a scenario where the transport sector is supplied exclusively by biofuels, electricity demand would be 73 TWh lower, but biofuels in the range of previous 163+39 TWh fossil fuels would have to be produced (comparison: total bagasse production 2021 was at 20 TWh).[4]
To illustrate the scale of the decarbonisation challenge, we estimate the need for capacity expansion to meet this demand. We use very optimistic assumptions of 3 TWh/a/GW installed generation from wind turbines[5] and 1.8 TWh/a/GW installed from solar PV[6] and calculate the capacity (GW_p) required to meet demand in four hypothetical scenarios of wind only, solar PV only, 50% both technologies and 50% wind and solar with transport not supplied by electricity, but other sources (73 TWh less). The results can be understood as minimum required capacity, under optimistic assumptions. For example, technological performance is assumed to be high, with existing transmission losses not calculated.

Fig. 43: Estimated installed capacity needed (GWp) for decarbonisation, assuming electrification by wind/PV/mixed/biofuel transport



Source: own calculations based on UPME data (2022, 2023b, 2023a), for calculations contact author.[7]

[4] While this strategy would greatly reduce pressure on the electricity sector, it may have serious implications for the land-use sector, as biofuel production at this scale may generate emissions (deforestation), ecological (loss of biodiversity through monocultures), and social problems. Other scenarios with modal shifts in transport (freight and passenger trains, and bicycles in cities, etc.) should be considered in the future to limit the role of biofuels in the decarbonisation strategy.

[5] Generation depends on specific circumstances (e.g. wind speed) and technologies (e.g. size, efficiency). In Denmark, a wind speed of 8m/s (the average for the Colombian coast) was reported to be (World Bank, 2010, p. 22)) 2TWh/GW (DWI, 1998) in Germany, with less favourable conditions and inland, 1,6 TWh/GW (Germer & Kleidon, 2019)and in the US 3.1 TWh/GW (US EPA, 2022).

[6] For Colombia, PV generation of 1500 kWh/kWp is estimated for large parts of the territory and up to >1800 kWh/kWp for favourable areas (e.g. Guajira, Caribbean, Andean zone).(Solargis et al., 2023).

[7] The retention of hydropower in all scenarios at 13 GWp assumes that no net additional hydropower plants enter the system. Although this is realistic for large hydropower, some medium or small-scale hydropower is feasible and in some cases can be good complements to solar and wind projects (such as pumped hydro). Other hydro plants may be decommissioned.

Until 2036, UPME projects an increase in energy demand that is supplied, in our scenario, by 50% wind and PV. Compared to the current fleet of hydro and thermal (fossil) plants totalling a capacity of 19 GW (XM, 2023), 10-14 GW of NC-RES would be needed to replace the current thermal plants. With the increase in consumption, between 20 GW (wind only) and 34 GW (PV only) are needed to decarbonise the electricity sector alone.

If all fossil fuel consumption in all sectors projected by the UPME (2022) until 2036 were replaced by electricity, the additional NC-RES fleet would have to add up to 66-110 GW. If the transport sector (example) were to be supplied with other sources than electricity (e.g. biofuels), this would reduce electricity consumption and consequently the additional capacity needed to about 56 GW.

This analysis is not a realistic scenario. It does not include a model of the electricity system or an analysis of storage needs in a system based on fluctuating NC-RES (although Colombia has flexibility because of the 12.5 GW of hydropower). Instead, the calculation demonstrates the immense task of a complete decarbonisation of the energy system and underlines the need to curb the increase in energy consumption and include consumption reduction strategies. With increased energy consumption, the key sector is transport which requires a shift from individual vehicles to electrified public modes to reduce energy demand, and a realistic decarbonisation strategy, possibly relying on biofuels (biodiesel, bioethanol).

It also shows that decarbonisation through electricity alone will be difficult and Colombia urgently needs to complement wind and solar strategies with other renewables such as biomass and geothermal. The range of 56–110 GW potentially required for national decarbonisation stands against a technical potential (according to current estimations, see section 5.2) of up to 138 GW – with high uncertainty on the potential that can be developed in the medium term. If the goal is to decarbonise the entire Colombian economy, it seems difficult to export significant amounts of energy in the short to medium term.

6 Challenges and interconnections of transition strategies

6.1 Demand for green energy imports from the Global North

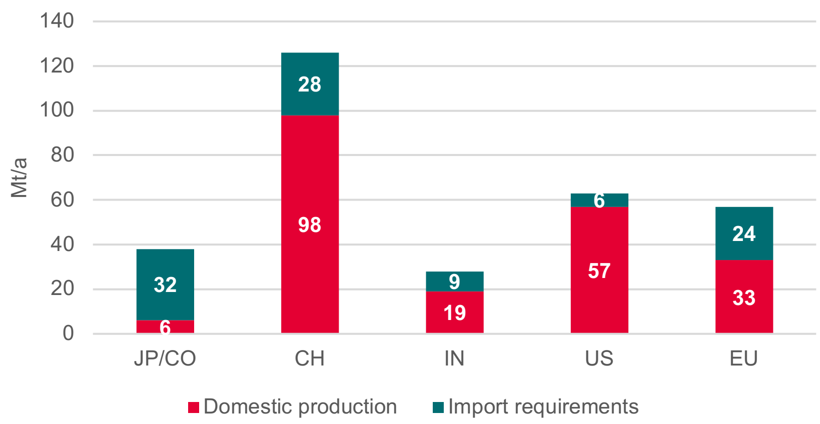
After the hydrocarbon-exporting Arab countries and other exceptional cases, the countries of the Global North with their energy-intensive industries and high levels of consumption have the highest per capita emissions (UNEP, 2021). At the same time, many are densely populated and lack possibilities to expand biomass production. Despite a sufficient technical potential, the main decarbonisation options (wind and PV) in many scenarios are expected not to cover the entire demand in a decarbonised future, and many scenarios project a future import of clean energy.[8]

Colombia's hydrogen roadmap estimates that global hydrogen demand could reach 99 Mt/a by 2050 (i-deals & Montoya & Asociados, 2021)(Fig. 44). In parallel, the decarbonisation scenarios of Germany (section 3.6) show high imports of hydrogen and hydrogen derivatives, because the expansion of NC-RES is not sufficient to meet the domestic demand. These scenarios do not specify from which countries exports will come. A global market for decarbonised sources and imports at lower costs is expected and assumed to develop in the decades up to 2050.

[8] This is due to the modelling of energy systems, in many cases techno-economic optimisation models. The optimisation algorithm chooses the least-cost combination of sources. When faced with the options of choosing exogenously priced energy carrier imports or other storage technologies that allow for a high degree of self-sufficiency (such as batteries, hydrogen or other options), in many cases significant imports result.

For Europe, this means that importing from closer regions with favourable climatic conditions is more likely, especially if pipelines or transfer lines exist or can be built. North Africa and sub-Saharan Africa are currently focal regions.

Fig. 44: Global hydrogen production and import demand in 2050



Source: i-deals et al. (2021)

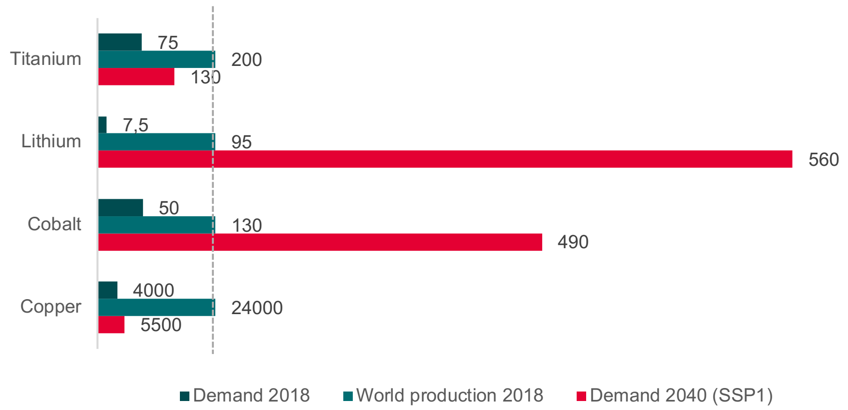
As transport costs rise with distance (Merten, Frank et al., 2022, p. 38), Latin America does not seem to be the first-best region to supply Europe. Future competitiveness in the European market for Latin American hydrogen depends on the evolution of transport and generation costs.
Nevertheless, market players and governments have already started to push hydrogen technology worldwide, in Latin America and in Colombia. In Germany alone, there is a multitude of initiatives. Both countries are holding a "Binational dialogue on Colombia's reindustrialisation policy based on renewable energies and the development of a green hydrogen sector" (Cancillería, 2022). German GIZ cooperation supported hydrogen development in Colombia from the very beginning:

- H2LAC (https://h2lac.org/): "collaborative platform whose objective is to boost the development of green hydrogen and its derivatives in Latin America and the Caribbean in order to **promote its production, use and export"**. It was created in 2020 by GIZ together with the World Bank, ECLAC and the European Union's Euroclima Programme to foster cooperation and exchange between different stakeholders and accelerate the advancement of green hydrogen in the region.
- Hidrogeno Colombia (https://www.hidrogenocolombia.com/) receives support from H2LAC
- GIZ Colombia conducts training together with the Ministry of Mines and Energy, FENOGE and the support of HINICIO (H2LAC, 2022)
- The government will finance 10 study projects for the development of green and blue hydrogen in Colombia for more than COP$6.5 million through FENOGE (Minenergia, 2022b) and with the support of GIZ.
- Project to "Promote hydrogen projects in developing and emerging countries: H2-Uppp" (giz, 2023)

6.2 Demand on resources to implement the Global North strategy

Watari et al. project an increase in global resource demand for energy transition and decarbonisation sectors from a level of 2 Gt/a to 12 GT/a TMR (reduction possible with recycling), focusing on iron, copper, nickel and lithium (Watari et al., 2019). In an analysis of critical materials for energy transition technologies, DERA (2021) calculates the demand for 19 metals based on a multitude of products and applications and for various scenarios (IPCC shared socioeconomic pathways, SSP). Fig. 45 shows a summary of the results for a sustainable scenario (SSP1): While they find a reduction in demand for copper and titanium, demand for lithium expands by a factor of 6 and demand for cobalt by a factor of 4 (for more results: DERA 2021, p. 24).

Fig. 45: Annual critical resource demand for energy transition technologies: 2018 and 2040 SSP1 (kt/y)



Source: Extract from DERA (2021, p. 24). More critical materials in original diagram.
Note: normalised to 2018 global production level. SSP1=sustainable scenario

Among Colombia's exports, metals make up only a minor percentage. However, according to DANE (2023)ferronickel exports amounted to 1.5 Mt in 2022 with a value of USD 0.9 bn (total exports: USD 57 bn). Growing demand for metals and expected increases in respective prices are also likely to generate pressure to expand extraction in Colombia.

6.3 Investment and technology for transition in the Global South

Colombia does not have a manufacturing industry for wind towers and photovoltaic cells. In addition, power plant management and construction companies do not yet have the experience in planning and managing large-scale investments for new NCRE projects, nor the funds for the required investments. In 2023, Colombia depends on foreign technology, expertise and capital. Technology and expertise is imported with the participation of foreign companies, with training from international cooperation institutions (such as GIZ, section 6.1). For the required capital there are various forms of national financing such as the FONENERGIA, FENOGE and SGR funds (Stockholm Environment Institute et al., 2023, p. 3). For the planned dimensions, additional funds are required, which are sought with international credits and financing from entities such as the World Bank, Interamerican Development Bank, European Development Bank, German KfW. Financing includes for example

- 2017 IADB: USD 45M funding line (IADB, 2021)
- 2021 KFW: 150M €.
- 2022 KFW: 200M € financing of wind and photovoltaic farms
- 2022 World Bank: USD 1bn "to accelerate Colombia's climate action by advancing the low-carbon energy transition, promoting sustainable land use, and strengthening climate resilience and adaptation". (World Bank, 2013)
- Colombia applied for a USD 350M credit, with USD 70M from the CIF (disbursed by IDB) with reduced interest rate and USD 3.5M non-refundable. The remaining USD 280M are market credits from IDB, CTF, Bancoldex, FDN and FENOGE or other banks (CIF, 2023, p. 36).

In many renewable energy projects, energy and construction companies are also involved in the financing, management, ownership, operation and maintenance of the projects. Examples include

- Ecopetrol signed an agreement with the Ministries of Mines and Energy and Science and Technology to advance the energy transition. The initiatives in the agreement will be funded by Ecopetrol resources of around COP$33 billion to be administered by the ministries.
- The company Alumbrado Público de Barranquilla signed a memorandum of understanding with the Danish company Copenhagen Infrastructure Partners for the development of the first 350 MW offshore wind power plant (to be expanded later)(Mayor's Office of Barranquilla, 2022). The company also offers financing support and has its own funds. More detailed information on the financing of this project is publicly available. It is possible that it will be financed by the sources mentioned above.
- Ecopetrol selected Total eren to finance, build and operate a nearly 100 MW_p Solar PV plant (Ecopetrol & TOTAL eren, 2023). The project will be 51% owned by Total eren and 49% by Ecopetrol, the amount of investment is not mentioned in the press release.

There are also a variety of international cooperation initiatives, including the following:

- SEED - Scaling Up Renewable Energy programme funded by the United States Agency for International Development (USAID), which helps create competitive energy markets. The activity runs from 2017 to 2025.
- The Energy for Peace Initiative (E4P) led by USAID seeks to provide energy to 9 Development Programmes with a Territorial Approach (PDET in Spanish) in Non-Interconnected Zones of Colombia, in order to generate sustainable economic and social development.
- The Colombian Ministry of Agriculture and Rural Development and the German Federal Ministry of Food and Agriculture are consolidating their cooperation with the aim of transforming the agricultural sector into sustainable systems. The areas of cooperation are mainly in research and development, the sustainable use of fertilisers, the adoption of biofertilisers and the strengthening of cooperatives and associations of small producers.
- The city of Bogotá and the German embassy promote partnerships between Bogotá and German companies for the transfer and generation of knowledge regarding the use of renewable energies and the development of the green hydrogen sector.
- Proparco, the financial arm of the French Development Agency (AFD), expects to finance projects worth €500 million over the next five years.
- A public-private partnership (PPP) was formed as a result of the Binational Dialogue on Reindustrialisation Policy based on renewable energies between Colombia and Germany. The aim is to bring together the public and private sectors of the two countries and agree on joint projects to be implemented in the following years of government. The Ministries of Trade, Industry and Tourism and of Mines and Energy, Ecopetrol, the Bogota Energy Group and Promigas signed a memorandum of understanding to advance the process of sustainable industrialisation.

6.4 Colombia's dependence on fossil exports and the geopolitics of transition

Colombia has maintained a foreign trade deficit over the last 20 years (except in the periods 2003-2005 and 2009-2013 when it had high oil exports), which has represented a devaluation pressure on the currency. Of all exports (2022 total: USD 41 bn), fossil energy (oil and coal) has played a key role with 55% (2022) in value. The continuity of this export revenue is at risk for the following reasons:

- The progressive energy transition in the Global North will lead to a decrease in demand for coal and oil. There is a risk of a reduction in demand volumes and prices, although some of this reduction in demand is being offset by mining of transition minerals and demand from other countries in the Global South.
- Climate change and Colombia's responsibilities under the Paris agreement/UNFCCC generate pressure for decarbonisation and reduction in hydrocarbon exploitation.
- The volume of oil and gas exploitation in Colombia is already declining due to dwindling reserves. Estimates vary, but national demand surpluses could be reduced until 2028 (chap. 2.7) and Colombia could become a net importer.

In the current framework of global trade relations, countries with economies dependent on commodity exports, are under pressure to maintain a balanced foreign trade balance. This can be offset by foreign investment and debt (deficit control) to prevent massive currency devaluation. This is also the case for Colombia. Alternatives envisaged to compensate for declining fossil export revenues include:

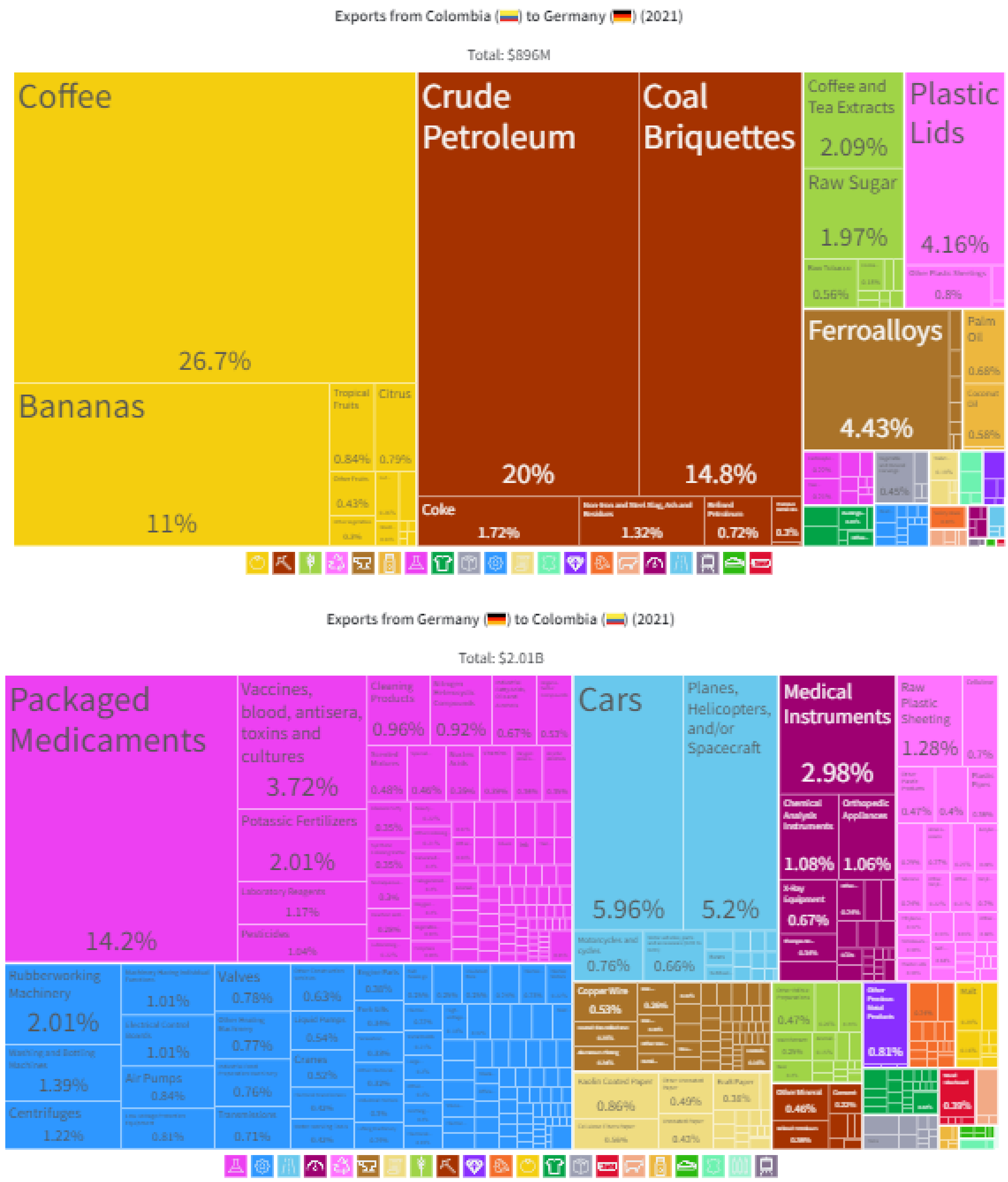
- alternatives for export (agriculture, industry, mining, hydrogen/green energy development)
- reduction of import of other goods (see type of imported goods [industrial inputs]: restrictions difficult /possibly counterproductive)
- reduction of fossil energy consumption to avoid future import of fossil fuels

In this context, Colombia, like most countries in the Global South, will not have the monetary sovereignty to create productive capacity for its energy transition and will continue to depend on the export of cheap raw materials and the import of technology at high costs, which will keep it on the path of growing indebtedness. Under current conditions of the global political economy, the energy transition as a planetary project could become a zero-sum game, in which rich countries decarbonise their energy consumption by importing minerals and clean energy, while the countries of the global South maintain an export dependency on these resources, but still need to achieve their energy transition, without the resources to finance it themselves and by importing all technology.
Decarbonisation as a response to the global climate crisis can only be achieved if the conditions are created for all world regions to rapidly access the required technologies and raw materials. Colombia, due to its high dependence on exports that are currently decreasing and of uncertain future value, requires rapid and preventive political action to avoid future fossil imports, and a resulting deepening of dependence and deficit in foreign trade.
There are doubts about the possibility of the entire planet achieving decarbonisation because solar and wind infrastructure requires increasing amounts of fossil energy, water and other raw materials in their manufacture, transport, installation, operation, maintenance, decommissioning and recycling, and generates polluting emissions to air, water and solid waste (Valero et al., 2021). Moreover, in transition mineral-producing regions and in territories where large wind and solar projects are installed, the new wave of capital accumulation by decarbonisation or dephosphorisation is based on predatory processes of dispossession (Argento & Kazimierski, 2022). The planetary climate crisis must be understood in its full dimension as the final synthesis of a historical project of appropriation of the material world, which can only be reversed through the collapse of the structures of social domination consolidated in the coloniality/modernity project. (Quijano, 2013). Therefore, decarbonisation, as the only accepted solution, may even accelerate the climate crisis because, without addressing structural changes, it places excessive faith in “technological solutionism” (Morozov, 2013) to solve what is perhaps the most complex problem humanity has ever faced in its history.

Colombia-Germany trade relations

Germany-Colombia trade relations are typical of North-South relations. Colombia exports to Germany almost exclusively agricultural products, energy and raw materials for industry, while Germany exports to Colombia mainly pharmaceuticals, automobiles, aircraft and machinery (see Fig. 46). In 2021, Colombia exported USD 896 million (0.58% annual growth since 1995), and Germany USD 2,010 million (3.83% annual growth since 1995) (OEC World, 2023).

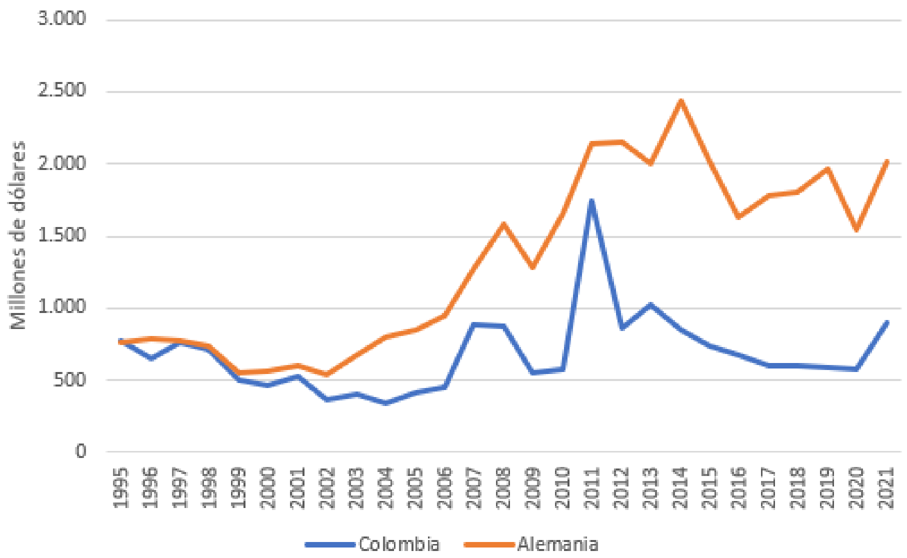
Fig. 46: Composition of the trade exchange basket between Germany and Colombia (2021)



Source: OEC (2023)

The trade balance between the two countries since 1995 is shown in Fig. 47, which shows a growing gap in the value of trade and an accumulated trade deficit for Colombia of USD 17.483 billion. This balance is a reflection of the structurally unequal exchange between the regions of the world and represents the coloniality of relations between the global North and South, which in the total aggregate yields an appropriation of goods worth USD2.2 trillion per year and an accumulated value of 62 trillion since 1960 (in constant 2011 values); these values will tend to increase as long as the price and wage structure of the world economy is maintained (Hickel et al., 2021).

Fig. 47: Colombia-Germany trade value



Source: OEC (2023)

In a context characterised by these structural inequalities, Colombia's ability to finance the energy transition itself in terms of decarbonisation is slim. The narrative of the economic imperative framed by dependence on commodity exports at the prices given by this trade structure leads to further indebtedness and perpetuates the loss of monetary sovereignty.

The alternative for the Global South to be able to finance an energy transition beyond decarbonisation, not to be diluted in the trap of growing balance of payments deficits with the Global North, and to be able to advance in the different dimensions of a just transition, is to resolve the three structural traps created by the modern/colonial order: building 1) food sovereignty, 2) energy sovereignty and 3) technological sovereignty. Thinking about the energy transition in terms of the sovereignty of these three dimensions requires going through monetary sovereignty as an answer to the question of how to finance a productive transformation of systemic dimensions. President Petro's proposal in international scenarios to exchange debt for climate action is a step in this direction, as it puts into perspective the accumulation of debt in the countries of the Global South as a structural cause of the lack of monetary sovereignty to finance the energy transition.

In the current logic of global trade, the only way for the countries of the Global South to generate the resources to finance their energy transition is through increased economic growth, which requires exporting more and more commodities to pay off growing debts, and attracting capital to maintain low value-added economic activities. Under this scheme, the energy transition in countries like Colombia will be done through international cooperation, increased indebtedness or philanthropy.

In line with new interpretations of modern monetary theory (Hickel, 2021), Petro's proposed debt-for-climate action debt swap, through concerted action among regional blocs of countries, could create the regional markets required for the development of productive capacity in food, energy and technology.

Energy transition diplomacy should be concerted between regional blocs in the Global South to convince creditors to cancel debts generated by international trade based on colonial relations. These resources could then be used to finance the recovery or creation of productive capacity in regions today destined to sell their transition minerals in a new wave of green extractivism so that the Global North can decarbonise its economy and its consumption excesses. Monetary sovereignty would give the countries of the Global South the autonomy to develop their productive capacity in the three major axes and would force the Global North to undertake a transition not only based on decarbonisation, but mainly on de-growth and the end of relations of colonial exploitation.

7 Reflections and conclusions: just transition and swift action

Understanding of the energy transition. Both Colombia and Germany have focused their energy transition on the narrative of decarbonisation through "technological solutionism" without detailed reflection on its physical feasibility in alignment with planetary boundaries, social impacts and the systemic dimension of global climate justice. The Colombia-Germany case as a representation of North-South relations calls into question the possibility of decarbonisation based on the model of the Global North. A just energy transition necessarily implies transcending decarbonisation, to incorporate the structural causes of the climate crisis rooted in relations of colonial domination.

Systemic analysis. To understand each country's challenges in its energy transition, a systemic analysis of the evolution of demand and generation/supply in each sector is required, allowing for sectoral strategies for both transformation and decarbonisation. Sectorised proposals may not be realistic if they do not consider their interdependencies with production and consumption chains. A cross-sectoral view is necessary to inform sectoral plans. In Colombia, decarbonisation and systemic transition studies are still in their infancy. In Germany, there are more than 15 years experience with comprehensive plans and strategies, but they do not consider sufficiently the global dimensions, nor the conditions of the countries of origin of their projected energy imports.

Sectoral action. Fundamental changes in infrastructure, investments, legal frameworks and financing are needed for all sectors to achieve decarbonisation. This requires sector-by-sector plans/roadmaps on how to create emission reduction options up to full decarbonisation. In Colombia such planning is currently scarce, with each sector developing disconnected schemes (there are no decarbonisation plans and, in several cases, existing plans are not adequate). The country needs sectoral roadmaps for full decarbonisation and energy transition, articulated in a national vision. In Germany, based on the results of 10-20 years of national and sectoral analyses and projections for decarbonisation, there is an idea of how decarbonisation could be realised. However, implementation plans in specific sectors are insufficient and do not take corresponding measures.

Global articulation. A just energy transition implies national planning exercises articulated with global exercises. The global energy transition should not consist of the Global North creating energy export structures in Global South countries that are disjoint from local decarbonisation processes, because it puts the decarbonisation of the Global South at risk. As a global process, the energy transition requires global analysis and strategy. For the Global South, full decarbonisation is a colossal challenge and will allow for a national transition and significant exports (e.g. of hydrogen) in the medium term only if renewable potentials are sufficiently high and can be sustainably developed. A just energy transition is a global project to transform relations to the material world and will require a high level of commitment from the Global North to transform the structure of international trade relations. Financing the energy transition implies thinking about a global scheme allowing for the development of national productive capacities.

Inclusion of all actors. Existing Colombian sectoral roadmaps and policy processes and debates show a separation of actors: investors, companies, state, NGOs/communities. This means that insufficient progress is made and that large projects remain stagnant due to the lack of inclusion of local communities. The state should organise a dialogue between all actors and guarantee by law the participation of communities in decisions, ownership and profits of NC-RES generation projects ("democratisation of production"). In Germany there are extensive rights for the community, including prior consultation, favourable financial conditions for cooperative and intercommunal projects and the obligatory financial participation of the localities (0.2 ct/kWh, additional: industrial tax). Popular participation increases the acceptance of projects - on the other hand, in Germany the narrow opportunity for objection has slowed down many projects and lately it has been partially limited to accelerate project development.

Recovery or creation of sovereignty. Colombia and many countries in the Global South are highly dependent on fossil fuel exports to maintain an acceptable balance of payments. This represents a risk due to possible reductions in oil/gas exploitation in relation to projected national demand. This could translate into greater monetary dependence, and possible loss of energy security. The energy transition should contemplate scenarios of monetary sovereignty in order to have control over the speed and options for substituting fossil exports and for preventing currency devaluation. These scenarios should contemplate a rapid decarbonisation of the transport sector to prevent reliance on imports in the short term. Replacing fossil exports with hydrogen does not seem very feasible, especially given the high energy demand of other domestic sectors (transport, industry) that still require decarbonisation and the speed at which infrastructure development would be required. Consequently, the emphasis of Colombia and similar countries in the Global South should be on generating productive capacity to create food, energy and technological sovereignty based on local resources, knowledge and industries to achieve their own transition.

Land use changes in the global context. In Colombia, 59% of GHG emissions are from the agricultural sector and changes in land use, which explains the efforts to control deforestation. National strategies to control deforestation as the main driver of emissions over the last twenty years have failed to halt the phenomenon, perhaps because it has been approached as if it were an exclusively national problem. Understanding land use change and deforestation in the global contexts of the illicit drug market, land grabbing and speculation, growth in demand for meat and the timber trade would allow solutions to be developed that address structural causes. Solutions based on carbon sequestration in countries such as Colombia through various market mechanisms overlook the differences in slow and fast carbon cycles and do not address the urgent need to reduce emissions in the sectors and countries with the highest consumption. Despite the importance of emissions from the AFOLU sector in Colombia, the decarbonisation of energy-consuming sectors cannot be relegated to the background due to the complexity of the time-consuming and planning-intensive task.

Swift action. The risks of inaction are rising: every point above indicates a need for immediate political action by the governments of Colombia and Germany - delays in action raise costs and risks.

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Annex: Existing and planned strategies and public policies

This section lists key strategies, roadmaps, draft laws or analyses for energy transition in the countries analysed. The tables are not exhaustive as the policy and legal framework is extensive and complex and there are already a significant number of analyses. The list is a prioritisation by the authors. Due to space limitations, they cannot be summarised, but the tables summarise the main contents.

8.1 Colombia

Tab. 3: Energy transition policies in Colombia, key documents

Theme	Document	Content	Author/reference
Electricity/ wind power	Wind Energy in Colombia	Techno-economic analysis of wind energy	World Bank (2010)
Electricity	Generation - generation baseline expansion plan	Results of quantitative model of electricity capacity evolution up to 2034	UPME (2020)
Hydrogen	Hydrogen Roadmap	Techno-economic analysis, national/international demand, potentials, roadmap for action	i-deals et al. (i-deals & Montoya & Asociados, 2021)
Long-term carbon neutrality	Colombia's E2050 long-term climate strategy to comply with the Paris Agreement [Duque Government].	Assessment: quantitative carbon neutral modelling scenarios to 2050	Evaluation: Government of Colombia (2021) Journal paper version: Delgado et al. (2020)
Transport	National Strategy for Sustainable Transport [Duque Government].		Mintransporte (2022)
Imports/exports, economy	Understanding the impact of the low-carbon transition in Colombia	Analysis of economic risks in the climate and energy transition	UA & WTW (2022)
Offshore wind	Offshore Wind Roadmap	Analysis of offshore wind energy: techno-economic, environmental and social, supply, financial, regulatory framework	World Bank et al (2022)
General energy transition	Colombia, a world power for life. Basis of the National Development Plan 2022-2026	Basis of the NDP	Government of Colombia (2022)
General energy transition	Social dialogue to define the roadmap for the Just Energy Transition in Colombia [Petro Government].	Definition of the roadmap development process (the same foreseen for 2023)	Ministry of Mines and Energy (2022a)

8.2 Germany / European Union

Tab. 4: Energy transition policies in Germany, selected documents

Theme	Document	Content	Author/reference
Energy transition scenarios	Publications	Analysis and comparison of carbon neutrality scenarios up to 2050	SCI4climate.NRW (2022) Wiese et al. 23/06/2023 11:43:0000
Official government scenarios	Langfristszenarien	Website with access to the government's official long-term scenarios for the decarbonisation of Germany.	Fraunhofer ISI et al. (2023)
Building Act	Gesetzentwurf der Bundesregierung Entwurf eines Gesetzes zur Änderung des Gebäudeenergiegesetzes, [...]	Building law, including heating system regulation	BMWK (2023a)
Accelerating the increase of renewable energies	Law for the development of renewable energies	Revision of renewable energy law, including: classification of NCRE as a priority (accelerated permits), increased public tenders, subsidies for supply and hydrogen, high remuneration for PV, support for energy cooperatives, participation of local authorities, etc.	BMJ (2022)

Tab. 5: Energy transition policies in the European Union, selected documents

Theme	Document	Content	Author/reference
Long-term strategy	A Clean Planet for all [...]	Strategy for a GHG-neutral European Union in the long term (2050)	European Commission (2019)
National medium-term strategies	National Energy and Climate plans	Page with access to national medium-term strategies (2030)	European Commission (2020)
ETS: GHG Certificate System	Infographic	Information on agreed revision of the GHG certificate scheme (directive under development)	European Council (2023)
Vehicle regulation	Directive [...] setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles [...].	EU directive revision: new cars using fossil fuels will not be allowed to be sold in the EU	Directive 2019/631/EU
Construction regulation	Energy Performance of Buildings Directive (EPBD)	2023 review includes: restrictions and elimination of fossil heating systems, charging points and mandatory bicycle parking.	Directive 2010/31/EU
Ensuring secure and sustainable supply chains for EU	Critical raw materials act	2023 review includes regulation of critical and strategic materials with benchmarks for domestic extraction, processing, recycling and concentration of imports	EU 2019/102