1 Energy sector trends and clean energy prospects

Colombia relies heavily on fossil fuels to meet its energy needs, but declining domestic reserves for oil and gas are contributing to growing dependence on energy imports. This is evidenced by increased reliance on fossil fuel inputs for power generation, despite the country's significant hydropower installations. Droughts and constraints on water resources have also highlighted the need to diversify Colombia's power mix, and the first renewable energy auctions in 2019 and 2021 drew attention to the country's sizeable solar and wind resources. Bioenergy opportunities, by contrast, remain largely untapped, in spite of considerable available feedstock. Targeted policy interventions are needed to meet political ambitions to unlock this potential, which will also provide other benefits such as reduced waste to landfills, emissions mitigation and ability to supply local, reliable electricity.

Introduction

Colombia has made considerable socioeconomic progress over the last two decades and is the fourth largest economy in Latin America. Gross domestic product (GDP) per capita grew ten-fold since 1990, supported in particular by exports of natural resources such as coal, crude petroleum, gems, precious metals, iron ore (including exports of manufactured steel) and agricultural products like sugar, coffee and fruits (WITS, 2021[1]). Progress on trade agreements, infrastructure developments such as Colombia's high-draught ports, and policy reforms enabling a strong legal regime for businesses also have contributed to economic growth, as has the country's geographic advantage as a gateway to and from Central America. These factors, amongst others, have all made Colombia an attractive investment destination (ITA, 2021[2]).

Foreign direct investment (FDI) as a share of GDP doubled to 4.4% between 2010 and 2019, representing over USD 14 billion that year (World Bank, 2021[3]). This has largely gone to extractive industries (i.e. fossil fuels and mining), although FDI in financial services, communication technologies and clean energy has grown substantially since the mid-2010s. For example, FDI in renewable energy development grew eight-fold between 2018 and 2021, from seven projects worth USD 446 million in 2018 to 24 projects worth USD 3.8 billion in 2020 (EFE, 2021[4]). This growth was supported , in part, by efforts by the government to promote Colombia's considerable renewable energy potential, for instance through the state promotion agency, ProColombia. In particular, the government has aimed to attract private investment, for example through tax incentives and financial guarantees, to clean energy projects that strengthen the national energy mix and that improve overall supply reliability (Procolombia, 2021[5]).

These efforts are part of strategic plans to diversify Colombia's current power sector, which is highly dependent on hydro resources that are a structural weakness during periods of drought. Regulatory and market measures in recent years have consequently aimed to increase the installed capacity of other renewable energy sources, such as Colombia's large solar and wind potential. Bioenergy is another abundant potential resource, although market development remains relatively limited.

Increased investment in Colombia's vast renewable energy resources will help to improve the reliability of domestic energy supply through low-carbon power, while equally reducing growing dependence on energy imports such as liquefied natural gas (LNG). Renewable energy deployment will equally play a central role in meeting the government's ambitious emissions reduction targets to 2030 and beyond. Still, to achieve the country's clean energy goals, additional actions are required to strengthen market conditions and scale-up investment in those renewable energy solutions.

In particular, strategic action is needed if Colombia is to unlock its substantial bioenergy potential, including largely untapped opportunities for agricultural, industrial and municipal waste applications. This paper accordingly considers the status of bioenergy and waste-to-energy solutions in Colombia, and it looks at measures the government can take to increase the flow of finance and investment to those opportunities.

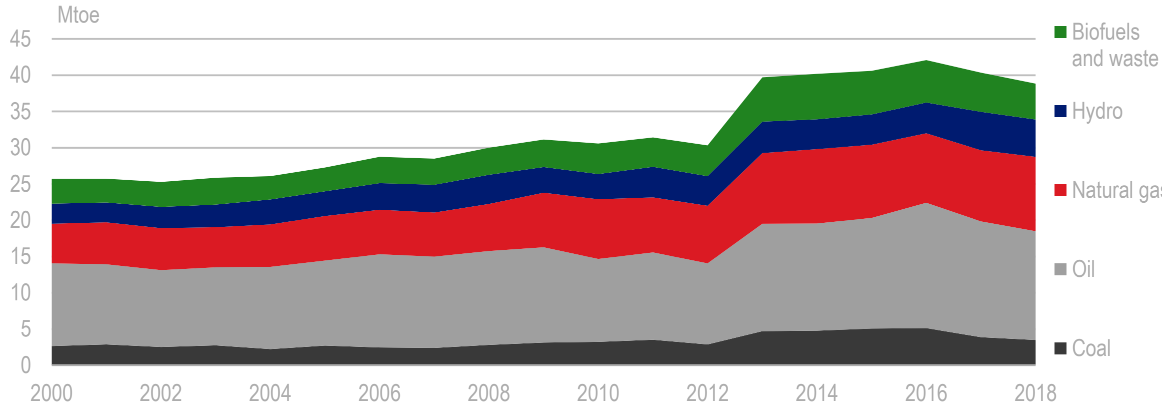
Highlights

- Fossil fuels dominate energy supply and demand in Colombia, with increasing implications for energy security and affordability as imports grow in order to compensate declining reserves of oil and natural gas. By 2050, fossil fuel imports could reach nearly 70% of total energy supply if measures are not taken to address the country's growing dependence.
- Abundant water resources have played a central role in developing Colombia's low-cost power system, but extreme weather events and the increasing impacts of climate change are amplifying the need to diversify the power system.
- Colombia has impressive renewable energy potential, including large, untapped solar, wind and bioenergy resources. Investment in these clean energy solutions can help to increase reliability and affordability of energy supply whilst equally decarbonising the country's energy mix.
- Wind and solar capacity additions have seen impressive growth in recent years, thanks to the introduction of renewable energy auctions. Bioenergy production, however, remains limited to biofuel production and some electricity and heat cogeneration in the sugar and palm industries.
- This gap is due in part to higher investment needs for bioenergy technologies, such as anaerobic digestion and gasification plants, but capital costs do not capture the socio-economic benefits from those projects, such as the value of reduced waste to landfills, emissions mitigation and the ability to supply local, reliable electricity.
- Examples such as the Doña Juana biogas facility in Bogotá illustrate the opportunity to produce clean energy using waste and residues from agricultural, industrial and municipal activities. Experiences and lessons learned from bioenergy developments in other countries, including those highlighted throughout this report, also highlight measures that Colombia can take to kick-start bioenergy projects.

Economic progress and population growth have contributed to steadily rising energy consumption in Colombia since the early 2000s, including a sharp increase in electricity demand, in spite of overall energy intensity improvements (in terms of units of energy consumed per unit of GDP). Industry and buildings in particular experienced big shifts to electricity over the last two decades, playing an important role in the near-doubling of electricity production between 2000 and 2018 (IEA, 2021[6]).

To meet rising demand, installed hydropower capacity was increased by around 40% since 2000, although these additions were not enough to keep up with growing generation needs, particularly in the warm phase of the El Niño–Southern Oscillation that led to important water shortages in 2015 and 2016. As a result, thermal power generation using fossil fuels swelled, reaching nearly 30% of Colombia's electricity output in the 2015-16 period (IEA, 2021[6]). When combined with oil demand in the rapidly growing transport sector, the net effect was a considerable jump in overall fossil fuel use in the mid-2010s (Figure 1.1). This came down slightly by 2018 as the effects of El Niño diminished, but fossil fuels nevertheless continue to play a major role in the country's overall energy mix.

Figure 1.1. Primary energy supply by fuel, 2000-18



Note: Mtoe = million tonnes of oil equivalent.
Source: (IEA, 2021[6]), World Energy Balances (database).

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Colombia is rich in natural resources, with large untapped renewable energy potential

Colombia boasts extensive energy resources with abundant hydro as well as sizeable reserves of coal, oil and natural gas. The country's fossil fuel reserves have been exploited for both consumption and export, providing low-cost energy domestically whilst supporting overall economic growth. Notably, Colombia has considerable coal reserves and was the world's 12th largest coal producer in 2019, making it the largest in Latin America with more than ten times the coal production of the second largest producer in the region, Mexico (EIA, 2020[7]). Exploitation is directed primarily at exports and, in 2019, Colombia shipped the equivalent of more than 47 Mtoe, making it the world's sixth largest coal exporter, with important economic implications (around 0.6% of national GDP in 2019) from coal rents (World Bank, 2021[8]).

Colombia also depends heavily on its oil reserves, both for domestic consumption and for export, where the country ranked as the sixth largest crude oil exporter to the United States in 2017 (EIA, 2020[7]). Colombia produced about 918 thousand barrels per day of petroleum oil and other related liquids in 2019, equal to 45 Mtoe in annual supply, thus making it the third largest oil producer in Latin America after Brazil and Venezuela. Yet, reserves are declining, and energy imports are increasing, thereby undermining national energy security. With proven reserves standing at around two billion barrels (about 275 Mtoe), there only remain roughly six years of current levels of domestic production. In addition, output is declining, and lower global oil prices have caused exploration activities to dwindle (Reuters, 2021[9]).

Natural gas reserves are also in decline and are relatively modest by regional standards. Around 95 Mtoe remained at the end of 2020, whereby in comparison, Mexico and Argentina had about 160 Mtoe and 325 Mtoe, respectively (EIA, 2020[7]). Outstanding reserves in Colombia only equate to around eight years of domestic consumption (Reuters, 2021[9]), and the country became a net importer in 2016 (EIA, 2020[7]). The Planning Unit of the Ministry of Mines and Energy (Unidad de Planeación Minero Energética, UPME) consequently recommended adding two new LNG re-gasification plants along the Pacific Coast to ensure supply for power generation to central and southern Colombia (Kraul, 2020[10]). These have not yet been constructed, though they would have long-term implications for continued reliance on imported natural gas.

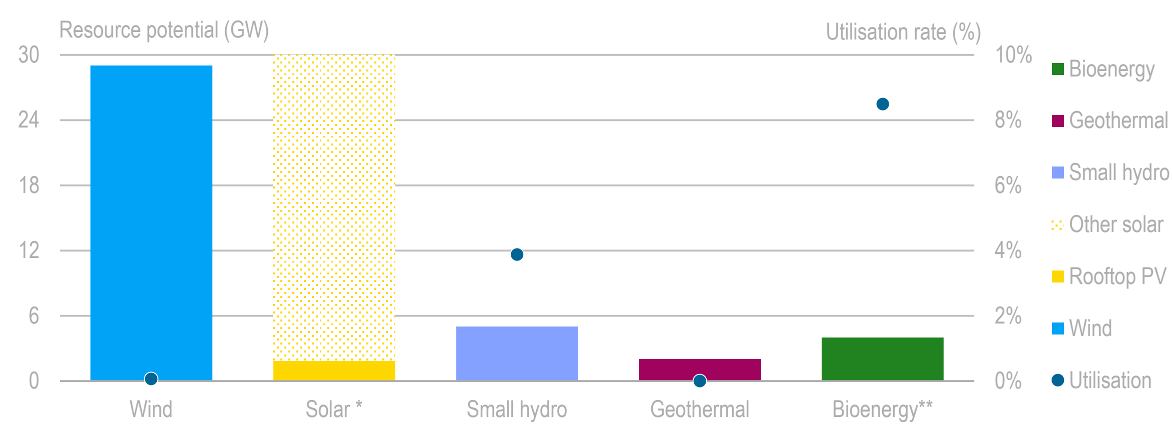
Colombia has equally been fortunate to have been one of the most water-rich countries in the world (FAO, 2003[11]), with historically abundant water resources that allowed the country to develop a low-cost power system, which boasts the third largest installed hydropower capacity in South America at nearly

12 gigawatts (GW) (IHA, 2020[12]). Yet, water availability has declined in the last decade, due to the impacts of climate change and increasing demand from population and economic growth. The country has also experienced extreme weather events linked to El Niño and La Niña phenomena, which respectively can cause prolonged droughts and extreme flooding, thereby impacting hydro electricity production. Recent El Niño events have had a particularly severe impact on hydropower reserves, amplifying the need to diversify the power system.

In response, the government has sought to exploit greater use of other renewable energy sources, which likewise have considerable potential (Figure 1.2). In particular, Colombia has favourable conditions for wind and solar energy, which have remained mostly untapped (Norton Rose Fulbright, 2016[13]). For example, wind potential in the department of La Guajira in the north of Colombia is estimated at 18 GW (Mordor Intelligence, 2020[14]), more than all currently installed electricity generation capacity in Colombia. Average annual wind speeds in certain locations off-shore of La Guajira are as high as 11 metres per second (IDEAM, 2020[15]), making Colombia one of only two regions in all of Latin America to reach these high levels, at more than double the minimum wind speed needed for utility-scale installations (Norton Rose Fulbright, 2016[13]).

Colombia also has strong solar potential, with the country averaging 4.5 kilowatt-hours (kWh) per square metre (m^2) per day (UPME, 2015[16]), where the higher bracket for high solar potential is benchmarked at 3.7 kWh/m^2 (Vesga, 2021[17]). By comparison, Spain, which had over 11 GW of installed solar capacity in 2019, receives on average around 3-3.5 kWh/m^2 per day in solar irradiance, while in Germany, with over 49 GW of installed solar capacity in 2019, this number averages around 2.2-3.2 kWh/m^2 per day (World Bank, 2020[18]); (IRENA, 2020[19]). Potential for large-scale solar generation is therefore particularly strong in Colombia, especially in the Orinoco region in the east and San Andrés islands in the Caribbean, where average radiation reaches as high as 6.0 kWh/m^2 per day (IDEAM, 2020[20]); (López et al., 2020[21]).

Figure 1.2. Renewable electricity potential and utilisation rate in Colombia, 2019



Notes: PV = photovoltaic. Solar * potential includes specific estimates for rooftop PV installations in large cities (solid), while other solar (dotted) potential is purely illustrative, given average solar radiation in Colombia in comparison with Germany (roughly one-third the land size and with lower solar irradiance), which had nearly 36 GW of solar PV installed in 2013 when PV prices were considerably higher (REN21, 2014[22]). Bioenergy** only includes estimates for electricity generation capacity from agricultural residues (Benavides and Cadena, 2018[23]).
Sources: adapted from (UPME, 2015[16]); (Benavides and Cadena, 2018[23]); (IRENA, 2020[19]).

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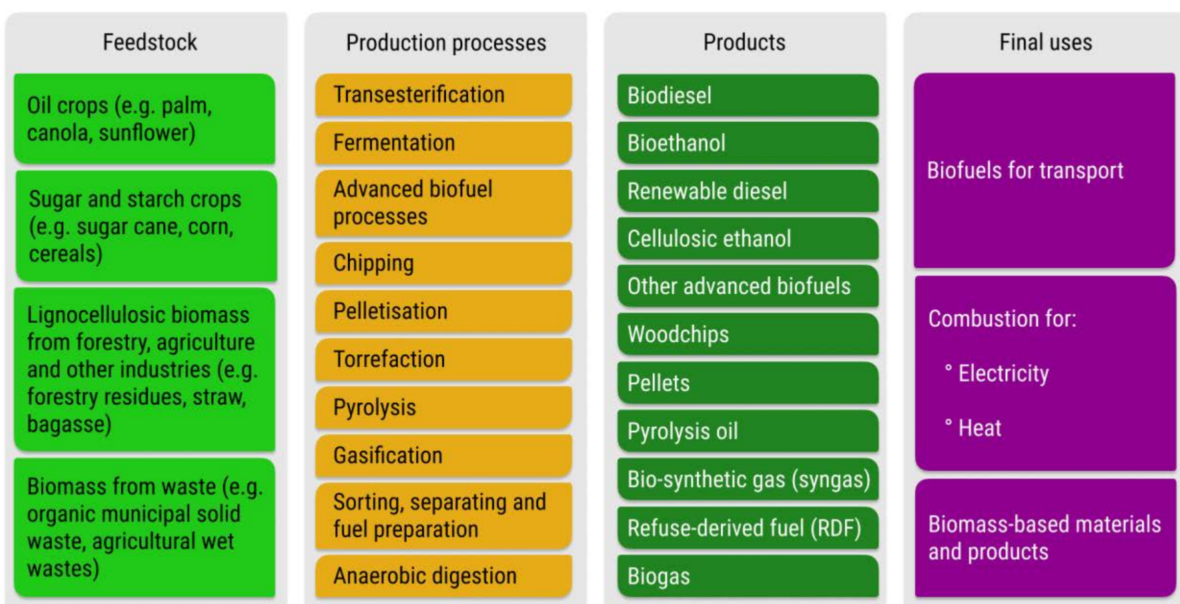
While solar and wind potential are substantial, integrating increased levels of these variable renewable energy will require investment to open grid capacity and to improve system flexibility (e.g. using energy storage and demand-side response). In addition, wind potential is largely concentrated in regions that can be far from demand centres and thus requires investment in transmission capacity to connect supply and demand. A particular risk is that long lead times or mismatches between transmission capacity and renewable energy additions will hamper future clean energy progress. In response, the government started awarding contracts for new transmission lines in 2018 to connect a first wave of clean energy projects in La Guajira. Grid reinforcements under the government's "Caribe 5" plan[1] also aim to strengthen capacity through as much as USD 4 billion of investment in transmission and network projects in the country's Caribbean region.

Bioenergy solutions can equally contribute to a flexible clean energy system, and Colombia is fortunate to have substantial potential bioenergy feedstocks. This includes agricultural residues from palm oil and sugar crops, which are already used for the production, domestic use and export of biodiesel and bioethanol. Other residues and waste from agricultural, municipal and industrial activities remain largely untapped opportunities for bioenergy production, and these resources, often in proximity to demand centres, could be used to create a number of clean energy products for uses such as local baseload power to municipal and regional electricity networks (Figure 1.3). Bioenergy production from available domestic feedstocks would help to reduce reliance on fossil fuels and growing dependence on LNG imports. Redirecting waste streams towards energy recovery can likewise have added environmental benefits, for instance by limiting the amount of waste going to landfills or being disposed of illegally, and proper management of these available waste streams can help to ensure that clean energy production does not encourage indirect land use change impacts, such as deforestation for biofuel feedstocks.

Figure 1.3. Potential products and uses of bioenergy resources



Source: adapted from (IEA, 2017[24]) Technology Roadmap: Delivering Sustainable Bioenergy.

Residues and waste can play a supporting role in clean energy development.

On average, around 178 million tonnes of organic waste are produced each year in Colombia from agricultural activities (41%), livestock (59%) and the residential sector (<1%). While some of these go through a compositing process to increase their value as fertiliser, the majority is re-integrated into crops in a non-technical way, which has been linked with decreasing productivity of land (Government of Colombia, 2019[25]). Development of bioenergy solutions can thus help to improve the overall bioeconomy in Colombia, for example using biodigestion to convert organic waste from farms into bioenergy and biofertilisers.

UPME estimates that agricultural biomass residues, via direct combustion and/or anaerobic digestion, could be converted to around 8 Mtoe of energy, equivalent to roughly a fifth of Colombia's total energy supply in 2018 (UPME, 2011[26]). Residues from livestock (e.g. cattle, swine and chicken manure) could likewise generate as much as 33 terawatt-hours (TWh) of electricity, or nearly half the power supplied (77 TWh) in Colombia in 2019 (IEA, 2021[6]). A further UPME study from 2017 highlighted opportunity for biogas production, noting a technical potential of 11 TWh from agricultural residues and an additional 1.7 TWh from livestock waste (Table 1.1) (UPME, 2017[27]). For instance, biogas could be produced from bagasse residues that remain from liquid biofuel production, of which Colombia already is amongst leading global producers and is in the top ten employers in that field (IRENA, 2020[28]).

Energy generation from municipal and industrial waste also has good potential, particularly as most of this waste ends up in landfills and consequently is a significant contributor to greenhouse gas emissions (GHG) such as methane. In fact, the waste sector alone accounted for 6.3% of Colombia's GHG emissions in 2018 (ClimateWatch, 2021[29]). Most of this was from municipal solid waste (MSW), where Colombia produces around 18 million tonnes of organic residues (59%), plastics (13%), paper and cardboard (9%), glass (2%), metal (1%) and other wastes (16%) each year (Government of Colombia, 2019[25]). About 83% of MSW is collected for disposal in landfills without further sorting, which if done would allow for greater recycling, re-use and recovery, including waste-to-energy solutions, which would reduce the environmental footprint of the sector whilst also prolonging the lifetime of landfills (RVO, 2021[30]). Indeed, if MSW were exploited fully, the technical biogas potential could reach as much as 1.4 TWh per year (Duarte, Loaiza and Majano, 2021[31]).

Table 1.1. Technical potential for biogas production by residue type and quantity

Sector	Residue	Quantity	Technical potential	
		thousand tonnes/year	*million m³/year*	*GWh*/year*
Livestock	Poultry manure	2 793	168	1 000
	Swine manure	1 410	99	589
	Bovine manure	501	20	120
Agriculture	Rice straw	252	353	2 054
	Banana fruit rejects	249	0.4	2
	Coffee pulp	185	5	28
	Coffee mucilage	63	5	63
	Corn stalk	559	287	1 372
	Oil palm (oxidation pond)	6 710	134	854
	Plantain fruit rejects	117	0.2	1
	Sugarcane bagasse	6 549	1	6 294
	Panela cane bagasse	238	<0.1	227
Municipal	Solid urban waste (organic)	4 278	282	724
	Sludge (sewage)	289 969	101	654
Industrial	Dairy sludge and fats	10	0.4	5
	Brewery sludge	2	0.1	1
	Cane stillage	9 587	158	902
	Slaughterhouse rumen	62	1	6
Total		**323 534**	**1 615**	**14 896**

Note: GWh = gigawatt-hour. *GWh/year represents the technical energy potential for biogas production (not the electricity generation potential).
Source: adapted from (UPME, 2017[27]).

Industrial waste represents another opportunity for recovery of energy. The industry sector generates around nine million tonnes of waste each year, with a technical biogas potential of around 1 TWh (DNP, 2016[32]). This includes hazardous industrial waste such as oil, solvents and sludge, which together represented over 300 000 tonnes of waste in 2016. One third of that required special, secure landfills. Given the often high-calorific content of these types of wastes, there is a clear waste-to-energy opportunity, for instance through incineration plants and co-processing (e.g. in cement production). Waste recovery for energy production would also limit the disposal of such hazardous wastes in landfills.

In spite of the large untapped potential of available waste and residues in Colombia, use of bioenergy remains relatively limited, notably to biofuel production and to electricity and heat cogeneration in the sugarcane and palm industries. Use of technologies such as anaerobic digesters and direct use of biomass and waste (e.g. for co-processing in industry) would help to tap into this prospective, at the same time as providing a number of potential benefits such as increased access to reliable electricity in rural areas and improved energy security from reduced imports of fossil fuels. Yet, enabling widespread uptake of these bioenergy solutions will require greater awareness amongst industry and energy actors, as well as stronger policy signals such as deployment targets and use of fiscal incentives that can drive early market adoption. Encouraging uptake of bioenergy solutions will also need to take into account the government's bioeconomy and circular economy strategies (discussed in Chapter 2) to ensure that policy measures and market incentives do not encourage unsustainable bioenergy production.

Bioenergy can help decarbonise the energy mix, which is dominated by fossil fuels

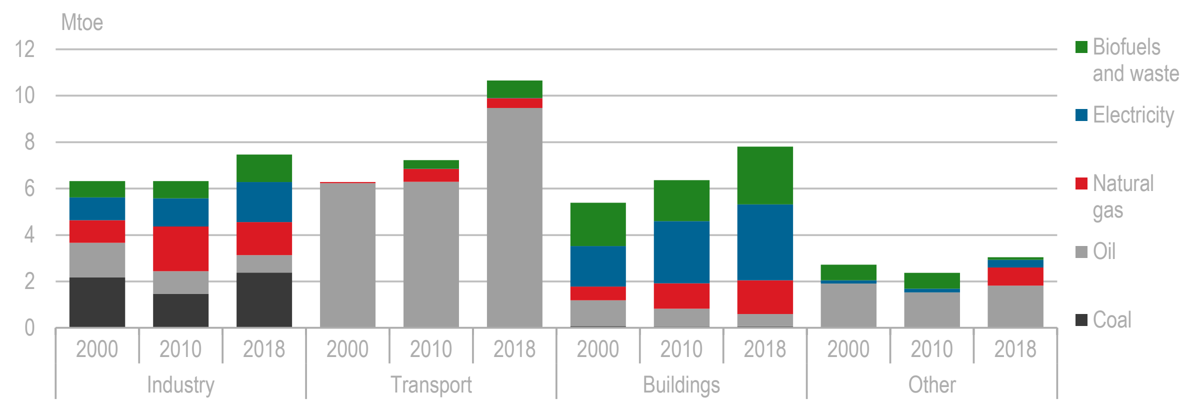
Energy supply and demand in Colombia are primarily met by fossil fuels, which accounted for around two-thirds of final energy consumption in 2018 (IEA, 2021[6]). The power sector may be dominated by hydro, but electricity only accounts for 18% of total energy use. Biofuels and waste[2] account for another 16%, but this is mostly traditional use of solid biomass[3] for cooking and heating in households, with smaller amounts of biomass used for cogeneration in industry as well as for biofuels in the transport sector (Figure 1.4).

Energy demand from industry and buildings accounted for just over half of final energy use in 2018 (26% and 27%, respectively), while the largest share of demand (37%) was for transportation. The transport sector was the fastest growing energy consumer over the last decade, increasing by nearly 50% between 2010 and 2018, due to rising demand for motorcycles, passenger cars and light commercial vehicles (BBVA, 2019[33]). Currently, 90% of transport energy demand is for oil, making the sector a critical driver of increased fossil fuel consumption. Fuel mandates, including requirements for 8% blend of ethanol in gasoline and a 9.2% blend of biodiesel in diesel, helped to allay some of this growth, though not nearly as quickly as transport energy demand grew since 2010. The sector's oil demand consequently reached nearly 9.5 Mtoe in 2018, eating into more than 20% of Colombia's oil production that year. Biofuels, thanks to blending requirements, represented around 7% of the sector's fuel use, with a slightly lower share (5%) of road transport energy consumption in 2018 (Rueda-Ordóñez et al., 2019[34]). This share could be further increased (e.g. with 15% ethanol and 85% gasoline [E15] blends), but changes in the current blends would be best if done in dialogue with automotive and original equipment manufacturers, as higher volume mixtures can require modifications to engines (The Royal Society, 2008[35]).

Industry, representing 26% of GDP value added (including construction), is also heavily dependent on fossil fuels, although to a lesser extent than the transport sector. Industry in Colombia includes a number of energy-intensive activities, such as coal and oil extraction, chemical products, metallurgy and cement production. Agricultural products (e.g. coffee, sugarcane, fruits and nuts) and commodities such as textiles also are important economic outputs (Santander Trade, 2021[36]). The variety in these industrial activities contributes to a greater mix in sectoral fuel use, even if fossil fuels account for around 60% of total industry energy consumption. Electricity accounts for another quarter of the sector's energy demand, and bioenergy, primarily for cogeneration with bagasse residues from Colombia's sugar and palm industries, makes up the remaining 16%. Other forms of bioenergy (e.g. biogas) from industrial or agro-industrial residues remain limited (Asocaña, 2021[37]).

The carbon intensity of industrial energy consumption has fluctuated since 2000 and was marginally lower in 2018 at 49 grammes (g) of carbon dioxide (CO_2) per megajoule (MJ) than in 2010 (51 gCO_2/MJ) (IEA, 2021[38]). This improvement is thanks to the growing share of electricity and bioenergy, which each grew by 40% and 60%, respectively, between 2010 and 2018. Part of this bioenergy growth is due to industry concerns with price volatility for oil and natural gas, while net-metering regulation (see Chapter 2) in 2015 provided additional incentive for cogeneration in the sugar and palm industries. Still, in spite of this progress, industry coal use increased by 60% during the 2010-18 period, highlighting the important role of low-cost domestic coal production in the country's reliance on this fossil fuel (IEA, 2021[6]).

Figure 1.4. Final energy consumption by sector and fuel, 2000-18



Note: "Other" includes final energy consumption in agriculture, forestry, fishing and other fuel use not elsewhere specified.[4]
Source: (IEA, 2021[6]), World Energy Balances (database).

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Buildings account for the last major share (27%) of final energy consumption, and the sector is the second fastest growing demand after transport. This is linked to steady population growth (51 million people in 2020, as compared to 45 million in 2010), increased household income and a large, growing services sector, which accounted for 57% of GDP in 2019. The latter is driven in particular by business from outsourcing and a dynamic tourism industry (World Bank, 2021[8]). The services sector, together with growing household demand, has principally contributed to strong growth in electricity use, which accounted for 42% of buildings sector energy consumption in 2018. Simultaneously, biofuels and waste (mostly in the form of traditional use of solid biomass such as firewood) accounted for around a third of buildings energy demand. In fact, while electricity use in buildings increased 20% between 2010 and 2018, biomass consumption grew by 40%. This underscores the important role that traditional use of biomass plays for heating and cooking in households, most commonly in rural populations (18.5% of the population in 2020) and in areas that do not have reliable access to the electricity grid (roughly 3.6% of the population) (IADB, 2016[39]).

The high shares of fossil fuels and traditional use of biomass in Colombia's energy mix stress the critical challenge of deploying efficient, affordable and clean energy solutions over the next decades if the country is to achieve its sustainable development goals and targeted carbon neutrality by 2050. Modern bioenergy and waste solutions can play a pivotal role in this transition, as highlighted by UPME estimates of technical potentials. Yet, policy levers will need to ensure the enabling conditions for these investments, starting first with clearer signals on the expected role renewable energy technologies will play (beyond their theoretical potential) in the country's future energy mix.

One such example of this need is illustrated by coal use in industry. Despite opportunities for clean energy uptake such as the current use of bagasse in the sugarcane industry, overall coal use in the sector increased since 2010, reversing the declining share from the early 2000s. Signals on policy expectations for industry fuel mix and/or decarbonisation pathways under the auspices of Colombia's climate commitments would help to encourage a pipeline of clean energy solutions like biomass cogeneration. Support for technology demonstration in target industries beyond sugar and palm production would also help to build the business case for bioenergy applications. These actions could be complimented by other measures such as the use of incentives like the financial assistance scheme that supports biomass-based cogeneration projects in India under the country's Ministry of New and Renewable Energy.[5]

Industry mandates and emissions trading schemes, such as those used in the European Union and the People's Republic of China (hereafter "China"), have also been successful in driving clean energy solutions like biogas and biomass cogeneration in industry. Colombia introduced a carbon tax in 2016, (Law 1819 of 2016[6]), although industry use of fuels such as coal, coke crude oil and refinery gas are not currently subject to the tax. Additionally, natural gas is only subject to the tax if used by refineries or in the petrochemical industry (OECD, 2019[40]). Addressing these exemptions, for example through an emissions trading scheme that is currently under development (Law 1931 of 2018[7]) will encourage the phase down of fossil fuel use in industry through solutions such as biomass cogeneration. Other signals, such as progressive increases in tipping fees for landfills, can similarly help to drive uptake of clean energy solutions, for instance supporting development of waste-to-energy solutions for biogas and clean electricity generation.

Power sector development and bioenergy opportunities

Improving access to reliable and affordable electricity supply has been and continues to be a policy priority in Colombia. There has been significant restructuring of the electricity market since Law 142 of 1994 (later modified by Law 689 of 2001[8]) and Law 143[9] of 1994 were passed, allowing for private investment in generation capacity. The government has also made concerted effort to expand electricity access over the last two decades, including financial support for electricity system development, and by 2019 around 97% of the country was connected (IEA, 2020[41]). Electrification rates are highest in urban areas, covering nearly all (>99%) of the population, and the country has adequately installed capacity with respect to meeting overall electricity demand. Still, only 48% of the country (in terms of territory) has access to the national interconnected system (Sistema Interconectado Nacional), while the other 52%, representing about 1.8 to 2.2 million people, remains as non-interconnected zones (zonas no interconectadas, ZNI) (IADB, 2016[39]).

ZNI areas can lack connection to the national grid due to a number of technical, financial or environmental constraints, such as issues with transporting fuels and difficulties building transmission and distribution infrastructure. ZNI are mostly rural (89%) and are usually sparsely populated, but they can include some municipalities, cities, towns and villages that rely on isolated grids or diesel generators for electricity generation (Garces et al., 2021[42]). The challenges of expanding the national grid to these "last mile" ZNI subsequently means that distributed and off-grid solutions such as local, sustainable energy resources like bioenergy and waste can be an effective and economical opportunity to achieve full electricity access.

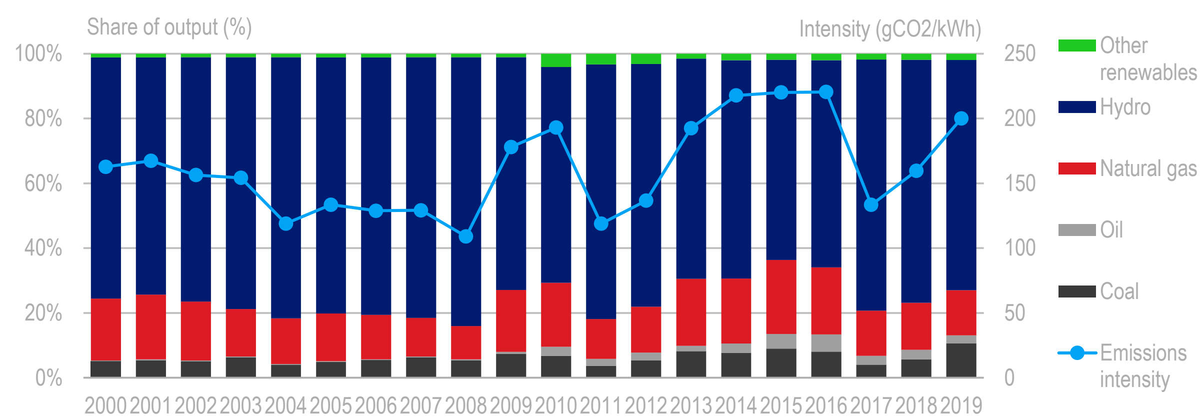
Elsewhere, in areas connected to the national grid, some regions rely heavily on thermal power generation using fossil fuels, in spite of Colombia's abundant hydro resources, at least on a national level. For example, Córdoba, La Guajira and Norte de Santander in the northern part of the country relied exclusively on coal for electricity generation in 2017 (OECD, 2021[43]). In fact, new coal capacity has received permits in the Córdoba and Cesar regions (Global Energy Monitor, 2021[44]), despite the high potential for solar production in those parts of the country. Given the average lifespan of a coal power plant of around 40 years, adding such new capacity would not be in line with Colombia's sustainable development targets to 2030 and beyond. The additions also point to the need to enable a robust pipeline of affordable clean energy solutions like bioenergy to compete with and substitute fossil fuel power generation in the country.

Secure and affordable electricity supply requires more diverse capacity

Colombia had around 18 GW of installed power generation capacity in 2020, and the sector's carbon intensity averaged around 160 gCO_2/kWh over the last two decades, compared to a world average of about 475 gCO_2/kWh in 2018 (IEA, 2021[38]). However, this relatively low CO_2 intensity depends considerably on available hydropower, which represents two-thirds of total installed capacity (IEA, 2021[6]). In years of low hydro availability, coal, oil and natural gas power generation ramp up, leading to jumps in related emissions, such as the 2016 peak of 221 gCO_2/kWh during the El Niño cycle (Figure 1.5). More recently, power sector emissions intensity rose again in 2019 due to considerable deficits in precipitation in the first quarter of the year, underscoring growing risks from more frequent anomalies in the El Niño phenomenon and from climate change (Minambiente, 2021[45]); (Parra et al., 2020[46]).

While fossil fuels may only represent 30% of installed power generation capacity, they nevertheless play a critical role in ensuring secure supply of electricity in years of prolonged drought. At the same time, this intermittent use of those generation assets has noticeable effects on the electricity market, not just in terms of power sector emissions but also in terms of electricity spot prices. The latter is the natural consequence of sporadic need for fossil fuel capacity, which creates challenges for operators as well as for finance and capital investment in energy exploration, production and transportation (World Bank, 2019[47]). The uncertainty of weather-related events (and subsequent demand for fossil fuel power generation) also creates challenges in securing energy supply contracts, particularly as natural gas producers prefer the more stable consumption profiles of industry and the residential market.

Figure 1.5. Share of electricity generation by fuel and resulting carbon intensity, 2000-19



Source: (IEA, 2021[6]), World Energy Balances (database).

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The government's 2020-50 National Energy Plan (Plan Energético Nacional, PEN)[10] highlighted that growing fossil fuel imports (equivalent to 7% of national energy supply in 2020) could reach nearly 30% of Colombia's total energy supply by 2030 under a business-as-usual scenario. This would reach a staggering 69% by 2050 if left unchecked, risking costly price fluctuations and creating considerable potential energy security issues for the country (UPME, 2020[48]).

Growing reliance on fossil fuel standby increases exposure to price volatility, especially in periods when hydro capacity is diminished. To help ensure reliable and cost-effective supply of electricity during periods of drought, Colombia's energy and gas regulation commission (Comisión de Regulación de Energía y Gas, CREG) introduced a hedging mechanism in 2006 to reduce market uncertainty and to help recover a portion of fixed costs for standby power. The mechanism is based on firm power[11] obligations awarded through auctions[12] that commit generators to provide given amounts of energy at a pre-determined situational scarcity price. In return, the generators receive a fixed annual option fee, known as a reliability charge ("Cargo por Confiabilidad"), for each kWh contracted.

While in principle the reliability charge is an effective tool, a number of weaknesses were highlighted during the extreme droughts of 2016. That year was the second strongest El Niño event in the recorded history of Colombia and led to a 40% decrease in rainfall. This diminished available water in hydropower dams by as much as 60-70%. At the same time, demand for cooling and refrigeration amplified with increased temperatures, and unforeseen operational issues (including a fire that forced the outage of the 560 megawatt (MW) hydro plant in Guatapé) took another portion of remaining sources offline. This resulted in a cumulative shortage of 200 MW, more than 1% of installed capacity, in April 2016, even after taking into account successful energy saving campaigns by the government (World Energy, 2019[49]).

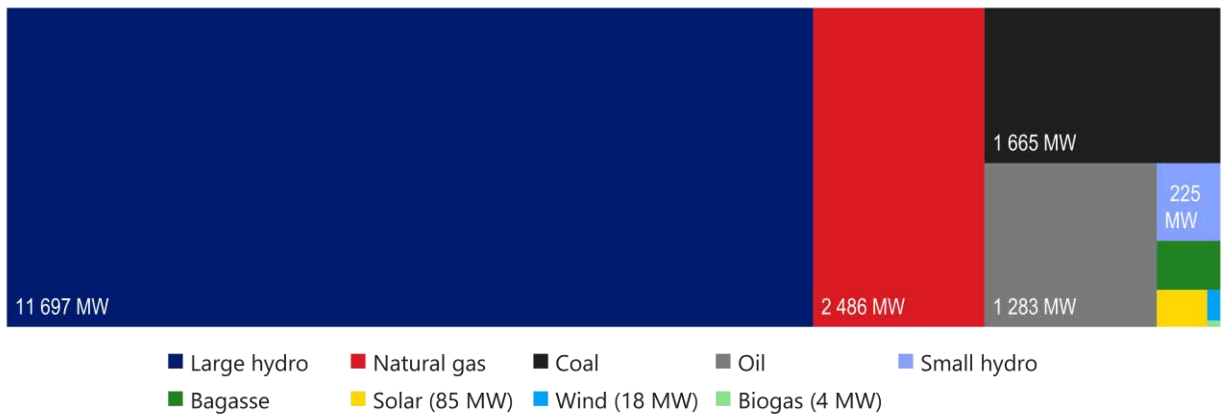
Thermal plants under the reliability charge subsequently kicked in, and fossil fuel power totalled around 55% of electricity produced in April 2016. This had important consequences on price stability in the market, hitting generation and distribution companies that were not adequately hedged. Scarcity prices, which were set to USD 110 per MWh, were as much as seven times lower than the actual cost of producing electricity, while the average spot price rose from around USD 30-50 to USD 400 per MWh. In fact, this higher bound was set by regulatory intervention to cap the maximum price (World Bank, 2019[47]).

A new reliability charge auction was consequently held in 2018, securing an additional 100 MW of natural gas and 260 MW of coal power to ensure higher margins of non-hydro capacity. A further renewable energy auction was planned for 2019. The extreme drought also served to push forward the renewable energy agenda as a means to diversify the power mix and address a number of the issues brought forward during the 2016 event, including growing reliance on fossil fuel imports. Much of this focus has centred on increasing wind and solar capacity additions, although bioenergy, like fossil fuel (thermal) power, has the additional potential to provide capacity on demand.

Clean energy solutions can help to achieve secure and reliable electricity supply

In response to exposure to price volatility from fossil fuel generation and increasing dependence on energy imports, the government set forth intentions to increase development of non-conventional renewable energy (NCRE) sources, defined under Colombian law as renewable energy sources outside large hydro.[13] NCRE represents a significant opportunity to diversify Colombia's energy mix, for instance through greater uptake of solar, wind and bioenergy technologies, and policy measures such as net-metering regulations (see Chapter 2) have helped to spur renewable power additions. By mid-2021, around 80 MW of wind and 18 MW solar generation capacity was connected to the national grid (Figure 1.6). Small hydro accounted for another 225 MW of installed capacity, followed by 145 MW of bioenergy, mostly in the form sugarcane bagasse (141 MW) and some biogas from three anaerobic digestion plants (around 4 MW) (SIEL, 2021[50]). Altogether, these NCRE represented about 3% of total installed capacity.

Figure 1.6. Installed grid-connected power generation capacity by source, June 2021



Source: (SIEL, 2021[50]) Generation Statistics Queries (database).

StatLink https://stat.link/ksgt3d

This share of NCRE is set to increase as another 2.5 GW of additions will come online in 2022, accelerated in part by the country's first successful renewable energy auctions in 2019 (Djunisic, 2020[51]). In fact, the World Economic Forum listed Colombia in its 2020 Energy Transition Index as having made the most progress on renewables in Latin America and the Caribbean, thanks in particular to the introduction of the country's first auctions (WEF, 2020[52]). Specifically, an auction was held in February 2019, although this was not successful due to issues with market concentration. A second, successful auction was then held in October of 2019, securing more than 1.3 GW of new wind and solar projects, with awarding based on competitive generation costs. These seven wind and three solar PV projects represented an estimated USD 2.2 billion of investment, primarily from large international and national players such as Trina Solar, EDP Renovables, Celsia, and Jemeiwaa Ka'I (IRENA and USAID, 2021[53]).

In addition to the auctions, UPME also approved 5.2 GW of solar and 2.5 GW of wind power additions in 2020 (Djunisic, 2020[51]). When combined with the October 2019 auction, these planned additions should add at least 2.5 GW of renewable electricity capacity by 2022, corresponding to about 12% of Colombia's expected electric power generation capacity (20 GW) by then (ITA, 2021[54]). 0.8 GW of new capacity was also awarded in a third auction held in October 2021, counting 11 solar projects worth an estimated investment of USD 875 million (Renewables Now, 2021[55]). Participants included domestic players such as Empresas Públicas de Medellín (EPM), Celsia, Empresas de Urrá and Fotovoltaica Arrayanes. There were also international developers, including the French utility EDF, the Chinese-Canadian manufacturer Canadian Solar, Italy's Enel and the Spanish solar companies Solarpack and Genersol (XM, 2021[56]). The 0.8 GW awarded should be operation in 2023 (Scully, 2021[57]).

These capacity additions in recent years have greatly supported solar and wind progress in Colombia, while by contrast, expected bioenergy additions remain limited to around 48 MW of capacity set to come online by 2022. Moreover, despite the potential for bioenergy to play a role in reducing Colombia's reliance on fossil fuels, no such capacity was awarded in the 2019 or recent 2021 auctions, even though bioenergy projects participated. This was due in part to direct competition with the diminishing costs of solar and wind power, where auctioning of electricity generation (in cost per kWh) does not necessarily capture other socio-economic benefits from bioenergy projects, such as the value of reduced waste to landfills and the ability to supply reliable electricity in areas not connected to the national grid.

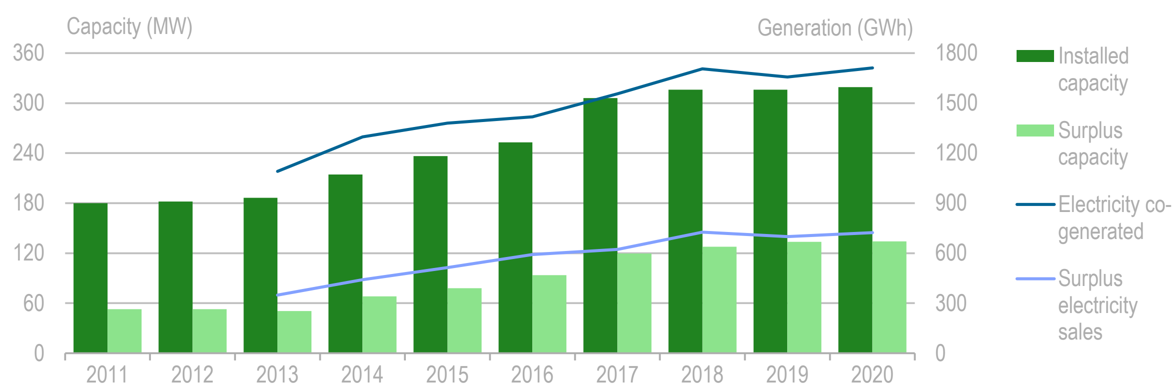
Experiences in other countries, such as the "Biovalor" initiative[14] in Uruguay, highlight how bioenergy can generate local economic value whilst improving the security and reliability of energy supply. Biovalor is an initiative by the government of Uruguay, supported by the United Nations Industrial Development

Organization. Since 2016, the initiative has co-financed eight bioenergy projects, which are transforming local agricultural, industrial and municipal waste into energy and/or other bi-products such as biofertilisers (Biovalor, 2021[58]). In addition to reducing over 100 thousand tonnes of annual waste, the projects have helped to develop local technical capacity and energy technology solutions (e.g. biodigesters for micro- and small-scale production). In one project, a small biogester (12 litres of waste per day) was installed in a municipal dining hall, whose organic waste produces enough biogas to supply the kitchen's stoves for two to three hours a day, cutting the site's supergas (butane and propane) use in half. In another project, a biodigester installed at a dairy farm in the department of San José began generating around 240 kWh of electricity per day in late 2019, allowing the farm to run nearly independently during expensive peak hours and to export around 2.8 MWh of electricity per month to the national grid. Solutions similar to these could be applied in Colombia, for example in ZNI, and would help to ensure secure and reliable electricity generation through nearby available resources, with potential added benefits for local businesses.

Bioenergy capacity additions need a kick-start if they are to reach their potential

Despite promising growth in bioenergy cogeneration in the mid-2010s, new capacity additions began to slow in 2017 and have since plateaued (Figure 1.7). As of June 2021, UPME's generation project registry[15] only had two proposed bioenergy projects under review, representing around 26 MW of capacity additions. By comparison, over 200 solar projects were under review, representing 11 GW of proposed additions, and a further five thermal (fossil fuel) power projects under review would add 2.6 GW of electricity generation capacity (UPME, 2021[59]).

Figure 1.7. Installed biomass cogeneration capacity, surplus and electricity sales, 2011-20



Source: adapted from (Asocaña, 2021[37]).

StatLink https://stat.link/0396te

Part of the slow-down in bioenergy project development relates to competition in pricing. The most recent UPME Reference Generation and Transmission Expansion Plan (Plan de Expansión de Referencia Generación - Transmisión) for 2020-34[16] highlighted that the average capital expenditure (capex) costs for biomass cogeneration and other bioenergy technologies were amongst the most expensive of the potential NCRE technologies (in USD per kilowatt). Additionally, experience with bioenergy developments has mostly been restricted to cogeneration in the sugarcane and palm oil industries, and even then, it is a relatively limited number of applications. As of 2021, only 13 cogeneration plants sold to the grid, representing about 150 MW of capacity (UPME, 2021[60]). Most of this capacity (eight plants) is fuelled by bagasse, and the remainder uses bagasse combined with coal or natural gas (XM, 2020[61]) (Table 1.2). Technologies like anaerobic digestion are typically at lower capex levels than other bioenergy projects such as gasification or incineration plants (Alzate-Arias et al., 2018[62]). Still, on average, the capex for bioenergy is much greater than for wind and nearly double that of solar.

Table 1.2. Capex by technology under the UPME reference expansion plan for 2020-34

Technology	USD per kilowatt		
	Minimum	*Average*	*Maximum*
Coal	1 300	1 900	2 500
Oil		1 613	
Natural gas	1 086	1 150	1 213
Large hydro	1 704	1 792	1 880
Small hydro		2 542	
Wind	1 108	1 454	1 800
Solar	710	1 105	1 500
Bioenergy	950	2 200	4500
Biomass cogeneration		2 141	
Geothermal		4 500	

Sources: (UPME, 2020[63]) Generation and Transmission Reference Expansion Plan 2020-2034 and OECD correspondance with UPME.

In terms of growth, the bulk of bioenergy cogeneration additions happened between 2014 and 2017, thanks notably to the passage of Law 1715 of 2014 (Colombia's Renewable Energy Law)[17] and then UPME Resolution 45 of 2016,[18] which enabled self-generators to connect to the grid. Electricity available to the grid from bagasse cogeneration consequently increased from 51 to 120 MW between 2014 and 2017 (Asocaña, 2014[64]), although this then slowed considerably, with capacity only growing a further 14 MW by 2020 (Asocaña, 2021[37]). New developments are expected to increase total capacity to around 206 MW of bagasse cogeneration connected to the grid by 2024, albeit again from the sugar and palm industries.

A few self-generation projects (industry actors with on-site power generation) using bioenergy came online in recent years, due in part to policy reforms on net-metering and also thanks to a number of tax exemptions with accelerated depreciation rules under the 2014 Renewable Energy Law. Yet, despite these, bioenergy self-generation remains uncommon, and only 2.9 MW of capacity was approved for new connections to the grid in 2021. By comparison, there were 34 MW of on-site solar PV approved for connection as self-generators (UPME, 2021[65]).

Other bioenergy generation additions remain limited to a handful of projects. Specifically, three anaerobic digestion (biogas) plants were connected to the grid in 2016, accounting for 4 MW of installed capacity (SIEL, 2021[50]). Energy in these cases is produced from wastewater treatment and landfill methane recovery. For example, the Bogotá Doña Juana biogas facility (1.7 MW) produces electricity sold to the national grid from landfill emissions. While a promising example of this sector's potential to produce grid-connected energy production, most of Colombia's industrial and municipal waste is nevertheless disposed of in one the 62 official regional landfills that do not have any further sorting or waste recovery. Low tipping (landfill) fees contribute to this lack of further treatment (RVO, 2021[30]).

To address the lack of incentive to capture waste-to-energy potential, other countries have raised disposal fees, put forward more stringent policy measures limiting landfilling of waste, or applied a combination of such measures. For instance, China has taken several actions in recent years to recycle valuable wastes and reduce the amount of MSW disposed of in landfills (Zhu et al., 2020[66]) (Yan et al., 2019[67]). This has included strengthening the country's regulatory environment on MSW, increasing tipping fees and offering financial support for recycling, waste management and waste-to-energy facilities. Similar measures were taken in the European Union, where in addition to assertive regulation on landfilling, multiple regulatory, economic and administrative measures have also been used to encourage bioenergy projects (Box 1.1).

Countries have also applied more targeted measures to encourage bioenergy capacity additions. This includes measures to address bioenergy project development in the face of increasingly competitive energy sources like solar and wind power. For example, Denmark, like Colombia, has large feedstock potential from agricultural waste, in addition to competitive pricing from the country's offshore wind market. To promote bioenergy capacity additions, the government took a number of actions to encourage the production and use of those resources, including through long-term policy signals on the role biogas is expected to play in Denmark's clean energy transition to 2050. Initiatives such as subsidies for biogas projects and funding under the country's Energy Technology Development and Demonstration Programme also helped to enable rapid growth in biogas production over the last decade. In fact, by 2020, biogas already constituted about 20% of Denmark's energy supply (MoF, 2021[68]).

Enabling a strong pipeline of bioenergy and waste-to-energy projects in Colombia will require similar policy actions to encourage development and address challenges such as increasing competition with solar and wind projects. For instance, UPME can highlight the opportunity for bioenergy projects by clarifying clean energy targets through signals such as those in the European Renewable Energy Directive, which included "biomass, landfill gas, sewage treatment plant gas and biogases" as non-fossil sources under the legally binding objective to achieve 15% of energy from renewable sources. The government can also look to experiences in other countries, building upon good practices that for example enabled pre-processing and co-processing of MSW in cement production in Japan, the United States, Australia, Brazil and South Africa (Hasanbeigi et al., 2021[69]). Further measures can include working with both international and local partners to improve awareness for bioenergy solutions and to strengthen the capacity to implement them (see Annex A on the Organic recycling programme, or Reciclos Organicos).

Box 1.1. Application of different measures encouraging bioenergy development in Europe

Legislation in the European Union discourages disposal to landfills and has been a driving force behind deployment of bioenergy solutions like anaerobic digesters, composting plants and waste incineration. Specifically, the European Union's 1999 Landfill directive[19] placed landfill disposal as the least preferable option in the waste hierarchy.[20] Landfilling of organic material is entirely banned in several countries, including Sweden, Switzerland, Austria and Germany. Landfill fees, such as the USD 132 tax per tonne of waste in the United Kingdom, also provide incentive to increase sorting, treatment and recovery for energy production.

In total, more than 700 economic, regulatory and administrative measures across the European Union were put in place between 2005 and 2017 to support bioenergy solutions such as anaerobic digestion technologies. Around 150 of these measures were financial incentives aimed at creating more favourable finance and investment conditions for biogas. Altogether, the various measures helped biogas plants in Europe to increase substantially, from around six thousand installations in 2009 to nearly 18 thousand plants in 2017.

Several European countries also combined schemes to promote deployment of bioenergy technology. This included use of feed-in tariffs, feed-in premiums, quotas, tradable certificate systems and tenders. Broadly speaking, the trend since the mid-2010s was to use capacity market mechanisms combining feed-in tariffs, feed-in premiums and tenders, for example in Germany, France, Italy and the United Kingdom. A combination of feed-in tariffs and feed-in premiums was also used in Bulgaria, Ireland, Latvia, and Croatia. At the same time, developments over the second of half of the 2010s suggest that these capacity market additions, including growing use of auctions, may have an adverse effect on bioenergy deployment, as the pace of biogas projects in Europe slowed since 2014. At the same time, this may equally be due to important shares of bioenergy in European countries' overall energy mixes, for instance in Nordic countries where waste-to-energy is rather prevalent.

European experience nevertheless highlights that clear policy signals, combined with regulatory measures, landfill pricing and other financial incentives encourage a robust pipeline of alternatives to waste disposal. These combined measures in Europe were particularly effective in encouraging early stage uptake of technology solutions like anaerobic digestion, which without this broad enabling environment would have had a far more challenging pathway to market development.

Sources: (Banja et al., 2019[70]); (Government of the United Kingdom, 2021[71]).

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Notes

[1] For more information (in Spanish), see: https://www.minenergia.gov.co/plan-5-caribe.

[2] Biofuels and waste can include: primary solid biofuels such as firewood; biogases; municipal waste (renewable and non-renewable) and industrial waste; charcoal and other biofuels (e.g. biogasoline, biodiesel and other liquid biofuels). For more information on the product definitions by the International Energy Agency, see: http://wds.iea.org/wds/pdf/WORLDBAL_Documentation.pdf.

[3] Traditional use of biomass refers to the combustion of wood, animal waste and traditional charcoal. For more information: https://www.irena.org/bioenergy.

[4] For more information see the database documentation for the International Energy Agency's *World Energy Balances*: http://wds.iea.org/wds/pdf/WORLDBAL_Documentation.pdf.

[5] For more information, see: https://mnre.gov.in/bio-energy/schemes.

[6] For more information, see: https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=79140

[7] For more information, see: https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=87765

[8] For more information (in Spanish), see: https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=4633.

[9] For more information (in Spanish), see: https://www.funcionpublica.gov.co/eva/gestornormativo/norma.php?i=4631.

[10] For more information (in Spanish), see: http://www1.upme.gov.co/DemandayEficiencia/Documents/PEN_2020_2050/Plan_Energetico_Nacional_2020_2050.pdf.

[11] Firm power obligations are commitment to deliver electricity and/or heat (power) at all times during the period covered by the terms of the auction, even under adverse conditions.

[12] Auctions are governed by Article 2 of CREG Resolution 71 of 2006. For more information (in Spanish), see: http://apolo.creg.gov.co/Publicac.nsf/Indice01/Resolucion-2006-Creg071-2006.

[13] Non-conventional renewable energy (NCRE) sources, or *'Fuentes No Convencionales de Energía Renovable'*, was defined in Article 5 of Law 1715 of 2014 (the "Renewable Energy Law") and include bioenergy, small-scale hydro, wind, geothermal, solar and tidal power. For more information on Law 1715 (in Spanish), see: http://www.secretariasenado.gov.co/senado/basedoc/ley_1715_2014.html.

[14] For more information (in Spanish), see: https://biovalor.gub.uy/.

[15] For more information (in Spanish), see: http://www.siel.gov.co/Inicio/Generaci%C3%B3n/Inscripci%C3%B3ndeproyectosdeGeneraci%C3%B3n/tabid/113/Default.aspx.

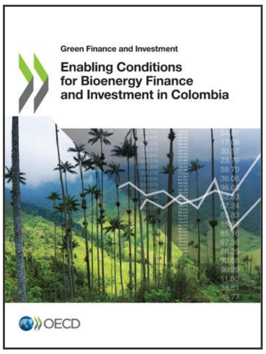
[16] For more information (in Spanish), see: http://www.upme.gov.co/Docs/Plan_Expansion/2020/Volumen3_Plan_Expansion_Generacion_Transmision_2020_2034_Final.pdf.

[17] For more information (in Spanish), see: http://www.minminas.gov.co/documents/10180//23517//22602-11506.pdf.

[18] For more information (in Spanish), see: https://www.incp.org.co/Site/2016/info/archivos/resolucion-045-minminas.pdf.

[19] More information available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L0031.

[20] More information available: https://ec.europa.eu/environment/topics/waste-and-recycling/waste-framework-directive_en.



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