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Sustainable Energy in Brazil:

Reversing Past Achievements or Realizing Future Potential

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1 Ensuring a sustainable energy future

The country's future will depend on the decisions taken at this historic moment that will determine the development model for this millennium. There is a need for responsibility, perseverance, leadership and dedication with the current and future generations. The tools are at hand. They just need to be used.
- Observatório do Clima[1]

Brazil is at a crossroad with regard to its sustainable energy future. Despite currently boasting one of the world's cleanest energy supplies, a number of current trends are pointing towards a deterioration of the country's sustainable energy performance in the future.[2] These include a growing demand for energy (especially fossil fuels), heavy emphasis on expansion of oil production, carbonization of its electricity sector, a bioenergy sector struggling with expansion, stagnating energy efficiency performance, and, most worryingly, rapid growth in energy-related greenhouse gas emissions.

Brazil's unique emissions profile, long dominated by deforestation, is now changing due to a decade of successful policies, relatively fast economic growth, and rising living standards. As a result of the declining rates of deforestation, energy use and agriculture are becoming the two key drivers of emissions growth. From an 11 per cent share only ten years ago, energy-related emissions currently account for around 30 per cent of Brazil's total emissions. Curbing emissions growth in the future will not be an easy task given the already high share of renewables in the country's energy supply (43 per cent of overall primary supply and well over 80 per cent of electricity) and the socio-environmental and economic limitations to further expansion of key renewable energy sources. However, the existence of enormous potential is undeniable: Brazil is estimated to have the capacity for an additional 180 GW of hydropower and up to 350 GW of wind power. According to government estimates, the land area used to cultivate sugarcane – the primary source of biofuels in Brazil – could be expanded over seven-fold without contributing to deforestation or food insecurity. Solar energy remains a further area with vast unexploited potential.[3]

Current government estimates expect energy demand and related emissions to grow by around 60 per cent during the ongoing decade (2012–22). Whilst renewables are expected to maintain their high share, the absolute increment in demand for fossil fuels is projected to be substantial given the scale of the economy and expectations of significant increases in domestic oil production, even in a slower growth scenario. Moreover, the numerous policies and programmes currently in place to support renewable energy, energy efficiency, and to curb emissions growth are fragmented and their effects are countered by those in place to support fossil fuels. Nevertheless, this paper argues that an alternative future is possible, and that with the right kind of signals and policy support Brazil can still avert the carbonization of its energy supply, decouple emissions and economic growth, and ensure competitiveness in a carbon-constrained world.

By analysing current trends and policies, together with future energy projections, this study evaluates the prospects and potential for sustainable energy in Brazil in the medium and long term. It argues

[1] 'O futuro do país dependerá das decisões tomadas neste momento histórico, que vai definir o modelo de desenvolvimento deste milênio... É preciso ter responsabilidade, firmeza e liderança e compromisso com as gerações atuais e futuras. As ferramentas estão à mão. Basta usá-las.' (OC 2009, 49).

[2] Sustainable energy is commonly defined as: energy supply that originates from renewable and other low-carbon sources, coupled with supply and demand side energy efficiencies, which result in low greenhouse gas emissions. Brazil's performance in these terms is top-ranking. The World Energy Council's 2013 energy sustainability index, for example, ranks Brazil at 34 (of 129). In the period 2011–13, Brazil's energy security (at 27) and equity performance (86) improved, but its environmental sustainability score fell by 4, to 17 (WEC 2014a).

[3] Brazil is also estimated to have 106 bn bbl of recoverable conventional oil resources, and 12 tcm of recoverable conventional natural gas. Of these, 15 bn bbl and 459 bcm are proven reserves, respectively (IEA 2013c; BP 2013).

that there is still plenty of room for increased ambition and warns that, unless current trends are reversed with determined policy and implementation, Brazil will place at risk the decarbonization of its energy supply at a time in which global attention is turning to resource-efficient low-carbon transitions.

The paper starts with an overview of Brazil's current energy sector dynamics (Section 2) – showing how energy demand is rising and related emissions are becoming a key driver of national greenhouse gas emissions. It highlights the challenges of diversification and expansion in the hydropower-dominated electricity sector, and discusses the plight of the national bioethanol industry and how this is intimately linked to the growth of demand for oil in transport. The paper then examines, in Section 3, domestic energy policy and its implementation, focusing on the policies, plans, and programmes set in place to control greenhouse gas emissions, enhance energy efficiency, and support renewable energy. It explains how the different policies and interventions have come into existence and how many of them, with the partial exception of climate policy, are fragmented in character and limited in impact. Following this, Section 4 presents the key energy and emissions projections from the most recent national mid-term plan for the sector, running through 2022, alongside two international longer-term scenarios for energy and emissions. Based on these projections, the section provides a review of expected sustainable energy trends through 2035; it also points towards areas of potential 'problems' and to those with scope for increased ambition. The concluding section provides policy recommendations for achieving a diversion from current plans and projected trajectories; these include: a diversification into non-hydro renewables in the electricity sector, a sustainable expansion of bioethanol, increased attention to energy efficiency across the economy, and an ambitious post-2020 climate change mitigation policy.

2 Current energy and emission trends

Brazil's current energy sector dynamics in relation to 'sustainable energy' – defined as energy supply that originates from renewable and other low-carbon sources, coupled with supply and demand side energy efficiencies, which result in low greenhouse gas (GHG) emissions – can be characterized through four key trends. Firstly, despite the high shares of renewables, energy demand (together with related greenhouse gas emissions) continues to grow and given the decline in emissions from land use, this means that energy is turning into a key driver of domestic emissions. Secondly, the electricity sector, dominated by large-scale hydropower, is facing challenges in meeting the growing demand. Worrying trends include the shrinking relative storage capacity in the system and the growing use of natural gas in lieu of cleaner sources. Thirdly, demand for transport fuels is growing fast, prompted by rising living standards and a long-term policy of favouring road transport. Expanding volumes and shares of oil are of particular concern and are intimately interlinked with the present troubles of the bioethanol sector. Consequently, transport and oil continue as the top drivers of Brazil's energy-related GHG emissions growth. Finally, despite low levels of carbon and energy intensity, the country's energy efficiency performance remains stagnant. The sections below examine these trends in more detail.

2.1 Growing energy demand and related GHG emissions

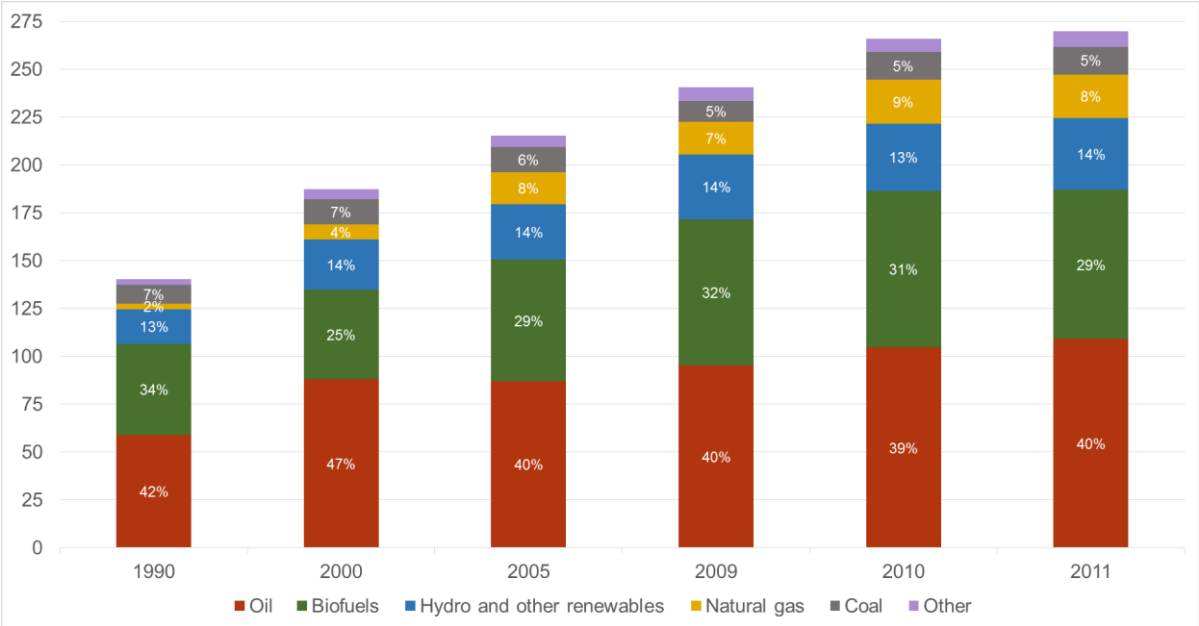
Brazil is a major emerging economy: it has a population of nearly 200 million, the world's seventh largest economy, and a land area equal to approximately two European Unions. With a primary energy supply of 270 million tonnes of oil equivalent (Mtoe) in 2011, it is also the world's seventh largest energy producer. Brazil's domestic energy demand keeps growing fast: the average annual growth rate in 2000–11 was 3.3 per cent. Over the past decade, the government has managed to increase energy accessibility and to expand the energy system to meet demand growth, whilst lifting tens of millions of people from poverty. With an electrification rate of 99 per cent, Brazil is expected to reach universal access over the next few years. Reflecting these trends, electricity demand has experienced rapid growth, surpassing average annual GDP growth (3.6 per cent) in the 2000s. (IEA 2013a; 2013c; World Bank 2013).

Despite its rapid rate of energy demand growth (both proportional and absolute) Brazil has succeeded in maintaining one of the world's cleanest energy mixes. In 2011, renewables accounted for 43 per cent of the primary energy supply, compared to a global average of 13 per cent. Other characteristics of Brazil's energy mix include a high overall rate of diversification, as shown in Figure 1 below, high levels of decarbonization in the electricity supply sector, and de facto energy self-sufficiency.

Given Brazil's vast road network and the predominance of transport via roads, oil products have continued to represent the largest share in the energy mix. However, bioenergy holds an important proportion owing to a long-term government effort to support domestic biofuels production. Electricity is primarily produced from hydropower, with smaller shares coming from natural gas and coal. Due largely to the successful expansion of large-scale hydropower capacity, together with that of domestic oil and ethanol production, Brazil is approaching self-sufficiency despite its fast-growing energy demand (the country's figure for energy production/total primary energy supply (TPES) stood at 0.92–0.96 in 2009–11 (IEA 2013a)[4]).

[4] Brazil's energy self-sufficiency rate climbed to 0.92–0.96 in 2009–11, from 0.70 in 1970 and 0.57 in 1980 (IEA 2013a). Given the insufficient refinery capacity, low quality of domestic coal, and imports from the Paraguayan side of the massive Itaipu hydropower plant, Brazil is currently a net importer of oil products (including, since 2011, gasoline), coking coal, and electricity, as well as natural gas. (IEA 2013a; 2013c; WEC 2013.)

Figure 1: Total primary energy supply by source (Mtoe), 1990–2011



Source: IEA 2013a.
Note: 'Biofuels' includes waste. 'Other' includes nuclear energy and electricity imports.

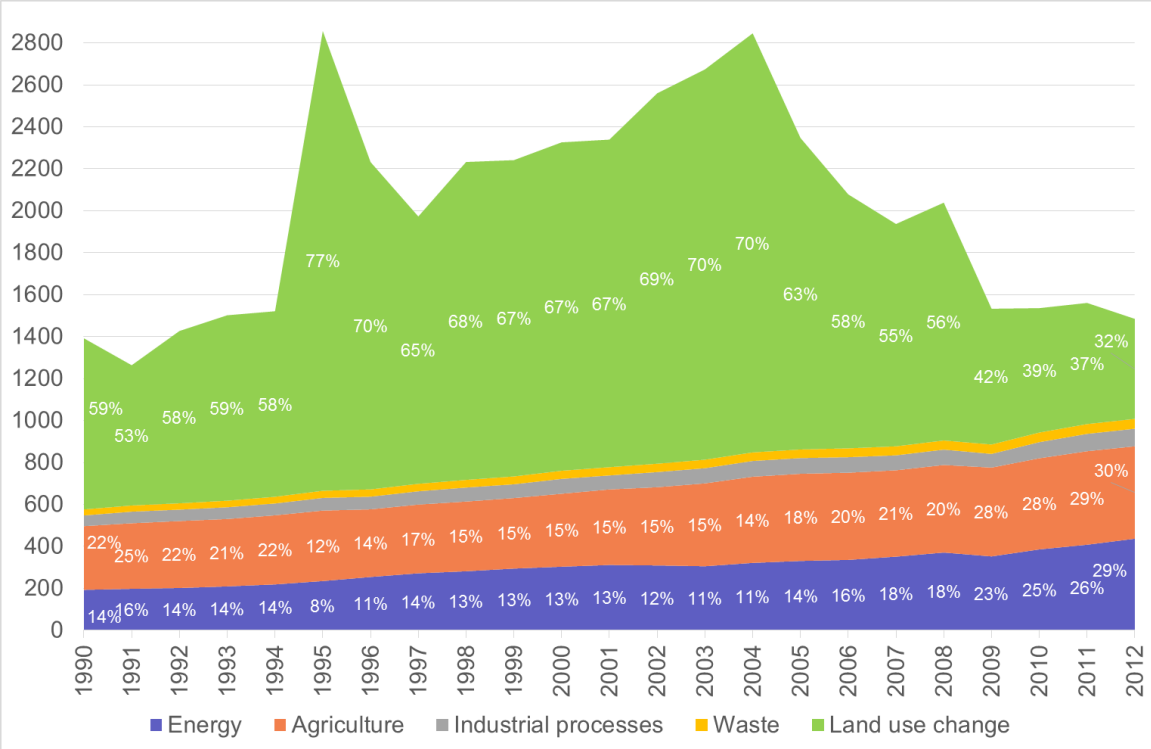
Measured by greenhouse gas (GHG) emissions, Brazil's sustainable energy performance to date has been exemplary. In a global comparison, Brazil's current GHG emissions from energy are low, at similar levels to countries with significantly smaller populations such as Australia, Italy, Saudi Arabia, or the UK (IEA 2013b). In 2012, the Brazilian Observatório do Clima estimated the country's energy-related GHG emissions at 437 $MtCO_2e$ (OC 2013a).[5] Given the high share of renewables, the CO_2 intensity of Brazil's energy mix (CO_2/TPES), at 1.51 in 2011, is also significantly below the global and regional averages of 2.39 (world) and 1.84 (non-OECD Americas). Given the relatively low energy intensity of its economy, Brazil's overall carbon intensity (CO_2 intensity of energy mix × energy intensity of economy) in 2011 stood at 0.20, which compared extremely favourably against other major emerging economies like China (0.79), India (0.44), and South Africa (0.75), and even the OECD average (0.33). (IEA 2013b.)

Brazil's per capita GHG emissions, if land use and forestation (LUCF) are excluded, are also low at 5.96 tCO_2e in 2010, according to the World Resources Institute (WRI). This is well below the per capita emission rates of many major emerging economies, including those of China (7.76) and South Africa (11.20), and the world average (6.47). (WRI 2013a.) However, given Brazil's massive deforestation rates, the picture changes radically when LUCF is included. The WRI ranks Brazil as the fifth biggest emitter in the world in 2010 and, in terms of cumulative emissions, one recent study places Brazil fourth in a list of countries most responsible for global warming (Matthews et al. 2014). With LUCF included, Brazil's per capita emissions, at 10.94 tCO_2e in 2010, are also significantly above the world average of 6.85 tCO_2e (2010). (WRI 2013a.)

[5] The Observatório do Clima is a network for civil society organizations working in the area of climate change. Its Sistema de Estimativa de Emissão de Gases de Efeito Estufa study uses Brazil's second national communication to the UNFCCC as the basis for data relating to 1990, 1994, 2000, and 2005. (Notably, national GHG inventories submitted by Brazil to the UNFCCC currently end at 2005.) Estimates for 2006–12 were calculated specifically for the study. Three Brazilian research institutions participated in the study. The Instituto de Energia e Meio Ambiente was responsible for energy data. This study used CO_2e data calculated with global warming potential (GWP), which is the most commonly used metric. Estimates on Brazil's greenhouse gas (GHG) emissions vary from source to another. National data has been given preference in this section to data by e.g. the World Research Institute. However, estimates from these two sources converge for energy-related emissions in 2011.

The Observatório do Clima estimates Brazil's total GHG emissions for 2012 at 1,485 $MtCO_2e$. Without land use change (LUCF), total emissions were 1,008 $MtCO_2e$.[6] Figure 2 below presents a sectoral breakdown of national emissions in 1990–2012. Three key trends are distinguishable: firstly, land use change-related emissions have reduced significantly over the past decade, dropping below 1990 levels in 2009. Secondly, total emissions from energy and agriculture have increased. While growth has been less rapid in agriculture (1.4 per cent/year, on average, in 1990–2000, and 2.0 per cent/year in 2000–2012), emissions from energy have grown significantly (4.6 per cent/year, on average, in 1990–2000, and 3.1 per cent/year in 2000–2012), equalling a 126 per cent increase over the period. Thirdly, as deforestation rates have fallen and emissions from energy and agriculture have increased, these two latter sectors are now the main drivers of emission growth in Brazil – in 2012, each sector accounted for approximately a third of total emissions. The change is particularly pronounced in the case of energy, whose share increased from 14 per cent in 1990 to 29 per cent in 2012. (OC 2013a.)[7] Reflecting the parallel trends of declining deforestation rates and rapid economic growth, in 1990–2010, Brazil's per capita emissions fell by 19 per cent with LUCF included, but increased by 22 per cent with LUCF excluded. (WRI 2013a.)

Figure 2: GHG emissions from major sectors ($MtCO_2e$), 1990–2012



Source: OC 2013a.

[6] Estimates by the WRI are considerably higher: in 2010 (latest available year), Brazil's total GHG emissions, according to the institute, equalled 1,163 $MtCO_2e$ (compared to 943 $MtCO_2e$ by the OC), excluding LUCF. With LUCF, the WRI estimated total emissions as nearly twice as high, at 2,136 $MtCO_2e$ (compared to 1,536 $MtCO_2e$ by the OC). Notably, very high uncertainties are associated with land use data and WRI uses a standardized methodology for its estimates. The OC data indicates significantly more variation from year to year, due to more specific LUCF estimates. OC data also estimates agricultural emissions as being significantly lower than the WRI: for 2009, this difference was 164 $MtCO_2e$. Differences in energy emission estimates are, however, less significant. As a result, for 2009, the WRI data places the share represented by energy in total emissions at 18 per cent and OC at 23 per cent. Given the availability of data and country-specific methodology, OC data is prioritized below.

[7] Brazil's land use change-related emissions are driven principally by deforestation and land degradation and conversion (93 per cent of sectoral emissions); most of this takes place in the Amazon and Cerrado areas. In the agricultural sector, enteric fermentation (cattle) and agricultural soils accounted for 92 per cent of sectoral emissions in 2012. (OC 2013b; 2013c).

2.2 Challenges in the hydropower-dominated electricity sector

Electricity constitutes around 18 per cent of Brazil's total final energy consumption. Despite the massive scale of the electricity system, the sector has maintained a high share of clean energy over the past decades. A number of challenges, however, lie ahead; these include keeping up with the growing demand and diversifying into sustainable sources, while maintaining stability of supply.

Over the past two decades, Brazil has more than doubled its total electricity generation. Growth in demand has been driven by rising living standards and partly supported by tariff policy and government-supported rural electrification and social tariff programmes.[8] In 2000–11, with demand growing faster than the economy, electricity generation saw annual growth rates of 3.9 per cent (IEA 2013a). In 2013 alone, electricity consumption increased by 6.3 per cent, with the residential sector registering the highest growth in three consecutive years (Lagreca 2014). Population growth, albeit relatively low, at 0.9 per cent, is also a contributor to rising demand, alongside industrial consumption (World Bank 2013). At present, the major end-users are industry (46 per cent), the residential sector (25 per cent), and commercial and public services (25 per cent) (IEA 2013a). (For a more detailed breakdown of electricity consumption by sector in 2011, see Annex 1.)

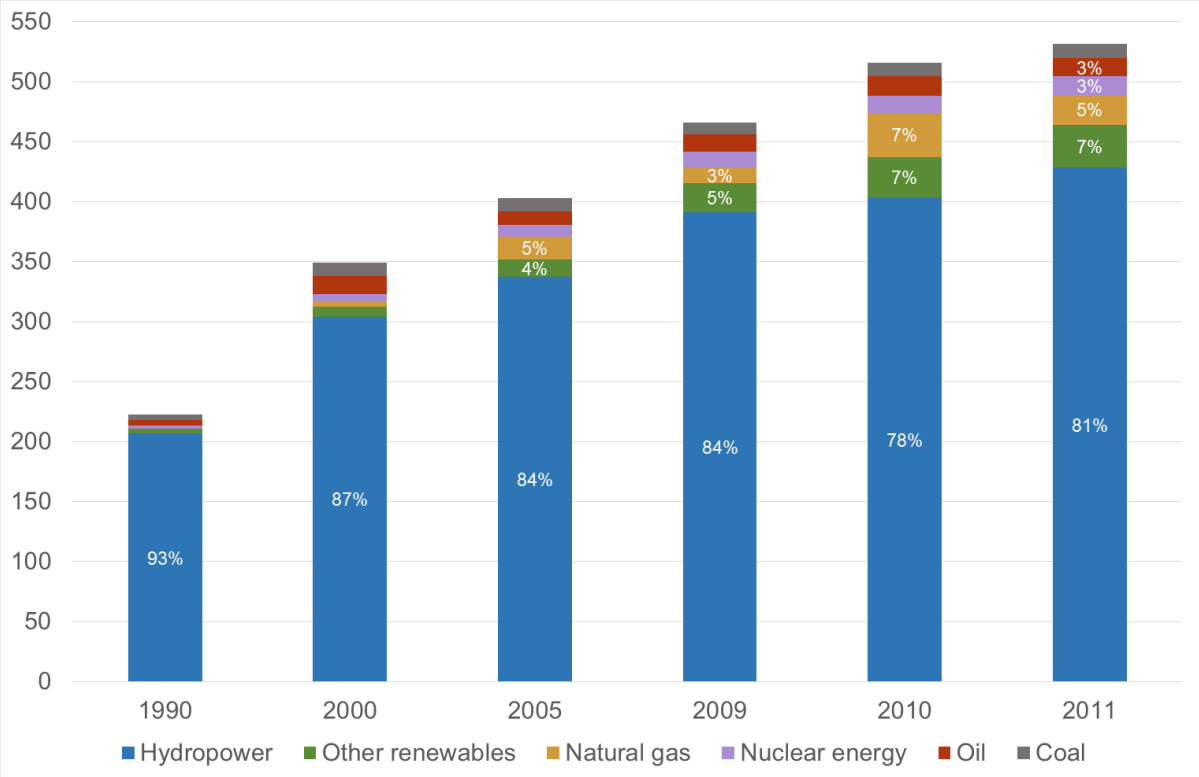
Clean sources, principally hydropower, dominate the electricity mix both in terms of capacity and generation. Of a total installed generating capacity of 129 GW, clean sources account for 85 per cent.[9] In 2012, of 592 TWh generated, 77 per cent came from hydropower. In terms of hydropower volume, Brazil is only second in the world to China, and is significantly above the global average of 16 per cent. Moreover, Brazil's built hydropower capacity of 84 GW is estimated to constitute only around 30 per cent of total available potential. (EPE 2013a; 2013c; IEA 2013a; 2013b; Carvalho and Sauer 2009.) Figure 3, below, illustrates the growth in electricity generation and the changes in shares of sources over the past two decades.

The dominance of hydropower in the electricity mix is, however, in decline. In the 1970s and 1980s, realizing the massive potential of Brazil's rivers, the government began large-scale investments in hydropower (EPE 2007). For the past decades, hydropower has remained the primary source of electricity in the national energy mix. Over recent years, however, natural gas-powered thermal generation has seen a rapid increase, as it is being increasingly used (together with non-hydro renewables) to compensate for variation in hydropower generation. In 2012, representing a significant drop from previous years, hydropower accounted for only 75 per cent of energy generation. That same year, natural gas surpassed biomass as the second source of electricity generation, with an 8.5 per cent share in generation (EPE 2013b). (For a more detailed breakdown of electricity generation by source in 2010–12, see Annex 1.)

[8] Owing to income transfer and minimum salary policies, the proportion of Brazilians living at US$2 a day fell from 30 per cent in the early 1990s to around 20 per cent in the early 2000s, and to 11 per cent in 2009 (World Bank 2013).

[9] At the end of 2013. Includes self-generation. (EPE 2013a.) However, the average share of assured energy of installed capacity in power plants is estimated to be only around 55 per cent (ANEEL 2014).

Figure 3: Electricity generation by source (Twh), 1990–2011



Source: IEA 2013a.

From a sustainable energy perspective, an added benefit of Brazil's vast and spread out hydropower network is its flexibility: the network functions as a complementary enabler for other renewable sources that have variable production, like biomass (seasonal production), small-scale hydropower (short-term variations), and wind (seasonal patterns). Further structural assets are the interconnectedness of the national power system, which keeps integration costs low, and the high wind capacity factors that reduce variability of this source. (IEA 2013c.) However, there are important limitations to the system's flexibility; rainfall variability (including climate change-induced variability) is an important resilience risk in a hydropower-dependent system, as are growing demand and diminishing relative storage capacity. Recent crises of Brazil's electricity supply system are examined in Box 1 below.

Future expansion of hydropower in Brazil is constrained by important socio-environmental considerations. Environmental concerns include inundation for reservoirs; this has strengthened a tendency towards building run-of-river projects with generally small or no reservoirs (IEA 2013c). A number of projects and their implementation have met considerable resistance from civil society, indigenous groups, labour organizations, and even environmental authorities (Leite 2013). One example is the controversial Belo Monte dam, with a planned capacity of 11 GW (third largest in the world), which has been accused of causing deforestation and of not complying with indigenous land protection commitments (ISA 2014). Also, typically for a run-of-river plant, Belo Monte is expected to have a capacity factor of 40 per cent, which is low compared to the 77 per cent of the similarly sized Itaipu plant (14 GW) (IEA 2013c).[10]

[10] Despite the massive area flooded by Itaipu (1,350 km^2 – over 2.5 times the area that will be flooded by Belo Monte), it is also considered a run-of-river plant because it lacks storage capacity and depends on upstream storage reservoirs.

Box 1: Vulnerability of Brazil's electricity system: from crisis to crisis

In 2000–1, following a decade of insufficient capacity investments, low rainfall led to a prolonged national power crisis and rationing (Vichi and Mansor 2009). As a consequence, the government's attention turned to strengthening its natural gas and fuel oil-powered generating capacity (Knight 2009). Over a decade later, as a result of this policy, Brazil has a more diversified supply and a more resilient power generation system. However, pressures on capacity and supply continue to be created by rising power demand coupled with the rising cost of generation, together with end-user prices that do not reflect the cost sending contradictory signals to consumers. In 2012, low water levels in hydropower reservoirs caused strong demand for fossil-fuelled electricity throughout the year (a 13 per cent share of production that year). In 2013, a similar pattern ensued. (IEA 2013c.)

In the summer of 2014, record droughts recurred, coupled with higher than average temperatures. As a result, in February 2014, peak demand reached a historic high of 86 GW while water levels in the key economic and hydropower regions (South-East and Centre-West) had fallen below 37 per cent of capacity – the lowest levels since 2001. At the time of writing, a number of consultancies estimated that immediate reductions in consumption would be necessary to solve the crisis. Although the existing thermoelectric capacity may be sufficient to avoid power cuts during 2014, some estimate the risk of rationing in 2015 to be high. Also ANEEL, the regulatory agency, has called for a consumer price increase to cover the higher costs of production – the implementation of which, in turn, would contribute to inflationary pressure (Dantas 2014; Brazil Weekly 2014). Given the unpopularity of rationing, the fact that the government holds affordability to be a key cornerstone of its energy policy (MPOG 2011), and the presidential elections in October 2014, the current government is unlikely to resort to rationing or price increases – potentially escalating the problem and related costs.

In seeking to diversify its electricity sector beyond large-scale hydro, the government has opted for a mix of clean and fossil fuels. At present, biomass is the second-largest renewable electricity source used in Brazil. Biomass use in the electricity sector has nearly doubled since 2008, and it is used particularly in co-generation systems in the industrial and agricultural sectors (UNEP FI 2010).[11] In 2012, total installed wind energy capacity was still low, at 1.8 GW, and wind power accounted for a mere 0.9 per cent of domestic electricity supply. However, wind energy has fared relatively well in the recent power sector auctions, and by 2013, capacity had already increased to 4 GW. Brazil's installed solar energy capacity remains extremely limited, at 8 MW in 2012 (EPE 2013b).

Nuclear power currently accounts for 3 per cent of Brazil's electricity generation. The ambitious plans of the 1970s – to become self-sufficient in nuclear technology and build eight reactors – were undermined by broader economic problems. Brazil currently has two operational nuclear energy units, located in the state of Rio de Janeiro, with a total capacity of 2 GW, and one under construction which will add 1.4 GW to capacity. Given its uranium resources, Brazil has developed domestic enrichment facilities for conversion and fuel fabrication. (WEC 2013.) Production is expected to rise to levels sufficient to cover the needs of the three reactors (IEA 2013c; Kidd 2013).[12] According to some estimates, nuclear power in Brazil is, in terms of price, attractive when compared to fossil fuels. It has been proposed to build eight more reactors by 2030. Despite indications that a nuclear expansion remains on the table, public support – especially after the Fukushima disaster – may not be guaranteed for further expansion. (Kidd 2013.) Furthermore, Brazil still has to set a long-term plan for radioactive waste disposal.

[11] Sugarcane bagasse and other agricultural residues are burned in steam turbine generators to produce heat and electricity, both on-site and to the grid (IEA 2013c).

[12] The IEA estimates that, in the near future, Brazil will produce up to 2,300 tonnes of uranium per year, which will be three times the needs of the three reactors. Other estimates predict much lower levels, at 500–700 tonnes. (IEA 2013c; Kidd 2013.)

Fossil fuels, natural gas in particular, have increased their share in the electricity mix since the early 2000s, driven by the electricity auction system and the attractiveness of thermal generation plants as a supplementary supply (IEA 2013c). Thermal power plants, running on natural gas and petroleum derivatives, provide an important support to generation during periods of peak demand and drought, and as a permanent supply to towns and communities not connected to the national grid. In 2011–12 alone, the share of fossil fuels in electricity generation grew from 8.4 to 12.7 per cent, mainly driven by natural gas (EPE 2013c). Expansion of natural gas-powered electricity generation, however, is currently somewhat limited by high costs, low domestic end-user prices, uncertain availability, and limited pipeline networks. In the future, the expansion of domestic natural gas supply is expected to change the situation. In 2013, the government allowed coal to compete in electricity auctions organized by the regulatory agency ANEEL, but initial experiences have been negative, with low success rates and criticism over related CO_2 emissions. (IEA 2013c; UNEP FI 2010; WEC 2013.) (For electricity sector investments, costs, and auctions, see also Box 2.)

Box 2: Dynamics of investments and costs in Brazil's electricity system

Since the early 2000s, stability of supply and expansion through a diversification of sources have been among the government's priorities in electricity policy. The sector has been split into regulated and unregulated markets to allow for both public and private investment. (EIA 2013.) According to the World Bank, investments in energy with private participation fluctuated between US$11bn and US$31bn in 2009–12, a significant increase since the 2000s when investment was as low as US$2bn (2004). (World Bank 2013.) Distributors and large consumers are obliged to enter into long-term electricity purchase agreements to provide stability for new generation capacity investments. The agreements are made through auctions (in which the most competitive bids are selected) organized by the regulatory agency ANEEL (Agência Nacional de Energia Elétrica). By 2013, there had been 24 auctions, some of which were technology-exclusive to support diversification. (IEA 2013c.)

A similar system of competition and long-term contracts exists in the transmission system, which currently is the source of most power interruptions (IEA 2013c). In 2013, according to some estimates, nearly 14,000 of the roughly 18,000 km of transmission lines projected for 2015 were behind schedule. These delays risk the functioning of the network that needs to compensate for the variations in Brazil's regional hydrological conditions. (Szklo et al. 2013.)

Rising costs are another key issue affecting the sector. A study from 2009 estimating the costs of different electricity alternatives in Brazil found that hydropower is by far the most economical and environmentally friendly option, at around a third of the cost of sugarcane bagasse and natural gas, and 35–40 per cent of the cost of nuclear and coal (Carvalho and Sauer 2009). Some recent studies have estimated even more substantive price differences, with large-scale hydropower at R$85/MWh (US$38) at one extreme and oil-powered thermal power at R$600/MWh (US$270) at the other (Oliveira 2014). In recent years the variability of hydropower production owing to unfavourable climatic conditions and the increased use of natural gas, have caused important fluctuations in the cost of electricity production. In February 2014, the need to resort to emergency supply (natural gas and oil) led prices in the free market (with an approximate market share of 30 per cent) to temporarily shoot to R$823/MWh, from a 12-month low of R$129/MWh in April 2013 (Daltro 2014).

Around 6 per cent of Brazil's electricity demand is currently covered through imports, primarily from the Paraguayan share of the Itaipu hydropower plant (IEA 2013c). In 2010, to harness the hydropower potential of the Peruvian side of the Amazon and to diversify Brazil's import sources, Brazil and Peru signed an agreement to develop Peru's hydroenergy infrastructure, with a view to allocating up to 6 GW of capacity for exports to Brazil (Gobiernos de Perú y Brasil 2010). Whilst not significant for Brazil, 6 GW would represent a massive increase for Peru which, in 2011, had a total installed capacity of 9 GW (Ministerio de Energía y Minas de Perú, 2012). These plans are moving forward slowly.

In terms of GHG emissions, alongside an increase driven by the absolute growth in electricity demand, the sustainability performance of Brazil's electricity sector has been slowly eroding over the past decade, driven by the increasing use of fossil fuel-fired thermal electricity. In 1990–2012, emissions from the sector grew by 414 per cent (39 $MtCO_2e$), which was proportionally significantly more than emissions growth from transport (144 per cent) or industry (131 per cent). As an illustration of the growing use of natural gas for electricity generation, between 1990 and 2012 emissions from this source shot up from less than 1 to 21 $MtCO_2e$, while emissions from oil and gas (both at approximately 4 $MtCO_2e$ in 1990) only increased to 14 and 10 $MtCO_2e$, respectively.[13] Since 2008, fluctuations in the use of natural gas and other fossil fuels in public service electricity generation plants have resulted in important variations in electricity generation-related GHG emissions – these have ranged from 28 to 48 $MtCO_2e$/year.[14] (OC 2013a; 2013d.) (See also Figure 4 in Section 2.3.)

2.3 Increasing demand for fossil fuels – difficult times for bioethanol

Beyond the electricity sector, growth in energy demand and emissions has been similarly fast and has reflected the special characteristics of different end-use sectors. The most important sectors in terms of consumption are transport and industry, at 42 and 36 per cent respectively in 2011. Table 1 shows a breakdown of energy use (excluding electricity) by source and by major end-use subsectors (those using over 1 Mtoe/y).

Table 1: Sectoral distribution of energy consumption excluding electricity (Mtoe), 2011

Sector	Source				
	Oil products	Biofuels/ biomass	Natural gas	Coal	Sector total
Transport	**59.2**	**12.9**	**1.9**	**0**	**74.0**
Road transport	53.3	12.9	1.6		67.8
Domestic aviation	3.6				3.6
Domestic navigation	1.3				1.3
Rail	1.0				1.0
Industry	**12.7**	**34.4**	**9.5**	**8.2**	**64.8**
Food and tobacco		19.2			19.2
Iron and steel		4.0		6.1	10.1
Non-metallic minerals	4.3	3.0	1.2		8.5
Paper pulp and printing		7.1			7.1
Chemical and petrochemical	2.7		2.3		5.0
Non-ferrous metals	2.0			1.0	3.0
Mining and quarrying	1.1				1.1
Other	**12.9**	**9.6**	**0.6**	**0**	**23.0**
Residential	6.4	7.0			13.4
Agriculture and forestry	5.7	2.5			8.1
Commercial and public services	0.8				0.8
Non-energy use	**15.4**	**-**	**0.8**	**0.1**	**16.4**
Total final consumption, excluding electricity	**100.2**	**57.0**	**12.7**	**8.3**	**178.2**

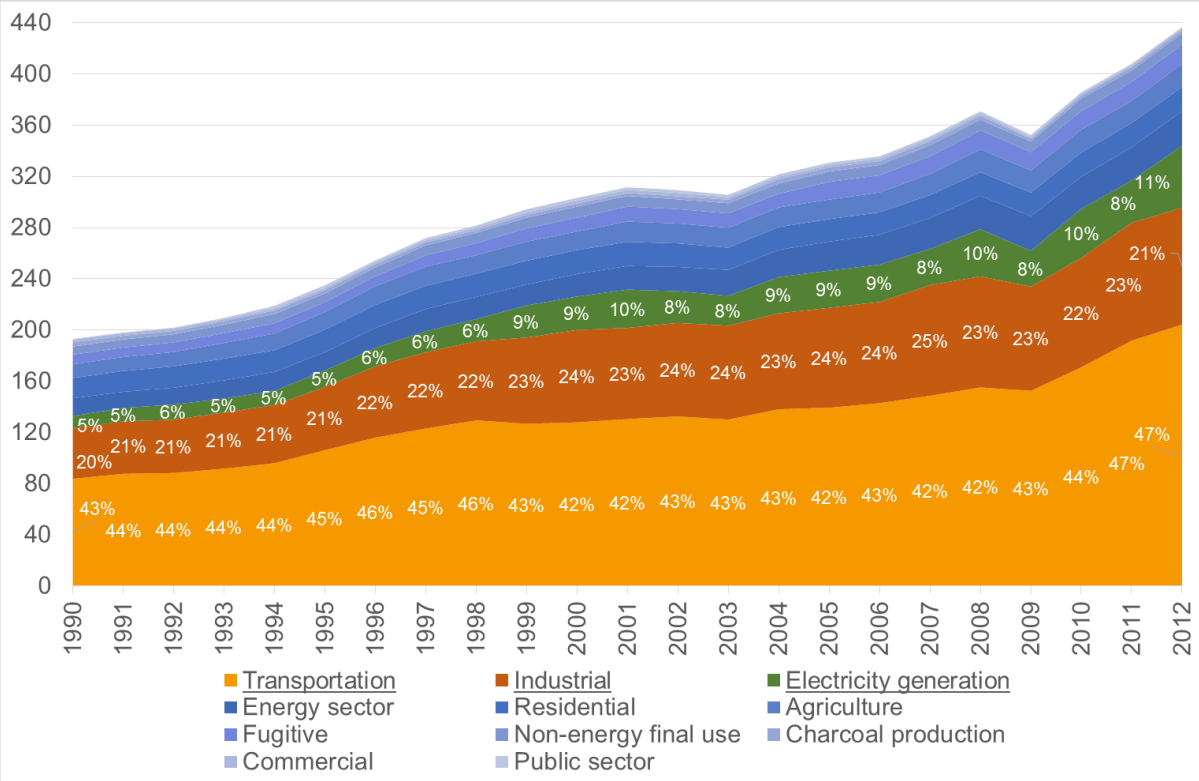
Source: IEA 2013a.
Note: Electricity consumption (18 per cent of TFC) not included. Subsectors with a consumption of over 1 Mtoe in 2011 are included, and those using over 5 Mtoe are marked in italics.

[13] In 2012, GHG emissions from natural gas stood at 44 per cent of electricity-related GHG emissions. Oil and coal amounted to 29 and 20 per cent, respectively. (OC 2013e.)
[14] 37 $MtCO_2e$ (2008), 28 $MtCO_2e$ (2009), 38 $MtCO_2e$ (2010), 33 $MtCO_2e$ (2011), and 48 $MtCO_2e$ (2012). (OC 2013d.)

As shown in Table 1, the transport sector is the dominant end-user of fuels and oil products in Brazil, given the prevalence of road transport in both freight and passenger transport. Use of transport fuels, in particular diesel and gasoline, has grown rapidly over the past years and decades. Despite a highly successful expansion in bioethanol production in the 2000s, its consumption has been in decline in recent years. The industrial sector, the second largest end-user of energy (if electricity is excluded) presents a more diversified energy consumption pattern, given the different characteristics of each key industry, but demand for fossil fuels has increased at similar rates. In the residential sector, a shift away from traditional biomass is maintaining energy demand at a constant level and resulting in positive impacts for human health. In terms of sources, oil dominates Brazil's energy consumption (excluding electricity), accounting for 56 per cent of total consumption excluding electricity in 2011. However, given their large-scale use in the food industry and transport sectors, biofuels rank as the second largest energy source, with a 32 per cent share.

Emissions. Observing trends in overall energy production and consumption (including electricity), over the past two decades, Brazil's GHG emissions have grown at a relatively even rate across energy subsectors, with emissions from transport and electricity generation exhibiting the largest proportional growth, as illustrated by Figure 4. In 1990–2012, energy-related emissions from transport saw the largest absolute increase: 120 $MtCO_2e$ (144 per cent). Industrial energy emissions increased at similarly high rates (131 per cent), by 42 $MtCO_2e$. In 2012, emissions from transport constituted almost half of all energy-related emissions (47 per cent, 204 $MtCO_2e$), followed by industry (21 per cent, 91 $MtCO_2e$), and electricity generation (11 per cent, 49 $MtCO_2e$). (OC 2013a; 2013d.)[15]

Figure 4: Energy-related GHG emissions ($MtCO_2e$), 1990–2012



Source: OC 2013a.

In terms of fuels, a predominant share of Brazil's total energy-related GHG emissions originates from the combustion of oil (72 per cent in 2012), followed by natural gas (15 per cent), and coal (7 per

[15] In terms of gases, carbon dioxide (CO_2) constitutes 97 per cent of Brazil's energy-related emissions, with methane (CH_4) and nitrogen oxide (NO_2) mostly accounting for the rest. (OC 2013a.)

cent).[16] Largely owing to the low shares of natural gas and coal in Brazil's electricity profile, oil occupies a higher share in its total fossil fuel combustion-related emissions (77 per cent in 2012) than in the world on average (36 per cent in 2010). Oil-related emissions span all energy-related subsectors, whereas coal use and emissions are concentrated in industry and electricity generation, and those from natural gas are primarily produced by industry and electricity generation. (OC 2013d; 2013e.) In theory, the only emissions from bioenergy are those generated by the use of oil products during production and transport, but in practice emissions also result from the cutting of virgin forests for cultivation. (IEA 2013c.)

Transport. Energy use patterns in Brazil's transport sector have been shaped by a combination of long-term political priorities, socioeconomic drivers, and current policy choices. Over the twentieth century, and particularly during its latter part, road transport was strategically supported by the Brazilian government over railways (which played an important part in the country's history) and other means of transport. This policy was underpinned by two aims: interlinking the national territory and supporting the emergence of a national automobile industry. At present, the share of road transport in national transport is relatively high: 52 per cent of freight and 95 per cent of passenger transport.[17] (MT 2012; MT/MD 2007.)

Economic growth and the expansion of the middle class lie behind the rapid growth in car ownership – a similar pattern to the growth of electricity demand – and demand for transport fuels. In 2012, over 3.6 million new cars and light duty vehicles were registered, which placed Brazil as the fourth country globally in terms of car sales after China, the USA, and Japan (Fenabrave 2013). Also, given the scarcity of rail networks, economic growth-induced increases in traffic in goods have been on the roads, increasing the demand for diesel (IEA 2013c). In the transport sector, consumption of diesel fuel and gasoline more than doubled and tripled, respectively, between 1990 and 2012. In 2012, these two together accounted for 79 per cent of transport fuel consumption. (On broader oil and gas sector trends, see Box 3 below.)

Reflecting the emphasis on road transport and the dominance of diesel use, in 2012, road transport accounted for 90 per cent of GHG emissions from the transport sector. Trucks using diesel fuel generated 40 per cent of transport-related emissions and passenger cars 30 per cent, mostly from gasoline.[18] (OC 2013e.)

[16] Fugitive emissions from oil and natural gas accounted for 3 per cent and biomass for 2 per cent of energy-related emissions in 2012. Emissions from biomass combustion (firewood, charcoal, vegetal residues, black liquor, alcohol, and bagasse) are not calculated, as the CO_2 captured during the growth phase is considered as compensating for the emissions. (OC 2013a.)

[17] Consequently, given the higher cost of this modality, logistical costs occupy a comparatively high share of the country's GDP, 20 per cent. The data for road transport in Brazil is from 2011 and for other countries from 2007. Of large countries, for example the USA, the share of road freight transport was 32 per cent. In Canada it was 43 per cent and Mexico 55 per cent. As for logistics costs, in 2002, they accounted for 11 per cent of the USA's and UK's GDP, 18 per cent of that in Mexico, and 21 of that in Argentina.

[18] Buses 10 per cent (diesel), light commercial vehicles 7 per cent (gasoline), and motorcycles 3 per cent (gasoline). (OC 2013e.)

Box 3: Oil and gas sector trends

After several decades of government efforts to decrease import dependence, Brazil is nearing self-sufficiency in oil production (IEA 2013a). At the end of 2011, it had 15.3 billion barrels in proven reserves, produced 784 million barrels, and had a reserves-to-production ratio of 19.5 years (BP 2013). Oil rents, which in 2011 represented 2.6 per cent of the national GDP (World Bank 2013), are set to rise significantly over the next decade. In addition to earlier offshore discoveries in the Campos basin, since 2006, important pre-salt era deep sea oil discoveries have been made in the Santos basin off the coast of São Paulo and Rio de Janeiro states (WEC 2013). Oil production has increased strongly over the past decade, standing at 1.9 b/d in 2008, and production in the pre-salt reserves that is starting slowly is expected to triple over the next two decades. However, in 2011, Brazil was still a net importer (3.6 Mtoe) of oil products, and many experts are less optimistic about future expansion prospects given Brazil's local content requirements, effective since 2005, and the production-sharing regime applied to the pre-salt areas, in place since 2010. The former are said to lead to reduced investment and increased costs, and to stifle local competitiveness and innovation. The inability of national industries to meet the resulting demand is a further possible challenge. The latter establishes the state oil company Petrobras as the sole operator of all exploration and production projects under the regime. Related challenges include potential financial and human resource limitations. (IEA 2013a; 2013c; Lima-Campos 2013; Costa 2012.)

The expansion of natural gas in Brazil's energy mix began in the 1990s (IEA 2013a). Brazil's own proven natural gas reserves, mostly associated gas, are estimated at 452 bcm, with a reserves-to-production ratio of 26 years in 2012. Production in 2012, at 17.4 bcm, covered a little over half of consumption (29.2 bcm). Bolivian gas imports accounted for 10.1 bcm, and the rest came in liquefied natural gas (LNG). (BP 2013.) Over the past decade and a half, Brazil has grown increasingly dependent on natural gas imports. Pipeline gas from Bolivia currently accounts for approximately 80 per cent of Brazil's natural gas imports. This dependence goes both ways, as two-thirds of Bolivia's natural gas production is exported to Brazil. In 2008, after political turmoil in Bolivia caused fears of uncertainty of supply, Brazil began importing LNG; this currently comes from Trinidad and Tobago, Qatar, and Nigeria, among others. Future increases in imported natural gas are expected to come in LNG rather than through pipeline. According to Petrobras – in control of the majority of Brazil's natural gas reserves and pipeline imports – natural gas contained in the pre-salt oilfields could significantly increase the country's reserves. (Knight 2009; WEC 2013.) The IEA estimates Brazil's recoverable conventional resources to be 26 times as high as proven reserves (IEA 2013c).

In addition to conventional natural gas, Brazil is estimated to have the world's tenth largest technically recoverable shale gas resources, at nearly 7 tcm. However, whilst the IEA estimates the costs of conventional gas production at US$1–5/million British thermal units (MBtu), the need to apply fracturing could raise the cost to uneconomical levels (up to US$9/MBtu). (IEA 2013c.) Brazil also has the world's third largest proven shale oil reserves, at 82 billion bbl in 2011, and is one of the few countries in the world producing shale gas. However, according to the World Energy Council, there are no plans for large-scale shale oil production (WEC 2013).

A unique characteristic of Brazil's transport sector energy mix is the high share represented by biofuels. Brazil is the world's top exporter and consumer of sugarcane fuel ethanol (IEA 2013a). However, in recent years the sector has encountered a number of difficulties, which have impacted both production and export levels. The factors that have caused the current 'crisis' of Brazil's ethanol sector are discussed in more detail in Box 4 below.

Box 4: The Plight of the Brazilian bioethanol sector

In 2003–9, bioethanol production in Brazil grew at unprecedented rates, prompted by the introduction of flex-fuel vehicles (running on ethanol, gasoline, or any combination of the two) and a strategic decision by the government to incentivize ethanol exports (the demand for which was growing in Europe and the USA) (FIESP 2013). After a peak in 2009–10 at 26–28 billion litres, production declined and is yet to recover to similar levels. This is due to a confluence of factors, the most cited ones including: domestic gasoline price capping, poor harvests due to unfavourable weather, rising production costs, switching to sugar production at times of higher international sugar prices, lack of investment, and the lack of available credit after the 2008 global economic crisis (ANP 2013b; Laporta 2013; IEA 2013c). According to an industry federation, after 2008, investment in the sector ceased and many producers became highly indebted. As a result, the sector has gone through an important reorganization and dozens of plants have declared bankruptcy and been deactivated. (FIESP 2013.)

Given the prevalence of flex-fuel cars, national demand for ethanol has become highly sensitive to changes in prices at the pump, which have been unfavourable to ethanol since 2009–10. (ANP 2013b; IEA 2013c.) The price ceiling beyond which the use of hydrous (pure) ethanol becomes uneconomical for consumers is approximately 70 per cent of that of gasoline, given ethanol's lower energy content per unit volume. For the past several years, domestic fuel prices have been capped by the government with the stated aim of controlling inflation (Cruz and Nery 2014) and, as argued by many observers, to maintain government popularity – particularly important as the 2014 presidential elections approach. The average gasoline price for consumers was R$2.50/l in 2008 and R$2.74/l (US$1.23) in 2013 (ANP 2013a). This pricing policy is causing harm to the ethanol industry, which says that the price at which ethanol is being forced to sell – combined with rising production costs – is shrinking profits and delaying debt repayments and investments. Furthermore, the state oil company Petrobras, has been forced to import gasoline to cover the growing demand and, as a result, has been banking significant financial losses over the past years (Laporta 2013; IEA 2013c).

Beyond pricing, the government also exerts influence over the consumption shares of ethanol and gasoline by changing the anhydrous ethanol mixing requirement in gasoline. Ethanol sold on the market currently includes the hydrous (E100) and anhydrous (E25) varieties, the latter of which is mixed in gasoline. In 2011, the limit was lowered from 25 to 20 per cent, but in 2013, in an effort to stimulate ethanol production and reduce the need for gasoline imports, the government again raised the blending requirement to 25 per cent, and announced tax exemptions for the sector. (EIA 2013; ANP 2013b.)

In addition, some have suggested that increasing predictability through government policy signals would help get production back on track, citing the example of the USA where the government has committed to ethanol purchases at a certain minimum price until 2022. Production has grown rapidly and has surpassed that of Brazil, representing 230 per cent of the latter in 2011 (compared to only 57 per cent in 2000) (Pires 2013).

If examined on a broader timescale, Brazilian ethanol appears to be a success story: in terms of volume, combined sales of hydrous and anhydrous ethanol reached nearly 23bn litres in 2009 – nearly 4bn litres more than gasoline sales that same year. By 2010, national consumption had doubled in comparison to 1990 levels, if measured in tonnes of oil equivalent. (OC 2013e; ANP 2013a.) However, over the 2000s and early 2010s, three distinct phases are distinguishable, presenting a more nuanced picture: 2000–3 when the ethanol fuel vehicle fleet and demand were in decline (with hydrous ethanol sales reaching a low point of 3.2bn litres in 2003); 2004–9 when the introduction of flex-fuel vehicles running on both gasoline and ethanol (and attractive pricing of the latter) led to a boom in consumption (and a peak of 16.5bn litres in hydrous ethanol sales was

reached in 2009), and finally from around 2010 onwards when reduced crops and lower levels of ethanol production lead to an important decline in the production and sales of hydrous ethanol (the latter of which totalled 8.8bn litres in 2012).[19] (ANP 2013b.)

Since 2010, domestic ethanol sales and consumption have been outpaced by demand for gasoline, measured by both energy equivalent (tonnes of oil) and volume. In terms of energy content, starting at nearly similar levels with gasoline in 1990, in 2012 ethanol accounted for only 12 per cent of total transport fuel consumption, compared to gasoline's 31 per cent. (OC 2013e.) Figure 5 illustrates the decline in the volume of ethanol sales (both hydrous and anhydrous) and the simultaneous rapid rise in that of gasoline since 2010.

Figure 5: Sales of ethanol and gasoline in Brazil – ANP, 2003–12 (thousand m³)

Source: ANP 2013a.
Note: 'Etanol' includes both hydrous and anhydrous (blended) ethanol.
'Gasolina A' refers to gasoline without ethanol.

The lower production levels of ethanol have also been reflected in exports: in 2012, net exports of bioethanol, at around 2.5bn litres, represented an important recovery from 2011 when they were only 0.8bn litres. However, they were still far from the record of 2008, at over 5bn litres (ANP 2013a).

Although at much lower volumes than ethanol, biodiesel production has grown rapidly since the launch of a support programme in 2005, and stood at 2 per cent of transport fuel use (toe) in 2012. Even so, it fails to compete with conventional diesel, the share of which was 48 per cent that same year. (OC 2013e; IEA 2013c.) Since the 2000s, compressed natural gas has also been used as a transport fuel, in particular in large cities by taxis and light commercial vehicles: in 2012, natural gas vehicles comprised 5 per cent (1.6 million) of the total vehicle stock, and natural gas comprised 2 per cent of transport fuel use. (Nijboer 2010; OC 2013e).

[19] A similar dynamic can be observed in the total sales of ethanol (hydrous and anhydrous), which stood at 8.4 million m³ in 2003, peaking at 22.8 million m³ in 2009, and declining to 17.8 million m³ in 2012 (ANP 2013a).

Industry. Industry is the other main energy end-use sector and source of GHG emissions. Despite a relatively large service sector, industry is the largest energy end-use sector when electricity use is included, and, together with transport, a key contributor to energy demand growth. Brazil's manufacturing, construction, and mining industries account for approximately a quarter of its GDP (Carbon Trust 2012). As shown by Table 1 above, the largest industrial energy users are the food and tobacco, iron and steel, non-metallic minerals (cement, for example), pulp and paper, and petrochemical industries. Given the variety of available energy sources and each industry's special characteristics, there are wide differences in the carbon footprint of different end-use subsectors. For example, the food and paper industries principally use bioenergy, whilst oil products are used primarily in the petrochemical, chemical, cement, mining, and other heavy industries. The iron and steel industries burn both imported coking coal and domestic charcoal. Brazil is the world's largest charcoal producer, with a 13 per cent share of global production in the 2000s (WEC 2013). Most of this is used for thermal energy in pig iron production. Charcoal production is a major cause of deforestation in Brazil and often involves inhumane working conditions. However, if produced sustainably and ethically, it can be a better option for steel production than coal, from an emissions perspective (Nogueira et al. 2009).

Reflecting the above-described differences in industrial energy consumption patterns, the four principal industries, accounting for 63 per cent of GHG emissions from fuel combustion in 2012 were cement, chemicals, pig iron and steel, and non-ferrous and other metals. Emissions from fuel combustion in industry come primarily from oil, which had a 50 per cent share in 2012, followed by coal (21 per cent), natural gas (25 per cent), and biomass (4 per cent). (OC 2013e.)

Buildings. In buildings, non-electricity energy use has hardly increased since 1990, owing to a shift away from traditional biomass (fuel wood and charcoal) and towards electricity (IEA 2013c). The residential sector is still, however, a major consumer of fuel wood and liquid petroleum gas.

2.4 Stagnating energy efficiency performance

Despite a low energy intensity score, Brazil's performance in energy efficiency has been stagnating and there is plenty of scope for improvement. The energy intensity[20] of Brazil's economy, 0.13, is close to the OECD average, 0.14 and equal to non-OECD Americas' average, 0.13 (based on data for 2011). Brazil fares particularly well in comparison to the other BRICS, at 0.36. Low levels of heating and cooling in buildings, and the dominance of hydropower (with low conversion losses) in the electricity mix are key explanatory factors of Brazil's efficiency rating. However, there has been practically no improvement in energy efficiency over the past two decades. (IEA 2013b; 2013c.)

An important potential for improved efficiency has already been identified: in 2012, according to estimates by Abesco, the Brazilian energy service companies' association, the country wasted over 46 TWh of electricity. This figure represents approximately half of the energy generated by the massive Itaipu hydroelectric plant (which has a 14 GW capacity), 11 per cent of all electricity generated in 2011, or well over the annual consumption of the state of Rio de Janeiro. (Ordoñez, 2014.)

Brazil has an old and strained electricity network, and reducing related losses will be a key challenge, alongside that of building a grid with sufficient capacity for future demand. (WEC 2012.) For the past two decades, electricity transmission and distribution losses have been high, at 16–17 per cent. In 2011, losses totalled 88 TWh. (World Bank 2013.) In addition to technical losses, energy theft and measurement errors elevate total loss figures (IEA 2013c).

Another distinctive characteristic of Brazil's energy profile is a low per capita electricity consumption rate, attributable to the lack of heating systems (IEA 2013c). Driven by an increasing rate of

[20] Calculated as TPES (toe) / GDP (thousand 2005 US$ PPP). Energy intensity is the most commonly used quantitative indicator of energy efficiency.

installation of air conditioning devices and other appliances, Brazil's per capita consumption of electricity saw relatively fast growth over the 2000s: from 1,901 to 2,441 kWh between 2000 and 2011, representing an average annual growth rate of 2.3 per cent. However, in 2011, per capita consumption still remained below the global average (2,933 kWh), and had shown significantly lower growth rates than had been seen in the non-OECD world, on average (5.4 per cent/year). (Vichi and Mansor 2009; IEA 2013a.)

Drawing from the sections above, the key aspects of Brazil's energy profile, with an emphasis on sustainable energy, are summarized in Annex 2.

3 Government policies, plans, and interventions

Over the past decades, key themes in Brazil's energy policy have included supply and infrastructure expansion, energy independence, source diversification, and universal access and affordability (MME 2013; Geller et al. 2004). From a sustainable energy perspective, recent policy has been somewhat contradictory in its focus: on the one hand, the government places great emphasis on the development of additional large-scale hydropower capacity and is seeking to incentivize the deployment of other renewable energy sources, principally biomass and, to some extent, wind. Energy efficiency and conservation, especially in industry and transport, together with greenhouse gas emissions reductions are also among the stated policy goals. On the other hand, the government is pursuing the development Brazil's pre-salt oil reserves (see Box 3), which is expected to result in increased domestic emissions, both from production in the energy sector and combustion in the end-use sectors (given the projected increase in oil consumption). (WEC 2014b; MT 2012.)

Policy coherence and effective implementation are strong determinants of the success of any policy goal. Focusing on the goal of sustainable energy, this section examines related policies, plans, programmes, and other interventions set in place by the government to guide developments in energy supply and demand. It discusses recent sector-wide climate change mitigation and energy efficiency policies, as well as a number of specific programmes, mechanisms, and funding instruments set up over the past three decades to support renewable energy, efficient energy use, and emissions reductions. Notably, whilst the existence, scope, and quantity of these policies and programmes are highly commendable, many are limited in scope, fragmented in nature, and lacking in true ambition.

3.1 Climate change policy

In 2008, a year after the publication of the fourth assessment report of the Intergovernmental Panel on Climate Change, and a year before the Copenhagen UN climate conference, the Brazilian government published the National Plan on Climate Change (Plano Nacional sobre Mudança do Clima), which seeks to integrate and harmonize relevant policies and actions across sectors. It is based on the principles of reducing social inequality and increasing income through a low-emissions trajectory. Two key challenges are outlined: reducing emissions from land use change and increasing efficiency in the use of natural resources. Among the cornerstones of the plan is the goal to reduce deforestation by around 70 per cent by 2017. The plan also outlines a number of mitigation and adaptation actions and measures that are relevant for the energy sector, including:

(i) stimulating energy efficiency and conservation;
(ii) replacing coal in steel plants with sustainable charcoal (from reforested wood);
(iii) replacing refrigerant gases and old fridges;
(iv) encouraging the use of solar heating for water;
(v) sustaining the high share of renewables in the electricity mix, including through specific electricity auctions and supporting a national PV industry;
(vi) reducing electricity transmission and distribution losses; and
(vii) fostering a sustainable increase in biofuels in the national energy matrix. (Government of Brazil 2008.)[21]

At the time of its publication, the plan was criticized by civil society groups for being timid, lacking in mechanisms for implementation, and for not establishing emission reduction goals. In the same year,

[21] Related quantitative goals with impacts on sustainable energy patterns include: (i) saving up to 106 TWh of electricity and avoiding 30 $MtCO_2$ by 2030 through energy efficiency measures; (ii) reducing non-technical losses of electricity by 400 GWh per year, until 2016; (iii) reducing electricity consumption by 2.2 TWh per year by 2015 through solar heating; (iv) increasing electricity supply from cogeneration, mainly from sugarcane bagasse, to 11.4 per cent of total supply, equal to 136 TWh, by 2030; (v) increasing ethanol production by 11 per cent per year, on average, by 2018; (vi) setting an obligatory blending share of 5 per cent for biodiesel in diesel; (vii) avoiding 1,078 $GtCO_2e$ from HCFCs in 2008–40 by replacement of refrigerant gases; and (vii) adding 34 GW of hydropower capacity by 2016. (Government of Brazil 2008.)

an NGO coalition proposed a total reduction target of 20 per cent below 1990 levels that would include a 2 per cent reduction per year in energy-related emissions, including transport. (OC 2008).

In 2009, the government passed a law (Law No. 12,187/2009) creating the National Policy on Climate Change (Política Nacional sobre Mudança do Clima, PNMC). Climate policies and laws have also been passed at the subnational level in several states.[22] The energy-relevant aims of the PNMC include alignment of socio-economic development with the protection of the climate system, mitigation of GHG emissions, adaptation to climate change, and encouragement for the development of a national carbon market. The PNMC also defines the instruments and institutions for its implementation. Amongst the former are the National Plan on Climate Change and the National Climate Change Fund.[23] The policy sets a voluntary national emission reduction goal of 36.1–38.9 per cent compared to projected (business-as-usual) emissions by 2020. It was formally announced in the Copenhagen UN climate conference in late 2009.[24] At the time the PNMC was passed, signalling the difficulty of fully reconciling economic and climate goals, President Lula vetoed one provision calling for the gradual abandonment of fossil fuels and another giving priority to small-scale hydropower over medium and large-scale, in a move that some labelled an indication of the prioritization of 'development at any cost' (Mudanças Climáticas, 2008; Iglesias 2009).

The PNMC also establishes sectoral plans for mitigation and adaptation, and mandates the establishment of gradual mitigation goals in each sector (Law No. 12,187/2009). The baselines for quantitative emission reduction goals by 2020 were set in Decree 7,390 of 2010. For the energy sector, this baseline was defined as 868 $MtCO_2e$.[25] In establishing the mitigation goal, the Empresa de Pesquisa Energética (EPE, responsible for the energy sector plan) considered as feasible a scenario in which energy sector emissions would be reduced by 27 per cent, or 234 $MtCO_2e$ – representing demand that would otherwise be satisfied by fossil fuels. This figure was later defined as the upper target limit of reductions, and 22 per cent, or 188 $MtCO_2e$, was defined as the lower limit (e.g. EPE 2013a).[26] As a result, Brazil's energy sector emission target for 2022 is (634–)680 $MtCO_2e$. Notably, this still represents as much as a 56 per cent increase compared to 2012 emissions (OC 2013d).

The decree from 2010 describes such key areas for energy sector mitigation action as: expansion of electricity supply from hydro and other renewable sources, notably wind, small-scale hydro, and biomass; expansion of biofuel supply; and increase in energy efficiency (Decree 7,390 of 2010). A national communication on Nationally Appropriate Mitigation Actions (NAMAs) by Brazil to the UN climate change convention secretariat lists quantitative reduction contributions from specific energy sources (biofuels, hydro, 'alternative energy', and charcoal) and energy efficiency up to 2020 (UNFCCC 2013).[27] Notably, the NAMA submission does not explicitly define reductions for fossil fuels.

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[22] Only a few examples include climate change policies in the state of Amazonas and the municipalities of São Paulo and Rio de Janeiro, the latter of which have also set emissions targets.

[23] Other instruments include: Brazil's national communications to the UNFCCC, the resolutions of the Interministerial Commission on Climate Change, fiscal and tributary measures, public and private credit and financing tools, support for research and technology development, specific budget allocations, and international and national financing mechanisms, among others. The key institutions are: Comitê Interministerial sobre Mudança do Clima, Comissão Interministerial de Mudança Global do Clima, Fórum Brasileiro de Mudança do Clima, Rede Brasileira de Pesquisas sobre Mudanças Climáticas, and Comissão de Coordenação das Atividades de Meteorologia, Climatologia e Hidrologia.

[24] In the 2009 conference, major emitters were expected to bring forth national emission reduction pledges. Since Brazil is classified as a developing country in the UN climate convention, UNFCCC, its national pledge is not internationally binding.

[25] The energy sector baseline is equal to an increase of 99 per cent from energy-related emissions in 2012, according to the Observatório do Clima. The baselines for the other key sectors are: 1,404 $MtCO_2e$ for land use change, 730 $MtCO_2e$ for agriculture, and 234 $MtCO_2e$ for industrial processes and waste.

[26] The share of energy-related emissions of Brazil's total 2020 mitigation commitment would therefore be 16–20 per cent at the lower end and 15–19 per cent at the higher end of the commitment.

[27] Energy efficiency (12–15 $MtCO_2e$ reduction in 2020); increasing use of biofuels (48–60 $MtCO_2e$ reduction in 2020); increase in supply from hydropower (79–99 $MtCO_2e$ reduction in 2020); increase in other renewables (26–33 $MtCO_2e$ reduction in 2020); and switching to sustainable charcoal (8–10 $MtCO_2e$ reduction in 2020). (UNFCCC 2013.)

As a positive feature, national mitigation plans for the energy sector are integrated into the Ministry of Mines and Energy's medium-term energy plans, PDEs (Planos Decenais de Expansão de Energia). The most recent PDE establishes energy and emissions trajectories until 2022. Regarding planned mitigation measures, the PDE reflects the three areas established in the 2010 decree: renewable electricity, biofuels, and energy efficiency. The PDE scenario projects energy-related emissions rising to 643 $MtCO_2e$ by 2020 (702 $MtCO_2$ by 2022), which indicates that national emissions are expected to remain within the set policy target. (EPE 2013a.)

Another policy goal included in the PDE is to maintain the carbon intensity of the economy (measured in emissions/GNP) below 2005 levels.[28] The growth of energy-related emissions over the period 2013–22 is expected to be slightly higher than that of the economy or energy, resulting in an increased emissions intensity (CO_2/energy and CO_2/R$) compared to 2005 levels. In relation to this goal, the PDE defines maintaining a high share of renewables in the energy mix as 'the major challenge'. (Ibid.)

Sectoral mitigation and adaptation plans have also been elaborated for the iron and steel industry, manufacturing and mining industries, and for transport and urban mobility, among others. The iron and steel industry plan aims to promote the use of domestically produced sustainable charcoal in pig iron production. Emission-reduction goals in this subsector relate to avoiding emissions from deforestation. The manufacturing industry plan focuses on energy and materials efficiency and includes: the establishment of a monitoring, reporting, and verification (MRV) system for industrial emissions; an action plan for incentivizing emission reductions in industry; and a 5 per cent emission-reduction goal compared to business-as-usual emissions from energy use and industrial processes in the manufacturing industries. The mining industry plan comprises a sectoral analysis for emission reductions and proposes three mitigation programmes: a switch to lower-carbon energy sources, the installation of energy-efficient equipment and parts; and the use of new mining technologies. The transport and urban mobility plan focuses on the expansion of transport infrastructure and increased use of energy-efficient modes of transport. Improvements in public transport are expected to result in a 2.7 per cent reduction in sectoral emissions. A freight transport plan promotes actions leading to a 3 per cent reduction compared to business-as-usual emissions, principally from a switch to rail and waterways from road. (Gex/CIM 2013.) (See also Section 3.3.)

At the time of writing, the national climate change plan was under review for an updated version. Furthermore, the Ministry of Foreign Affairs was reportedly leading work on national emissions scenarios, with a focus on mitigation actions post-2020, results being expected by the end of 2014. (Climate Wire 2014.)

3.2 Energy efficiency plan

At present, Brazil's energy efficiency framework is fragmented and consists of a number of separate programmes. The only major piece of energy efficiency legislation, which establishes (a committee for determining) efficiency standards for appliances and buildings, dates from 2001 (Law No. 10,295/2001; Decree No. 4,509 of 2001). In 2011, the Ministry of Mines and Energy published the National Energy Efficiency Plan (Plano Nacional de Eficiência Energética: Premissas e Diretrizes Básicas, PNEf), which presents the existing regulatory framework and instruments and actions in a number of economic sectors and areas. It also makes suggestions for improvement and further actions in each area; these include: studies, incentive mechanisms, capacity-building, financing, regulation, improved management, and better coordination and integration amongst the different existing programmes. The plan also seeks to clarify responsibilities for the different stakeholder institutions. The areas covered by the PNEf are: electricity, industry and micro, small, and medium enterprises, transport, education, buildings, public lighting, sanitation, solar heating, research and development, monitoring and verification, international partnerships, and financing. The national programmes on electricity conservation, rational use of oil and natural gas derivatives, and energy efficiency labelling are also evaluated. (MME 2011.)

[28] This figure is taken from Brazil's second national communication to the UNFCCC from 2010.

The PNEf incorporates only one quantitative objective: to reduce electricity consumption by around 10 per cent in 2030 compared to consumption without conservation measures.[29] This would be equal to 106 TWh saved and 30 $MtCO_2$ avoided. Of these savings, half are estimated to come from 'autonomous progress' (without government intervention) and the other half from actions stimulated by public policies (described in the PNEf). (Ibid.)[30] Notably, the PNEf does not include an efficiency goal for overall energy demand.

3.3 Other plans and policies

The National Plan for Logistics and Transport (Plano Nacional de Logística e Transportes, PNLT), developed by the Ministry of Transport with the Ministry of Defence and first launched in 2007, is a long-term planning document that is updated periodically.[31] It includes a broad investment programme which aims at a shift from road towards rail and waterway freight transport. The latest edition, from 2012, determines that, based on higher logistical costs and greenhouse gas emissions of freight transport via roads (52 per cent of all freight transported), a more balanced participation of transport modes is necessary. It expects the share of rail transport to increase to 43 per cent (from the current 30 per cent) and waterway transport to 15 per cent (from 13 per cent now). The planning document further highlights the fact that waterway and railroad transport can, under certain circumstances, be 37–62 per cent less expensive than road transport. (MT 2012.)[32]

Alongside the long-term sectoral plans elaborated by ministries, the government also publishes an economy-wide planning document (Plano Plurianual, PPA), for the duration of each presidential mandate. The current PPA, for 2012–15, in line with the PNEf, includes a target to conserve 20 TWh of electricity (compared to a trajectory without efficiency measures) through the use of more energy-efficient equipment over the period. With regard to biofuels, the plan mentions increasing production of biodiesel in accordance with the national biodiesel programme (see Section 3.4.1). (MPOG 2011.)[33]

3.4 Government policy tools, programmes, and other interventions

As in most countries, some of Brazil's older sustainable energy programmes were originally not devised with environmental sustainability as the primary goal but have resulted in important positive synergies in this regard. Prominent examples are the Pró-Álcool bioethanol programme and the ethanol blending mandate, and the electricity conservation programme PROCEL. A number of more recent programmes have energy efficiency and greenhouse gas emissions reductions amongst their key goals. The examples presented in this section are not an exhaustive list of government activities in the area, but are intended to provide an overview of some of the key federal-level actions.

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[29] The PNEf and the 10 per cent reduction goal were already referred to in the national long-term expansion plan PNE 2030 of 2007. Both the PNE 2030 and the National Plan on Climate Change of 2008 also make reference to an energy efficiency policy (yet to be published at the time of writing), which would provide the guidelines for the PNEf.

[30] Prior to its publication, the version circulated for public consultation included quantitative sectoral goals and an observation that the industrial and residential sectors have the broadest potential for efficiency, with 39 per cent and 37 per cent shares of total reductions, respectively. However, the sectoral goals were removed from the final version. The goals were proposed as follows: 40 TWh in the industry, 38 TWh in the residential sector, and 24 TWh in the commercial and public sectors.

[31] Prior to the PNLT, the previous broad planning effort had been taken in 1985 (MT 2014).

[32] The original PNLT, from 2007, set a target of expanding the railway network and of increasing rail and waterway transport to 32 per cent and 29 per cent respectively, over the next 15–20 years. The share of transport via road would consequently decrease from 58 to 33 per cent. (MT/MD 2007.) A re-evaluation of the plan, published in 2012, projects that the implementation of current government plans and projects would result in a more modest decline in the share of road transport, which would stand at 38 per cent by 2030. The share of rail transport, on the other hand, would be much higher, at 43 per cent, but waterway transport would only increase its share to 15 per cent. (MT 2012).

[33] The PPA also includes a thematic plan for climate change (Programa 2050: Mudanças Climáticas) that comprises six objectives including: the development and implementation of mitigation and adaptation instruments that take into account sustainable development and regional diversity (the responsibility of the Ministry of Environment), and creation and dissemination of knowledge and technologies for mitigation and adaptation (led by the Rede CLIMA network). (MPOG 2014.)

3.4.1 Clean energy programmes and policy tools

'Alternative' renewable energy. In 2002, the government launched PROINFA (Programa de Incentivo às Fontes Alternativas de Energia Elétrica), a programme to incentivize 'alternative' sources of electricity, namely wind, biomass, and small-scale hydropower. The pioneer stage support programme introduced a guaranteed feed-in price and long-term supply contracts for these renewables, and contributed to the creation of legislation in the area. PROINFA set a capacity goal of 3.3 GW and a quantitative long-term goal of 10 per cent of total electricity supply by 2022 (PROINFA, undated; Geller et al. 2004). By 2011, when PROINFA terminated, it had resulted in the deployment of a total capacity of 2.6 GW only, distributed as follows: 43 per cent small-scale hydro, 36 per cent wind, and 20 per cent biomass (Gex/CIM 2013).

Auctions. At present, some renewable technologies are already able to compete on a cost basis with fossil fuels in the electricity market. In 2013, two of ANEEL's electricity auctions, held for new projects, were opened to bids from solar energy projects for the first time. Given the high cost of solar energy, however, no such projects were among the winning bids. On the positive side, despite both auctions also being open to natural gas thermal power projects and one for coal, the 58.3 TWh sold through 20-year contracts in the first auction (held in November) were exclusively won by 39 wind power projects that will start generation in 2016. A larger auction, in December that year, that sold 325.6 TWh starting from 2018, similarly saw only renewable energy projects amongst its winners, which included five biomass thermal plants, 16 small hydropower stations, and 97 wind energy projects. The average sale prices in these two auctions were R$124/MWh (US$56) and R$110/MWh (US$49), respectively. (ANEEL 2013a; 2013b.)[34] A sign of increasing competitiveness is the decline in production costs: in the first wind energy-exclusive auction, organized in 2009, the average selling price was US$85 whereas in the December 2013 auction wind power sold at only R$119 (US$53) (Renewable Energy World 2009; ANEEL 2013b). Further demonstrating the competitiveness of wind power in the Brazilian electricity market, NGO reports recorded a total capacity of 4.7 GW of wind energy contracted through ANEEL's auctions in 2013 alone (Greenpeace 2013).

Platform hydropower. In order to mitigate the important socio-environmental impacts of large-scale hydropower, the Ministry of Mines and Energy has adopted a new concept for the construction and operation of hydroelectric power stations titled 'platform plants'. Related principles include avoidance of large temporary or permanent settlements, reduction of access infrastructure, reforestation of any deforested areas, and a small operational workforce (IEA 2013c). With large-scale hydropower, however, complete avoidance of impacts is impossible. A major platform project currently under construction in the Amazonian river Tapajós, with an approximate total capacity of 6 GW, has come under criticism from conservationists for its expected impacts on the local ecosystem (Angelo 2010).

Bioethanol. The history of government support to biofuels began with the Pró-Álcool programme in 1975, which was aimed at reducing dependence on oil imports and coincided with a period of low international sugar prices (OC 2008). Despite a promising start, the 1990s saw a large-scale abandonment of ethanol vehicles by consumers, following a series of detrimental policy choices in the 1980s, most importantly the removal of most subsidies to the sector. The downward trend in ethanol use by vehicles was reversed in 2003 by the introduction of flex-fuel cars that run on both gasoline and ethanol, and by the reintroduction of a mandatory blending mandate for ethanol in gasoline. The government also supports the position of biofuels in the sector through tax reductions, while the national economic and social development bank BNDES disburses funds for technology development. (Hira and Oliveira 2009; BNDES 2014). Despite this, the sector currently faces several other uncertainty factors, of which gasoline pricing (discussed in Section 2.3) is often cited as the principal.

A number of unresolved socio-environmental concerns also relate to bioenergy production; these include deforestation, biodiversity loss, and competing land uses. In addition to the ongoing and heated global debate over the sustainability of biofuels, the government's 2006 agroenergy plan recognizes that bioethanol production in Brazil has had dire socio-environmental impacts including:

[34] All currency conversions in this paper are expressed in current value at the time of writing (July 2014).

concentration of land ownership, poor conditions for workers, and negative impacts on ecosystems. According to experts, the emergence of the biodiesel industry has focused attention on socio-environmental aspects in the sugarcane production industry. (Leopold and Aguilar 2009.) Attempts to improve the situation have included the adoption of mechanical crop harvesting and economic–ecological zoning for plantations. In 2009, the government published a study on sugarcane agro-ecological zoning (ZAE Cana), which mapped, state by state, the potential for a sustainable expansion of sugarcane production. The results indicated that around 7.6 per cent of Brazil's territory (64.7 million hectares) would be suitable for expansion that would not invade areas with native vegetation or directly affect food production (MAPA 2009). To enforce the plan, public banks are only providing financing, and state environmental agencies are only licensing plantations, within the areas considered appropriate by ZAE Cana (Cana News 2013). However, indirect land use changes (which can cause GHG emissions and biodiversity impacts) remain a concern and are difficult to measure. These are caused when the expansion of sugarcane plantations into pasture and croplands pushes the latter two into environmentally sensitive areas.

Biodiesel. In the area of biofuels, in 2004 the government established the National Programme for Biodiesel Production (Programa Nacional de Produção e Uso do Biodiesel, PNPB). The programme aims to promote biodiesel production to reduce diesel imports while simultaneously promoting both regional development – through the creation of a decentralized production network, unlike the case of ethanol, which is mostly processed in the state of São Paulo – and social inclusion, through tax benefits for producers purchasing from small rural communities. A legal basis for supporting the production of biodiesel was set in 2005 in a law that established a mandatory blending rate of biodiesel in conventional diesel, at 5 per cent. A gradual elevation of this share to 7 per cent by November 2014 has been confirmed which, according to the Ministry of Agrarian Development, will boost production by 40 per cent and avoid 1.2bn litres per year of conventional diesel imports. Industry sources have estimated that this increment will save the national oil company, Petrobras, at least R$2.3bn (approximately US$1bn) per year. At present, biodiesel in Brazil is produced primarily from soybeans. Negative environmental impacts of biodiesel production include deforestation, increased use of agrotoxins, and competition with other land and crop uses, including food crops. On the positive side, if deforestation is avoided, the use of biodiesel can result in lower emissions of CO_2, sulphur, and other particles in comparison to diesel. (Xavier and Soares 2012; Leopold and Aguilar 2009; Freitas 2014; MDA 2014.)

Flaring. A relatively recent flaring-reduction programme has already resulted in significant reductions in the amounts of associated gas burned in the energy (oil and gas) sector. In 2010, after flaring had reached a record high (3.4 tcm in 2009), the regulatory agency ANP and the state oil company Petrobras signed an agreement by which the latter would minimize associated natural gas flaring in 20 main oil production fields in the Campos basin. A programme having reduction goals up to 2014 (Programa de Ajuste para Redução de Queima de Gás na Bacia de Campos, PARQ) has yielded commendable results, with flaring dropping to 1.3 tcm in 2013. (ANP 2014.) According to the IEA, the government is also committed to minimizing flaring at the Santos basin, a major pre-salt reserve (IEA 2013c).

3.4.2 Energy efficiency programmes and policy tools

End-user energy efficiency policies in Brazil began in the 1980s and related programmes have effectively functioned for over two decades (MME 2011). Currently, a number of initiatives and programmes exist, with some focusing on the electricity sector, reflecting the concern over power shortages, and others on the use of fossil fuels, supporting the goal of energy independence.

Electricity sector. In the electricity sector, the national conservation programme (Programa Nacional de Conservação de Energia Elétrica, PROCEL) was established already in 1985. The programme is executed by Eletrobras, the largest utility company, which is majority-owned by the state. It operates on both demand and supply sides through sector-based actions (including buildings, industries, sanitation, and street lighting), research, education, and labelling. (Perrone 2013.)

Pricing can function as a powerful tool in demand-side efficiency and conservation. However, in Brazil, electricity prices are yet to be explicitly harnessed for this purpose. In recent years, the government has grown increasingly concerned about the relationship between energy pricing and the economy, as illustrated by the gasoline price cap aimed at controlling inflation. Electricity prices in Brazil have been high compared to those in other emerging economies: US$0.18/kWh for industry and US$0.24/kWh for residential users in 2012. Accordingly, in 2013, in an effort to prevent a negative impact on the economy (already affected by slower growth rates) the government reduced electricity tariffs by 16–28 per cent (IEA 2013c). Even so, the price paid by industry, according to the IEA, is similar to that in the EU and nearly three times as much as that in the USA (Ibid.).

Fossil fuel use. Another area of focus has been the rational use of fossil fuels. In 1991, based on the example of PROCEL, the government launched CONPET (Programa Nacional da Racionalização do Uso dos Derivados do Petróleo e do Gás Natural) to incentivize conservation and efficiency in the use of oil and natural gas derivatives in all key sectors. The programme is led by the Ministry of Mines and Energy and executed by Petrobras. In the transport sector, the programme has supported maintenance actions and awareness-raising to increase the efficiency of diesel use in trucks and buses. (CONPET 2012.)

The key regulatory authority for both fossil and biofuels (oil, natural gas, and biofuels) is the National Agency of Petroleum, Natural Gas and Biofuels (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis, ANP), which is also responsible for implementing the national policy for these sectors – including policies relating to energy efficiency (MME 2011). Notably, however, despite a petroleum law from 1997 that determines conservation and rational use of oil and natural gas amongst the responsibilities of the ANP, the agency has not established a specific department or regulations for this purpose (MME 2011).

Vehicle efficiency. The more recent Inovar-Auto programme, from 2012, seeks to stimulate investment in the national automotive industry (and provide protection from competing imports) by providing tax benefits for companies producing and selling vehicles in the country and complying with a set of norms over the period 2013–17. From 2017 onwards, tax benefits for vehicles will be based on fuel efficiency. In this way, the programme encourages manufacturers to increase the efficiency of cars produced and, according to the IEA, if effectively implemented, it could increase light-duty vehicle efficiency by 12 per cent over the current five-year period. The IEA also sees the programme as a first step towards compulsory efficiency targets. (IEA 2013c.)

Eco-labelling. The Brazilian Labelling Programme (Programa Brasileiro de Etiquetagem, PBE), set up in 1984, provides an efficiency labelling system for a range of electric and fuel-using appliances which includes compulsory labelling for natural gas appliances and voluntary labelling for vehicles. Both PROCEL and CONPET also have their own labelling programmes (Selo PROCEL, Selo CONPET, and Selo Verde) for appliances and diesel vehicles that fulfil certain efficiency criteria. (CONPET 2012.)

Funding. Sources of funding for energy efficiency actions include: budget allocations from Eletrobras and Petrobras, funds from the Global Reversion Reserve (an electricity sector expansion fund, which also supports accessibility and 'alternative' energy projects), and international funds, such as the Global Environment Facility. An obligation set by ANEEL to all distribution companies (to spend 0.5 per cent of operating revenue on energy efficiency measures) has, according to some sources, mobilized US$378m. (Pollis 2013.) PROESCO, an energy efficiency credit line offered to energy saving companies by the national development bank BNDES had, by 2011, approved total finances of US$16.5m (Meltzer et al. 2014). While energy efficiency measures in buildings are still voluntary, a phasing out of incandescent light bulbs has begun (IEA 2013c).

3.4.3 Implementation instruments for mitigation actions

Specific funds and instruments designed to support the implementation of energy use-related mitigation actions have been introduced relatively recently. In 2009, the government created the

National Fund on Climate Change (Fundo Nacional sobre Mudança do Clima). This fund is linked to the Ministry of Environment, is partly administered by the national development bank BNDES, and has ten programmatic focuses in the areas of mitigation and adaptation which include: urban mobility, sustainable cities, efficient machinery and equipment, renewable energy, solid waste, and charcoal. The fund has a total budget allocation of R$560m (US$252m), derived partly from petroleum exploration and production revenues. (Pollis 2013.)

Further funding sources include public transport infrastructure project funding from the BNDES and resource allocations from several sub-national-level governments, including those of São Paulo and Rio de Janeiro. Furthermore, the Social Fund (Fundo Social), created in 2010, receives a share of hydrocarbon production royalties from pre-salt reserves. These funds are used for programmes in a number of areas, among which are climate change mitigation and adaptation. (PBMC 2013.)

The Clean Development Mechanism (CDM) of the Kyoto Protocol, operational since 2000, has also been used actively for financing additional mitigation actions in Brazil, and the BNDES has established a number of programmes and credit lines for this purpose (Ibid.). In March 2014, Brazil hosted 400 CDM projects (in the pipeline) and the country was ranked third in the world in terms of participation. These projects represent 6.5 per cent of Brazil's total emissions and are expected to result in an annual reduction of 56 $MtCO_2e$ compared to business-as-usual. (Risoe Centre 2014.)[35] Furthermore, once operational, Brazil will be eligible for funding through the Green Climate Fund.

The National Policy on Climate Change, from 2009, also defines the operationalization of a Brazilian Emissions Reduction Market (Mercado Brasileiro de Redução de Emissões, MBRE), which is still to be implemented. However, a voluntary carbon market has been operated by the BM&F Bovespa stock exchange in São Paulo since 2005; this, among other things, holds auctions for CERs (CDM carbon units). (EDF/IETA 2013.) At least two states, São Paulo and Rio de Janeiro, have been exploring an emissions trading system. In the latter, a pilot market, announced for 2013, has been postponed until further notice (Ávila 2014).

[35] Regulation and governance mechanisms for CDM are set in the National Policy on Climate Change (PNMC).

4 Energy projections to 2022 and 2035

Is Brazil planning for a low-carbon, energy efficient future? Are its policies and actions taking it there? This section examines how the energy trends and policies discussed in the previous sections are expected to affect future trajectories, particularly in terms of sustainable energy. The first part explains how the government's own energy plans and projections envisage Brazil's energy future up to the 2020s. The second part compares these projections with energy and emissions scenarios produced by the International Energy Agency and the World Bank, highlights similarities and differences in the three projections, and points towards possible problems and the scope for broader deviations with regard to sustainable energy. Although the scenarios examined in this section inevitably do not capture the full extent of possible futures, they illustrate, in quantitative terms, the vast potential for more ambitious action and the broad scope of future policy options that Brazil has at its disposal, should it wish to advance on a low-carbon, energy-efficient development trajectory.

4.1 National energy projections

Since 1970, the Brazilian government has based its national energy planning and investment activities on an annual energy balance published by the Ministry of Mines and Energy and, for the past decade, by its planning and research arm Empresa de Pesquisa Energética. (Vichi and Mansor 2009.) The two key planning documents that guide national energy policymaking are the long-term national energy plan (Plano Nacional de Energia 2030, PNE 2030) and the annually updated medium-term energy expansion plan (Plano Decenal de Expansão de Energia, PDE). The PNE for 2030 was published in 2007. At the time of writing, the document was being updated for 2050, and was expected to include an expansion plan for nuclear energy (IHU 2014).[36] Given this, the 'old' long-term plan is not considered at length in this study.[37]

The current edition of the medium-term plan (PDE), which dates from early 2014, extends to 2022 and incorporates a number of policy objectives including: energy security, affordability of prices and tariffs, universal access to energy, and an emissions reduction target. As a result, the PDE's energy projection is not a business-as-usual scenario but a de facto planning tool.[38]

Growth assumptions. The PDE operates under the following economic and demographic key assumptions: annual GDP growth at 4.5–5.0 per cent in 2013–22, and a population growth of 0.6 per cent per year, reaching 207 million in 2022. As a consequence of the high economic growth rates embedded in the model, final energy consumption is expected to grow at an annual rate of 4.5 per cent over the period, to 368 Mtoe, and electricity by 4.7 per cent, to 785 TWh. The share of renewables in the energy mix is expected to remain constant (41 per cent in 2022). Among the major sectoral trends over this period are: (i) large increase in natural gas and bagasse (biomass) use, (ii) growth in electricity use in the energy sector (subsector), (iii) important increase in coal consumption in industry, (iv) decrease in the share of fuel wood and charcoal in total consumption, and (v) slightly decreased share of gasoline in transport. (EPE 2013a.)

Clean electricity. Brazil's clean electricity capacity of 103 GW in 2013 is projected to expand by nearly 50 per cent, to 161 GW in 2022. Importantly, hydropower capacity expansions totalling 21 GW by 2018 have already been contracted, and an additional 13 GW are planned for 2018–22. However,

[36] Given that 2014 is the year of presidential elections, at the time of writing, a government decision on nuclear energy was not expected before 2015. Also, the next PDE (2023) was not expected to include such plans. Any discussion of an expansion of nuclear energy before the launch of PNE 2050 would therefore be speculative.
[37] Also, the PNE 2030's total energy demand projections fall roughly between those by the latest PDE and the IEA (from 2013).
[38] Notably, the mitigation section of the PDE underscores that the mitigation scenario incorporated in it is not to be considered as a 'baseline' scenario. A potential motive for this is based in international climate politics, as Brazil's current emission pledge is based on reductions compared to a 'baseline' scenario. If this were to be altered downwards, the target would become stricter.

given the trend towards run-of-river projects (see Section 2.2) reservoir capacity is expected to increase by only 2 per cent over the decade. For wind, small-scale hydro, and biomass, 11 GW have been contracted while a further 12 GW are planned. For non-renewable thermal generation capacity, 3.5 GW have been contracted and a further 1.5 GW are planned. Fossil-fuel-powered generation capacity in turn is projected to expand only by 2.4 GW, to 22 GW. Self-generation in the ethanol and natural gas and petroleum industries is expected to grow significantly, at 8.8 per cent per year. The plan does not include estimates for generation shares of different energy sources, or expansion plans for nuclear energy beyond the completion of Angra 3 (1.4 GW) in 2018. (Ibid.)

Transmission. The PDE envisages the development of the national interconnected system (SIN) through an expansion of the current transmission network by 50 per cent and of total transformation capacity by 41 per cent by 2022. To strengthen the transmission system and keep up with the increasing demand, the government has prepared a 10-year transmission expansion programme (Programa de Expansão da Transmissão) that aims to add more than 50,000 km of transmission lines over the period 2013–22. As a result of the improvements, losses in the SIN are estimated to drop from 17.3 to 16.0 per cent. (EPE 2013a; IEA 2013c.)

Fossil fuels. Demand for all fossil fuels is expected to keep growing through 2022. The use of natural gas in electricity generation (excluding cogeneration) is expected to rise by 3.2 per cent per year through 2022 (33 per cent over the period). Overall, natural gas is expected to keep expanding its share in the energy mix, from 7.0 to 8.4 per cent by 2022 in final consumption. The use of natural gas for non-energy purposes, particularly fertilizers, will further drive the expansion in demand for this source. In 2013, Brazil's oil demand was 2.44 million bbl/day, whilst production only reached 2.12 million bbl/d. Over the next decade, this situation is expected to be reversed as, despite a continued growth in demand, which reached 3.29 million bbl/d in 2022 (35 per cent growth over the period), production is expected to total 5.47 million bbl/d that same year. From levels that are currently similar to those of natural gas, consumption of coal is expected to grow by 43 per cent over the period, driven by strong expansion in the iron and steel industry. However, its share in the energy mix (excluding electricity) remains constant, at around 5.5 per cent. (EPE 2013a.)

Bioenergy in transport and industry. Regarding transport, the PDE expects domestic demand for ethanol to grow by more than 100 per cent, from 22 billion litres in 2013 to 47 billion litres in 2022.[39] As a result, the share of ethanol in total final consumption would increase from 4.6 per cent in 2013 to 6.6 in 2022, whilst the share of gasoline is expected to fall slightly, from 10.4 to 9.0 per cent. However, conventional diesel will still retain its supremacy in transport fuels, with an 18.2 per cent share (compared to 18.5) with biodiesel remaining at 1 per cent. The use of biomass in the energy and industrial sectors is similarly projected to increase by 52 per cent over the period, prompted by the increase in ethanol production, the primary end user of this source. (Ibid.)

Energy efficiency. Aligned with the PNEf reduction goal, but incorporating estimates for total energy use, the PDE expects energy savings from both energy and electricity efficiency measures to result in a 5.8 per cent reduction in 2022 compared to a business-as-usual trajectory; this represents 22.6 Mtoe in total energy, including 48 TWh in electricity. The greatest contribution is expected to come from the industry and transport sectors, which would account for 58 and 31 per cent of all savings, respectively. In electricity, the largest share of savings would come from the industrial and residential sectors: 40 and 38 per cent, respectively. Also, the PDE notes that these conservation measures could prevent an expected increase in Brazil's energy intensity. (Ibid.)

Emissions. In spite of planned mitigation actions in the transport and industrial sectors, such as biofuels and efficiency, the PDE expects these two sectors to continue generating the majority – albeit declining – of total energy-related emissions, 66 per cent in 2022 (down from 71 in 2012). The emissions from the three main subsectors would be: 306 $MtCO_2e$ from transport (50 per cent increase), 161 $MtCO_2e$ from industries (52 per cent increase), and 91 $MtCO_2e$ from electricity

[39] Ethanol production is projected to double from 27 billion litres in 2013 to 54 billion litres in 2022.

generation (107 per cent increase).[40] Despite the reduced competitiveness of ethanol over past years, the scenario projects that ethanol use in flex-fuel vehicles will increase. It also expects that emissions from (self-generation) thermoelectric plants running on natural gas will drive fast emission growth in this subsector. Emissions from the energy sector (subsector of energy-related emissions) and fugitive emissions will also increase their shares owing to increasing oil production and refining. (Ibid.)

4.2 Analysis of national and international projections

Another comprehensive country-specific scenario exercise, conducted by the International Energy Agency (IEA) in cooperation with Brazilian government agencies, looks at a longer time horizon, extending through 2035 (IEA 2013c). Published in late 2013, the IEA's baseline scenario (New Policies) coincides with the latest PDE on the broad contours of Brazil's future domestic energy profile. Like projections in the PDE, the IEA's baseline scenario takes into account current policy commitments and plans. Despite the similarities, important differences are also distinguishable, most saliently assumptions regarding the speed of energy demand growth. The 'Energy projections' section of Table 2 presents a comparative quantitative summary of core assumptions and projections by the Brazilian Ministry of Mines and Energy's PDE 2022 and the IEA's New Policies Scenario through 2035. The section 'Energy efficiency projections and plans' of the table also incorporates the energy efficiency and emissions goals set by the Brazilian government (see Section 3). Furthermore, given that the IEA's scenario is not compatible with the avoidance of dangerous climate change, emissions projections from the more ambitious country-specific low-carbon scenario from the World Bank's Energy Sector Management Assistance Program (ESMAP) in 2010 are incorporated in the comparison in the section 'Greenhouse gas emissions projections and plans'. (The IEA's energy outlook for Brazil through 2035 is presented in more detail in Annex 3.)

Table 2: Comparison of energy and emissions plans and projections

General assumptions			
	Present (see Annex 4)	**PDE 2013–22**	**IEA 2011–35**
Average annual GDP growth	3.6%	4.8%	3.7%
Population growth	0.9%	0.6%	0.7%
Energy projections			
	Present (see Annex 4)	**PDE 2013–22**	**IEA 2011–35**
Average annual final energy consumption growth	3.2%	4.5%	2.4%
Average annual electricity generation growth	3.9%	4.7%	2.9%
Total final energy consumption (at end year)	251 Mtoe	368 Mtoe	388 Mtoe
Fossil fuel consumption, other than electricity (end yr.)	134 Mtoe	192 Mtoe	207 Mtoe
Land area used for sugarcane harvest (at end year)	8.5 m ha	10.3 m ha	16 m ha
Electricity consumption (at end year)	520 TWh	785 TWh	939 TWh
Share of renewables of energy supply (at end year)	43%	41%	43%
Share of renewables of electricity generated (end yr.)	87%	-	80%
Clean electricity capacity (at end year)	103 GW	161 GW	203 GW
– Of which hydropower capacity	84 GW	119 GW	151 GW
Fossil fuel electricity generation capacity (at end year)	20 GW	22 GW	56 GW
Electricity consumption per capita	2,441 kWh	3,798 kWh	4,150 kWh
Transmission and distribution losses in electricity	17.3%	16%	-

[40] The PDE does not expect the PNLT (see Section 3.3) to have a significant impact on emissions over the current decade.

Energy projections (continued)			
	IEA 2011	**IEA 2020**	**IEA 2035**
Total primary energy demand (TPED, Mtoe)	267	352	480
– TPED of oil/natural gas/coal (Mtoe)	109/23/15	141/38/19	165/77/24
– TPED of bioenergy (Mtoe)	78	99	138
– TPED of hydropower (Mtoe)	37	44	58
– TPED of other clean energy (incl. nuclear, wind, Mtoe)	5	11	19
Total final consumption of energy (Mtoe)	219	287	388
– Consumption of fossil fuels in transport (Mtoe)	61	84	96
– Consumption of fossil fuels in industry (excl. electricity, Mtoe)	30	39	59
– Use of fossil fuels in electricity generation (Mtoe)	11	16	32

Energy efficiency projections and plans				
	PDE 2013	**PDE 2022**	**PNEf 2030**	**IEA 2035 (reference – efficient)**
Energy conserved compared to BAU	1.5 Mtoe	23 Mtoe	-	20–62 Mtoe
Share of energy conserved of BAU use	0.6%	5.8%	-	5–16%
Electricity conserved compared to BAU	5.3 TWh	48 TWh	106 TWh	-
Share of electricity conserved of BAU use	1.0%	5.8%	10%	-
National electricity energy efficiency target			10% equal to 106 TWh in 2030	

Greenhouse gas emissions projections and plans				
	PDE 2012	**PDE 2022**	**World Bank 2030**	**IEA 2035 (CO_2 only)**
Energy-related GHG emissions ($MtCO_2e$)	437	643 (2020) 702 (2022)	735 (reference) 480 (low carbon)	700 (reference) 610 (efficient)
– GHG emissions from transport ($MtCO_2e$)	204	306	-	-
– GHG emissions from industry ($MtCO_2e$)	106	161	-	-
– GHG emissions from electricity ($MtCO_2e$)	44	91	-	-
		IEA 2011	**IEA 2020**	**IEA 2035**
– CO_2 emissions from oil (Mt)		303	388	446
– CO_2 emissions from natural gas (Mt)		51	87	168
– CO_2 emissions from coal (Mt)		55	69	89
National climate policy goal for emissions			634–680 $MtCO_2e$ in 2020	

Sources: IEA 2013a; 2013b; 2013c; EPE 2013a; 2013b; ESMAP 2010; MME 2011; World Bank 2013.
Notes: Possible inconsistencies are due to the different methodologies used by each source. Where indicated, data for 'Present' is from the latest available year as displayed in Annex 4.

The subsections below review how these projections of Brazil's energy supply and demand are expected to evolve in relation to sustainable energy over the next two decades. Broad conclusions are drawn and possible 'problems' highlighted. The analysis is structured into five areas: (1) general parameters and projected energy demand growth; (2) the role of different energy sources and technologies in supplying the demand growth; (3) the expansion of the electricity system and the role of different sources; (4) energy efficiency; and (5) mitigation of greenhouse gas emissions. Key messages in each area are highlighted in italics.

4.2.1 General parameters

Brazil has ample resources for a secure energy future. Regarding overall energy resources, Brazil has at its disposal a vast range options for expansion over the coming decades. Petrobras is developing Brazil's massive pre-salt oil and natural gas reserves, and projections are optimistic in this regard. Significant additions to both biofuels (driven by sugarcane ethanol) and renewable electricity (driven by large-scale hydro) are also underway.

Outdated assumptions on economic growth can lead to unrealistic energy demand estimates. Regarding basic economic and demographic trends, the IEA's scenario assumes a continuation of trends seen in the 2000s over the next two decades. The Brazilian government's energy expansion plan, PDE, in turn assumes faster economic growth (4.8 per cent) through 2022. In light of current economic growth rates, 0.9 per cent in 2012 and around 2.3 in 2013 (World Bank 2013), it is argued that the government is probably basing its medium-term energy planning on estimates of economic growth which are too optimistic.

Domestic energy demand is expected to increase by over 50 per cent over the next two decades. Both scenarios project both absolute and per capita energy demand growth to continue but diverge over how fast this will happen. As a result of its higher economic assumptions, the PDE projects high demand growth for both total energy and electricity (4.5/4.7 per cent/year) over the next ten years whereas the IEA expects demand growth to slow from the 2000s, reaching a level of 2.4/2.9 per cent over the next 20 years. The PDE's total energy demand projection for 2022 is thus nearly as high as that of the IEA for 2035, and roughly 50 per cent higher than the figure for 2013 (368/388 Mtoe).

4.2.2 Role of different sources in meeting the growth

The projections expect fossil fuel use to grow across the end-use sectors. The two projections coincide on the expectation that the current shares of renewables and non-renewables in the total energy supply will be maintained. Consequently, both expect a significant absolute increase in the consumption of fossil fuels, only disagreeing on the speed of this expansion (increase of 58 Mtoe by 2022 or 73 Mtoe by 2035 excluding electricity).[41]

Unfortunately, the projections do not take into account the possibility of a growth in the share of renewables in the energy mix from present-day levels, which is a fully feasible trajectory if sufficient policy support and frameworks are provided. The room for manoeuvre is demonstrated in a scenario study by the Brazilian Ministry of Transport from 2012, which suggests that the share of renewables in the energy mix in 2030 could vary between 66 per cent in a 'green scenario', and 35 per cent in a scenario in which the pre-salt reserves are used in abundance (MT 2012).

Natural gas demand is expected to grow fast while oil remains the primary energy source. The IEA projects Brazil's primary supply of natural gas to see a nearly 3.5-fold increase by 2035, surpassing hydropower as the third most important energy source (and up from 9 to 16 per cent of the total). Despite rapid growth in bioenergy production, oil is expected to continue to dominate the energy mix, with a 50 per cent growth from 2011 (reaching 165 Mtoe in 2035), albeit with a diminishing share (down to 34 from 41 per cent).

The expected substitution of oil by natural gas in the growing energy supply is a highly positive trend from a sustainable energy perspective. However, the absolute growth in the use of oil and other fossil fuels is nevertheless significant. For example, the expected increase in oil demand by 2035 (56 Mtoe), driven by increasing vehicle ownership and the predominance of road transport, is relatively close to the total annual oil consumption (in 2012) of countries like the UK and Spain, which have a

[41] In 2035, the IEA expects the transport sector to consume three times more oil (92 Mt) than biofuels (35 Mtoe). In the industrial sector, demand for fossil fuels (excluding electricity) is expected to nearly double by 2035: of the 59 Mtoe consumed, half would come from natural gas and the rest from coal and oil. Bioenergy (excluding electricity) would provide for roughly a similar amount (55 Mtoe).

population size of 63 and 46 million, respectively (BP 2013; World Bank 2013). Over the next two decades, Brazil's population is only expected to grow by around 25 million people. Although improved living standards almost inevitably lead to increased car ownership, determined measures in transport and industry could offset a part of the projected growth in oil demand (and the increase in coal demand in industry). These measures include expanding the share of biofuels and investing in more efficient transport infrastructure, alongside other efficiency measures.

Bioenergy will continue as the main renewable source. The production of bioenergy (biomass and biofuels) is projected to grow by 77 per cent over the 24-year period, enabling it to retain its share in the primary supply, at 29 per cent, according to the IEA's estimate. Despite a strong expansion in wind power capacity, clean energy sources other than bioenergy and large-scale hydropower are expected to remain in a relatively marginal role in the energy supply, at 4 per cent in 2035.

Measured in terms of land area used, both projections expect sugarcane harvests (including both sugar and ethanol uses, and not considering efficiency and technological improvements) to increase at an annual rate of over 2 per cent, from 8.5 million hectares in 2012 to 16 million hectares (of which 9 m ha would be used for ethanol production) in 2035. With a total of 65 million hectares of land estimated by the government as being suitable for sugarcane production (see Section 3.4.1), there remains scope for more substantial production increases that could at least partially offset the increase in oil demand, if stable and attractive market conditions for biofuels are assured.

The primary determinants of expansion in biofuels production, especially that of ethanol, include: the domestic end-user prices of gasoline, international market prices of sugar, government support to biofuels, the bioenergy industry's ability to cover rising land and labour costs and to upgrade machinery, the development of advanced biofuels,[42] and, in the case of biodiesel in particular, competing uses of land. The existing pricing and tax regime currently harms the expansion of clean transport fuels, and also generates additional economic costs for the fossil fuel industry, as explained above in Box 4. Being optimistic about more favourable conditions in the future, the IEA's projections for ethanol production assume both the alignment of domestic oil prices with international ones and continued government support to biofuels (IEA 2013c).

Still unresolved environmental concerns, primarily deforestation and biodiversity loss, could negatively influence the future prospects of biofuels. Some suggest that this could only happen at much larger production volumes than those projected over the next two decades. The IEA's land use estimates for sugarcane crops in 2035 only concern 2 per cent of Brazil's land area, of which around half would be used for ethanol production (IEA 2013c).[43]

4.2.3 Expansion of the electricity supply system and sources

Major capacity expansions in the electricity system will be needed. The two energy projections agree on the need to significantly expand the national electricity supply capacity, while differing only slightly on how they expect Brazil's electricity generation profile to develop: the PDE expects a 50 per cent increase in electricity demand compared to 2013 (requiring a capacity expansion of 56 per cent) while the IEA expects an 80 per cent increase in demand (requiring a nearly 100 per cent expansion in capacity).[44]

The future of hydropower expansion is uncertain beyond 2035. By 2035, the IEA expects Brazil to have a total hydropower capacity of 151 GW. The PDE plans to have 119 GW in place already by

[42] These encompass advanced production techniques including: ethanol from biocellulose and other sources for biodiesel (such as palm oil), with higher productivity than first-generation biofuels (IEA 2013c).
[43] External considerations to be taken into account include policies in Brazil's key export markets. The IEA expects 20 per cent of ethanol produced in the country in 2035 to be destined for export (IEA 2013c). Changes in domestic energy and climate policy in the USA or the European Union could affect their import volumes of Brazilian biofuels. In the future, any unaddressed concerns over socio-environmental sustainability could also affect the exportability of Brazilian biofuels to key markets.
[44] The difference is possibly due to the increasing predominance, over time, of run-of-river-type plants in new hydropower projects; these have a lower capacity factor than ones with reserves.

2022. Despite a total hydropower potential estimated by the government at 261 GW, concerns over socio-economic impacts are expected to generate challenges even for the achievement of the above-projected capacity.[45] Currently, all new dams must conduct an environmental and social impact assessment and, as a result, most are run-of-the-river-type and many are expected to adopt the platform hydropower concept. On the down side, the trend towards smaller reservoir size is making the system even more vulnerable to rainfall variations. (UNEP FI 2010; IEA 2013c.) In the near future, Brazilian officials predict increasingly frequent heat waves, similar to those registered in the past three years (Verdélio 2014). Changing rainfall patterns could impact electricity production through decreases in river runoff and water availability, in particular in the semi-arid North-Eastern parts of the country (UNEP FI 2010). If energy demand growth continues high, Brazil will need to rethink its electricity policy, and if the PDE demand projection were to materialize, this would need to be in place during the next decade.

The speed of expansion of fossil fuel-powered generating capacity is uncertain. Illustrating the wide room for manoeuvre in this area, given the key role of the government in setting the frameworks for capacity expansions, the two projections differ on the shares of fossil-fuelled thermal capacity. The PDE estimates it will drop from 19 to 14 per cent in 2022, while the IEA expects it to rise to 28 per cent in 2035.

Without decisive policy, the share of renewables in the electricity mix is set to fall. Despite a rapid expansion of biomass and wind, at 39 GW in 2035, the IEA expects the share of fossil fuels in electricity generation will rise from 13 to 20 per cent, with most expansion taking place from the 2020s onwards. (The PDE does not include estimates for generation.) Over the next eight years the PDE projects fossil-fuelled capacity to expand by only 2 GW, to 22 GW, whereas the IEA expects this to nearly triple by 2035, to 56 GW. Of this, 40 GW would be natural gas-fuelled. From a sustainable energy perspective, to avoid a reversal of the decarbonization of Brazil's electricity supply (in particular from the 2020s onwards) the government should direct its policy support to maximizing the share of clean sources and, where this is not possible, to promote switching from oil and coal to natural gas-fuelled capacity.

Wind and solar energy are expected to grow modestly. Despite the recent successes in ANEEL's auctions, the IEA only expects Brazil's wind power capacity to increase to 23 GW by 2035 (from 4 GW in 2013). With an estimated total wind energy potential of up to 350 GW, it is evident that, with the right policy signals and support, expansion could be more ambitious. Reflecting the low attention received by solar energy in Brazil to date, and its high cost, the projected solar capacity in 2035, at 9 GW (which would represent 3 per cent of Brazil's total electricity capacity that year) is proportionally significantly lower than the figures projected for other major emerging economies – such as China (7 per cent) and India (10 per cent) – or even the world average (8 per cent). Neither of the projections expects Brazil's nuclear capacity to expand beyond the completion of the third reactor in Angra (2018). However, as noted in Section 4.1, the possibility of a policy change in this area should not be excluded.

4.2.4 Energy efficiency

There is significant potential for energy efficiency and conservation. Measured in terms of the energy intensity of the economy, Brazil is close to the OECD and non-OECD regional averages, but its efficiency has not improved over the past two decades. Conscious of the potential for savings, government has set a long-term efficiency goal of 10 per cent of electricity use in 2030. Furthermore, the PDE projection includes a mid-term goal of 5.8 per cent of all energy use by 2022, which translates to a 23 Mtoe deviation from a business-as-usual (with no conservation measures) trajectory. Going further, the IEA's energy efficient scenario finds potential for an 11 per cent deviation from its baseline scenario by 2035, which would amount to 42 Mtoe (given the IEA's lower total

[45] The IEA notes that if there is a failure to secure 'sufficient social consent' for new hydropower projects, other sources (including fossil fuels and nuclear energy) would need to cover the gap. This would lead to lower investment costs, but significantly higher fuel costs and CO_2 emissions (IEA 2013c).

consumption estimate). Around two-fifths (17 Mtoe) of this would come from oil saved in the transport (13 Mtoe), buildings, and industrial sectors.

Both future projections expect Brazil's growing middle class to drive the growth of per capita electricity consumption. Spurred by rising income levels and, consequently, the growing adoption and use of appliances, the residential sector will be the key driver of electricity consumption growth over the next decades. The IEA projects demand in this sector to increase by 120 per cent in 2011–35. Industrial demand, starting at similar levels, is expected to increase by 90 per cent. The IEA's energy efficient scenario estimates the total saving potential for these sectors at roughly 9 Mtoe by 2035.

4.2.5 Mitigation of greenhouse gas emissions

Energy use-related greenhouse gas emissions growth will be driven by transport and oil. The PDE estimates that the transport sector will be the key driver of energy-related greenhouse gas emissions growth in Brazil over the current decade (2013–22). The sector is expected to add over 100 $MtCO_2e$ to Brazil's annual energy-related emissions, followed by industry with a 60 $MtCO_2e$ contribution, and electricity generation with an additional 47 $MtCO_2e$. In terms of sources, the IEA expects oil to contribute two-thirds to emissions growth over the current decade (2011–2020), followed by natural gas (approximately a quarter), and coal (around 10 per cent).

Compared to Brazil's mitigation target, significantly more ambitious action is feasible. Should the PDE projection – which already incorporates Brazil's sectoral mitigation goal for energy-related emissions (634–680 $MtCO_2e$ in 2020) and expects high economic and energy demand growth over the current decade – materialize, the national policy target for energy-related emissions will be met comfortably, with emissions estimated at 643$MtCO_2e$ in 2020. The IEA projection, which is based on a lower – and possibly more realistic – energy demand growth rate, estimates 2020 emissions at a figure 100 $MtCO_2$ lower than that of the PDE.

Notably, owing to its higher energy demand growth assumption, the PDE projects emissions reaching 702 $MtCO_2e$ in 2022. The IEA projects more modest emissions growth, with similar levels (700 $MtCO_2$) only reached in 2035.

Furthermore, two sustainable energy scenarios, by the World Bank and IEA, indicate that more ambitious reductions – which are needed for the world to stay below 2°C of global warming – are possible. The IEA's energy efficient scenario (11 per cent deviation from the baseline scenario), which does not contemplate an accelerated deployment of clean energy, would curb emissions growth to 610 $MtCO_2$ in 2035. In the even more ambitious scenario by the World Bank, a combination of low-carbon and efficiency measures would keep Brazil's energy-related emissions growth to a minimum, whereby they would only rise to 480 $MtCO_2$ in 2030. On the other hand, if emissions from energy were to grow at rates projected in the PDE (nearly 5 per cent/year) they would reach 1,328 $MtCO_2$ by 2035; this represents a 200 per cent increase from 2012 and is nearly equal to Brazil's total greenhouse emissions (including LUCF) in 2012.

5 Policy recommendations

As the previous sections demonstrate, Brazil still has significant potential for progress in the area of sustainable energy. In terms of available resources and capacity, the country is extremely well positioned, but current government plans and actions are not directed at fully exploiting this potential. Climate and energy efficiency policies, whilst comprehensive and relatively well integrated in the relevant sectoral plans and policies, still lack ambition, and many of the existing programmes and interventions to support sustainable energy are fragmented and have a limited impact.

Drawing from the analysis above, this final section presents nine broad policy recommendations, aimed at supporting a reversal of the current energy trends in Brazil and transitioning into an even cleaner and more efficient energy mix over the coming decades. The first three recommendations involve key determinants of energy supply and demand patterns: economic growth, energy policy and investments. The subsequent five recommendations discuss ways to increase the shares of renewable energy and of cleaner fossil fuels in the energy mix, and to increase energy conservation and efficiency. The final recommendation calls for Brazil to adopt more ambitious greenhouse gas emissions targets and policy, in particular with an eye on the post-2020 era.

1. Decoupling energy and emissions growth; planning for lower demand growth. As in any country, a sustainable energy transition in Brazil will fundamentally require the decoupling of economic growth from both energy demand and emissions. Currently, however, economic growth still drives both. In this context, lower levels of GDP growth than those projected by the government's energy expansion plan through 2022 would significantly alter the outlook for Brazil's energy demand. Consequently, lower medium-term economic growth estimates – a possibility currently projected by a number of institutions[46] – should be reflected (even if only as an alternative trajectory) in future revisions of the expansion plan so as to ensure that appropriate decisions are made in relation to capacity expansions and investments and support to different sources.

2. Improving consistency of policy vis-à-vis sustainable energy. Consistency and predictability are key requirements for an effective sustainable energy policy. Given the fact that Brazil is a parliamentary democracy and has a recent history of changing emphases on different areas of sustainable energy policy (the changes in the bioethanol support policies over the past decades and the electricity capacity crisis of the early 2000s are two examples), the possibility of important changes in energy policy by future governments, especially after 2018 (when the current president can no longer be re-elected), cannot be excluded. Undoubtedly, certain key energy policy priorities are likely to be sustained over consecutive future governments, these include: the development and exploitation of Brazil's pre-salt reserves, the expansion of large-scale hydropower and ethanol production, together with energy affordability to lower-income segments of the population and attractive pricing for industry. Nevertheless, it is evident that wide scope for enhanced consistency between (sustainable) energy policy goals and broader political and economic priorities remains. In this sense, energy pricing is the area in most urgent need of reform; as discussed in the previous sections, the Brazilian government is currently intervening in energy pricing to support industrial competitiveness and curb inflation, with the effect of harming both the electricity sector and the transport fuel industry. As a first step, transport fuel and electricity prices should be adjusted to better reflect their true cost (while bearing in mind the need for affordability in the lower income segments).[47] This would not only support the recovery of the bioethanol industry and eliminate the losses Petrobras is incurring from gasoline imports, but it would also send the right signals to energy end-users – both in terms of the need for conservation and efficiency, and also by revealing the higher cost of using fossil fuels. Furthermore, as pointed out by the IEA (2013c), should the current price interventions be

[46] For example, in February 2014, the Brazilian bank Itaú's forecasts for GDP growth were 1.4 per cent in 2014 and 2.0 per cent for 2015. (Leahy 2014)

[47] Given the need to ensure affordability to lower income segments, the current 'social tariff' (Tarifa Social) support programme in the electricity sector should be naturally continued and further developed.

continued or reinforced in the future, they would not only result in faster demand growth than projected, but would also limit incentives to invest in supply and energy efficiencies.

3. Allocating and attracting investments in a low-carbon future. Investments are a third key determinant of future energy trends. Available estimates of the levels of financing required to meet future demand vary in scale but remain equally unambitious regarding the share going to clean energy: the PDE foresees total investments of around R$1,200bn (US$540bn) over the period 2012–22 (around US$54bn per year) of which 73 per cent would go to the oil and natural gas sector, 23 per cent to electricity supply, and 5 per cent to liquid biofuels (EPE 2013a). To meet similar levels of demand, the IEA has calculated that investments of US$90bn per year are needed (IEA 2013c). In both projections, considerably lower levels of investments – US$2bn–2.6bn per year – are directed to the expansion of liquid biofuels production than to that of oil and natural gas. The decision to allocate more funds to support the expansion of clean sources depends on the government. Whilst bold and possibly politically unpopular decisions will be required, and a number of established interests will need to be managed, decarbonization is not an issue of cost but of prioritization. For example, when compared to the investments planned for the oil and gas sector through 2022 (R$87bn or US$39bn), the additional investments estimated to be required (US$11bn per year) for implementing the World Bank's low-carbon scenario (examined in Annex 3) seem broadly feasible even without taking into account the co-benefits of a cleaner and more efficient energy mix for the economy and human health. Furthermore, while current studies diverge on Brazil's oil production outlook in a carbon-constrained world (one arguing that most of it could be exploited and another warning of the possibility of stranded assets[48]), investments in the oil and gas sector generally reduce the level of financing available for investment in a sustainable energy future.

4. Prioritizing renewables in the electricity sector. For the next decade or two, the expansion of large-scale hydropower will continue to be the key determinant of the development and sustainability performance of Brazil's power sector – supported by more moderate contributions from other clean energy sources. Unlike the situation in many other countries – where switching to natural gas results in lower emissions – in Brazil's power sector such a switch has the opposite effect. Therefore, in this sector, renewables should always be given priority. Overall, a key uncertainty factor in the electricity sector is whether transmission and generation capacity expansions will be implemented fast enough to meet the growing demand. Under any medium-term trajectory, new generation and transmission capacity will need to remain a key supply-side policy focus in the electricity sector, alongside the reduction of transmission and distribution losses. Here, policy support would ideally be directed to clean sources.

Future expansion of hydropower is principally constrained by the remote location of the remaining capacity, concerns relating to socio-environmental impact, and risk considerations. Some sources assert that existing climate models that seek to project impacts on the energy sector from droughts, rising temperatures, changes in wind potential, and frequency of cyclones are largely inconclusive (IEA 2013c). However, based on the precautionary principle alone, the power sector should increase its resilience to more extreme weather conditions by diversifying into other renewable sources; Brazil's interconnected power system supports such diversification well, due to the complementarities between hydro, wind, and biomass, as explained above (see Section 2.2). The higher cost of thermal electricity produced from fossil fuels, together with the associated environmental impacts, are powerful reasons for supporting a future expansion of renewable electricity capacity that is more

[48] If the cost of exploitation of Brazil's pre-salt reserves remains reasonable (below US$50/bbl), a continued expansion of oil production might be justified in a global climate change mitigation context, in terms of cost-effectiveness. The Carbon Tracker Initiative has calculated the remaining global carbon budget (or the amount of fossil fuels that can still be burned if the world is to avoid dangerous climate change) as 20–40 per cent of proven fossil fuel resources. In a special report on Brazil from 2013, the group evaluated current projects in the Petrobras pipeline and concluded that they fall entirely in the lowest end of the cost curve, which under a cost-efficient market logic (by which low cost and low political risk determine the choice of reserves to be developed) would mean that these projects would be likely to figure amongst the 'burnable share' of global fossil fuel reserves. (Carbon Tracker 2013.) However, in 2014, the same group launched another report, which places Petrobras among the top companies in the world at risk of wasted capital in a low-carbon world given the size of its (planned) investments in high-cost projects in the pre-salt reserves (Carbon Tracker 2014).

ambitious than government and IEA projections. The current electricity auction system has an important role in providing stability for future supply and can also be used to direct investments towards cleaner sources by organizing technology-exclusive auctions. Whilst the PROINFA programme played an important role in supporting 'alternative' renewable energy sources at their early stages in the 2000s, recent electricity supply auctions have demonstrated that biomass and wind are already able to compete with fossil fuels on an economic cost basis. Therefore, a much broader capacity expansion for these non-hydro renewable sources than currently projected is perfectly feasible, if underpinned by determined policy to support a further decarbonization (including through the deployment of solar energy) of Brazil's already clean electricity sector. Available policy tools mentioned in literature include renewable portfolio standards and carbon taxes (Lucon et al. 2013). Although nuclear energy is not considered in this study, it should be noted that, given the long-term environmental risks associated with nuclear energy, the declining costs of renewable electricity, the significant storage capacity in hydropower reservoirs, and the complementarities between hydro and other renewables in the national electricity system, renewables appear, in many ways, to be a more sustainable option.

5. Switching to biofuels in transport. Given Brazil's massive biofuel potential and the dominance of road transport, another key, parallel decarbonization strategy should involve transport fuel substitution. By investing in a more significant biofuel production expansion than is currently planned, large quantities of oil would be liberated from domestic use and diverted for export; this would have the double effect of mitigating domestic transport emissions and generating additional revenues, which could in turn be invested into national sustainable energy supply and support schemes. With even higher production levels – but still within the limits of sustainable land use – a share of the national ethanol production could be destined for export, generating further export revenues and contributing to a cleaner energy mix in other countries. Also, should Brazil's planned oil production capacity increases not materialize within the expected time frame, increased biofuel production volumes will serve as an important buffer against the need to import oil products.

A simple calculation is presented to demonstrate this in practice: for example, the IEA (2013c) expects Brazil to consume domestically around 60 per cent (3.4 million bbl/d) of its oil production in 2035. That same year, it estimates Brazil's domestic production of ethanol will be 0.8 million boe/d, the production of which would occupy 1 per cent of national territory. Even if ethanol production expanded to cover 2 per cent the territory (still far from the 7.6 per cent determined as suitable), an additional 0.7 million boe/d would become available, which is equal to more than Brazil's projected gasoline demand in 2035 (0.5 million boe/d). Despite the uncertainties associated with future demand and supply expansions, this rough calculation demonstrates that this strategy holds significant potential, even in a country as large as Brazil. However, in order to be successful, it must be underpinned by consistent policy support (including removal of harmful policies) and financing, as discussed above.

6. Switching to natural gas in non-electricity use. Switching to natural gas in the industry and transport sectors can be a good second option when renewables are not available or usable. The growth of domestic natural gas supply will depend on the availability and price of domestic natural gas, and will be enabled by the development of a more open Brazilian natural gas market and the expansion of the pipeline system, among other factors (IEA 2013c). In the transport sector, an expansion of the natural gas vehicle fleet could also cut emissions, if switching occurs from oil-based fuels to natural gas. Important potential for expansion in this area exists in the heavy-duty vehicle fleet, but growth is highly dependent on a strong government policy, yet to be established (Nijboer 2010).

7. Investing in a clean and efficient transport infrastructure. A further way of reducing the consumption of oil products, in particular that of diesel, is to invest in infrastructure for a modal shift in transport: freight transport should move away from roads, and passenger transport should move towards public transport. Currently, the outlook for an expanded railway network looks promising, with a long-term plan in place for the sector (PNLT) and investment plans for up to 10,000 km of railways announced by the government in 2012 (Soto and Goy, 2012). However, a timely implementation of this infrastructure is likely to be challenging, as indicated by the preparations for the FIFA World Cup

in 2014 and the Olympic Games in 2016. Furthermore, a lack of sufficient interlinking and coordination of large strategic objectives – namely hydropower and diversification in transport modalities – is hindering the expansion of transport by waterways.[49] More determined and concerted action in this area is therefore called for.

8. Improving energy efficiency through conservation and enhanced policy. Energy efficiency – as the de facto cleanest and cheapest energy source – has a key role to play in Brazil's future energy mix. While the government's long-term efficiency goal (set for electricity only) stands at 10 per cent by 2030, the IEA estimates that a 16 per cent deviation from business-as-usual total energy demand is possible by 2035. Other sources confirm the existence of further potential: according to Abesco, the Brazilian energy service companies' association, efficiency measures by consumers alone could result in a 10 per cent reduction in consumption and R$11.5bn (US$5.2bn) in savings (Ordoñez 2014).

With the residential sector driving electricity demand, education and awareness, electricity tariffs, and appliance standards should all be targets of action. The case of the electricity crisis of 2000–1 (see Box 1) is an interesting example of the impact of heightened consumer awareness on energy consumption; this episode led to a temporary drop in residential electricity demand that only rose back to 2000 levels in 2005 (IEA 2013c). With the heat waves of early 2014, consumer awareness and behaviour change were again considered by many officials and distribution companies as the primary tool for avoiding power rationing and blackouts (Lagreca 2014). Pricing is an even more powerful tool. Whilst universal access should undoubtedly guide energy policy, the present utilities tariffs have been criticized for working against the goal of energy efficiency (Daltro 2014). Furthermore, in appliance labelling and standards (and in the building sector overall), the trend should be from voluntary eco-labels towards compulsory and progressively more stringent efficiency standards, and the use of fiscal tools to encourage manufacturers to invest in efficiency improvements, as is the trend in the vehicles industry (see Section 3.4.2).

Importantly, a holistic energy efficiency policy and related strategies and actions are needed for the entire energy sector, not just for electricity. This was already recognized in 2007 in the government's long-term energy plan, PNE 2030, which also stresses that energy efficiency should be regarded as an investment option in the context of supply expansions (EPE 2007). The PNEf (from 2011) and the incorporation of energy efficiency in the medium-term plans (PDE) constitute steps in the right direction. Nevertheless, seven years after the publication of the PNE, an overarching policy (goal) is still missing and experts suggest that, in the current situation, investing in energy efficiency is still economically less attractive than supply expansions. Indicatively, China has nearly 3,000 energy service companies; Brazil only around 150. (Ordoñez 2014.)

The problems of Brazil's energy efficiency framework are multiple and well-known: the PNE identifies the lack of data and databases as the principal barrier to establishing robust energy efficiency programmes. Brazil's fragmented energy efficiency programme landscape (see Section 3.4.2) further contributes to this problem. Other measures called for in the PNE include: unified monitoring and verification procedures, the use of fiscal incentives in the energy supply and other industries, demonstration projects, provision of support to technological innovation, capacity-building, and optimization of transport modes. (EPE 2007.) The PNEf calls for an improved legal framework, sufficient financing mechanisms, and stronger coordination and operational mechanisms (MME 2011). Energy-efficiency auctions – a further idea suggested by both documents and promoted by NGOs – are also yet to materialize. Overall, it is clear that the government must play the lead role in overcoming the challenges and establishing the necessary regulatory frameworks and support mechanisms for enhancing energy efficiency.

[49] For example, a number of new hydroelectric plants are planned through 2020 along key rivers. These rivers could serve for crop and other types of cargo transport. In most cases, however, navigation locks are reported to be lacking in the design of these projects, rendering the waterways in question unnavigable if built as designed. (Levine 2012.)

9. Updating emissions targets and climate policy for the post-2020 era. If supply from fossil fuels (particularly oil) were to grow over the next decades as projected, Brazil's total emissions would keep rising until the 2020s, and beyond. The rate of growth is, however, not set in stone; as explained above, the Ministry of Mines and Energy is operating under a much higher emissions estimate for the early 2020s than, for example, the IEA. There may be a pragmatic explanation for the high official estimates: given that by 2015 all countries expected to come forward with ambitious emission targets for the post-2020 period, the Brazilian government may feel reluctant to revise its emissions estimates for 2020, for the time being.

Despite the sensitive timing, two findings of this study are of importance for Brazil's future emissions trajectories: firstly, there is significant scope for deviation from the PDE emissions trajectory if more ambitious clean energy and energy efficiency measures are taken. The World Bank's low-carbon scenario in particular, although produced in 2010, indicates that there is massive potential for Brazil to save energy and decarbonize its already rather clean energy mix even further, in line with a global shift to a low-carbon economy. Secondly, to provide a clear signal for energy planning and markets beyond 2020, the government should promptly set an ambitious mitigation target for the post-2020 period, for example for 2025 or 2030. This should particularly be contemplated in the context of the new national long-term energy plan, PNE 2050, still under preparation at the time of writing.

A report from 2013 by the Brazilian Panel on Climate Change (PBMC) agrees with the need for a post-2020 policy. It concludes that, in the absence of new mitigation policies, total greenhouse gas emissions will rise again after 2020, possibly reaching 2,500 $MtCO_2e$ per year by 2030 (nearly 70 per cent above 2012 levels), driven by fossil fuel combustion and agriculture. The PBMC calls for immediate mitigation actions in these two sectors and asserts that the cost of inaction is far greater than that of prompt action. According to the coordinator of the PBMC's mitigation report, energy-related emissions in particular require further attention and should be targeted through clean technology investments and incentives, sustainable hydropower solutions, transport sector efficiency measures, and the introduction of a carbon tax or an emission quota system for large industries, to limit the increase in thermal electricity generation from fossil fuels. (PBMC 2013; Spitzcovsky 2013.)

There is a range of available mitigation options for Brazil, and they come at different costs. According to the PBMC, carbon capture and storage (CCS) and solar power (PV and CSP) are among the technologies with the highest cost Whilst wind power is still relatively expensive, a number of incentives provided by the government have increased its competitiveness. A McKinsey analysis has identified energy efficiency in buildings as a further cost-negative opportunity. The industrial sector is estimated to have the greatest emissions reduction potential, a large share of which would be reached at a negative cost; appropriate measures could include the adoption of lower energy and carbon-intensive technologies, a switch to natural gas in industry, and the recycling and efficient use of materials. Key cost-effective mitigation measures for the transport sector include shifting to biofuels, vehicle efficiency, and moving away from road transport. The PBMC report also points towards key lacunae in relevant policies: a long-term incentives policy for renewable energy (including obligatory, periodical renewables-only electricity auctions) and an integrated energy efficiency policy. (PBMC 2013; Carbon Trust 2012.)

Alongside an ambitious climate policy, key enablers of scaled-up mitigation action include financing, technology, and institutional capacity. Some of the domestic and international funding mechanisms already in use are discussed in this paper (see Section 3.4.3). A study by the Fundação Getulio Vargas from 2012 (examining the barriers and opportunities in low-carbon financing in Brazil) found that, despite the existence of a number of lines of funding, the volume of utilized resources is low and insufficient for a low-carbon transition in the energy and agriculture sectors. Among other proposals, it recommends: making available further funds; improving related management, capacity, and practices in financial institutions; establishing new subsidies and fiscal and financial incentives; supporting the creation of new markets (including for solar energy); and improving R&D, communication, and capacity-building. (GVces 2012.) In addition to setting up domestic funding channels, Brazil has been actively taking advantage of the Kyoto Clean Development Mechanism. Currently, with the trend away from project-based activities to programmes and national targets, Nationally Appropriate Mitigation Actions (NAMAs) will be among the principal mechanisms for Brazil to communicate its mitigation

plans and related financing needs. As suggested at the beginning of this study, and demonstrated by the above analysis, Brazil has all the right resources and tools available for maintaining its role as a global sustainable energy leader. For the country of the future, action towards this end, however, must take place in the present.

Annex 1: Electricity generation and consumption statistics

Electricity generation by source and plant type (GWh), 2011 (IEA)

Plant type	Source						
	Hydro	Biofuels	Natural gas	Nuclear	Oil products	Coal	Total
Electricity plants (Share of total)	428,333 (80.6%)	354 (0.1%)	15,235 (2.9%)	15,659 (3.0%)	9,527 (1.8%)	5,625 (1.1%)	477,994 (90.0%)
CHP plants (Share of total)	- -	31,881 (6.0%)	9,860 (1.9%)	- -	5,269 (1.0%)	6,754 (1.3%)	53,764 (10.1%)
Total (Share of total)	**428,333** (80.6%)	**32,235** (6.1%)	**25,095** (4.7%)	**15,659** (3.0%)	**14,796** (2.8%)	**12,379** (2.3%)	**531,758** (100%)

Source: IEA 2013a.
Note: Inconsistencies between IEA and EPE owe to different methodologies (and data) used.

Electricity generation by source (GWh), 2010–12 (Empresa de Pesquisa Energética)

Year	Source						
	Hydro	Biomass & wind	Natural gas	Nuclear	Oil products	Coal	Total
2010 (Share of total)	403,290 (78.2%)	31,523 & 2,177 (6.5%)	36,476 (7.1%)	14,523 (2.8%)	16,065 (3.1%)	8,263 (1.6%)	515,799 (100%)
2011 (Share of total)	428,333 (80.6%)	31,633 & 2,705 (6.5%)	25,095 (4.7%)	15,659 (2.9%)	12,239 (2.3%)	6,485 (1.2%)	531,758 (100%)
2012 (Share of total)	415,342 75.2%	34,662 & 5,050 (7.2%)	46,760 (8.5%)	16,038 (2.9%)	16,214 (2.9%)	8,422 (1.5%)	552,498 (100%)
Change 2011/12	–3.0%	+9.6% & +86.7%	86.3%	+2.4%	+32.5%	+29.9%	+3.9%

Source: EPE 2013b.

Sectoral distribution of electricity consumption (Mtoe), 2011 (IEA)

Sector	Consumption
Industry	**18.0**
Non-ferrous metals	3.3
Iron and steel	2.4
Food and tobacco	2.3
Chemical and petrochemical	2.0
Paper pulp and printing	1.6
Mining and quarrying	1.0
Other	**21.1**
Commercial and public serv.	9.7
Residential	9.6
Agriculture and forestry	1.8
Transport	0.1
Total final consumption	**39.3**

Source: IEA 2013a.
Note: Includes only subsectors using over 1 Mtoe.

Annex 2: Brazil's sustainable energy profile

Energy supply overall	*Example*
Highly diversified energy mix, high share of renewables	Share of renewables: 43% (2011)
Nearly energy self-sufficient	Production/TPES: 0.92 (2011)
Hydropower and clean energy overall dominate in the electricity mix	Generation shares: 81/90% (2011)
Main sources in the energy mix (excl. electricity) are oil and biofuels	Oil: 56%; biomass 32%
Electricity sector characteristics	***Example***
Privatization and auctions system are spurring investment and supporting expansion and source diversification in the power sector	Investments with private participation: US$11–31bn/yr. (2009–12)
Droughts have made hydropower generation less reliable, leading to higher use of 'emergency' thermal power generation and costs	Generation share of fossil fuels: 8% (2011); 13% (2012)
Other clean electricity sources include biomass, nuclear, and wind	Generation share: 9% (2012)
Transmission system is the main source of power interruptions	Share of lines for 2015 delayed: 75%
Growth in electricity demand is driven by the expanding middle class	Generation growth: 3.9%/yr. (2000s) Population living under US$2/d: 11%
Sector-wise, industry and buildings are roughly equal consumers	Consumption shares: 46/50%
Energy supply characteristics (other than electricity)	***Example***
Industry is the main energy-consuming sector (including electricity) with a highly diversified pattern in sources used by different subsectors	E.g. iron and steel industries use coal and charcoal; food industry biomass
(Road) transport is the main consumer of oil	Transport: 59%; road: 53% (2011)
Car ownership is increasing, driven by the expanding middle class	New cars registered: 3.6 m (2012)
The share of biofuels in the transport sector is uniquely high	Biofuels in transport: 14% (2012)
Biodiesel consumption is growing but volumes are still low	Biodiesel in transport: 2% (2012)
Car ownership is driven by the expanding middle class	New cars registered: 3.6 m (2012)
Energy efficiency and greenhouse gas emissions	***Example***
Energy intensity of the economy is low but there has been no improvement in energy efficiency over the past two decades	Energy intensity (EI): 0.13 Global average EI: 0.19
Per capita electricity use and emissions (excl. LUCF) are relatively low	Electricity use: 2,441 kWh (2011) Emissions: 5.96 tCO_2e (2010)
Total emissions from energy are comparatively low and the economy's carbon intensity is very low	Total emissions, energy: 437 $MtCO_2$ CO_2 intensity/world average: 0.20/0.44
Emissions from land use changes are falling; those from energy and agriculture are now driving emissions growth	Share of energy-related emissions of total: 14% (1990), 29% (2012)
Emissions from transport are driving growth of energy emissions	Increase in 1990–2012: 120 $MtCO_2$ Share of emissions: 47% (2012)
Industry is the second major source and driver of emissions growth	Share of emissions: 21% (2012)

Sources: See Section 2.

Annex 3: Energy and emissions projections by international sources

Below, an overview is provided of the expected evolution of Brazil's energy sector and emissions through 2035 according to the International Energy Agency's (IEA) baseline scenario (IEA 2013c). Constituting the most comprehensive international up-to-date resource on the topic, the IEA's World Energy Outlook 2013 contains a special section on Brazil, which has been elaborated in cooperation with the Brazilian government. The New Policies Scenario for Brazil constitutes the IEA's new baseline scenario; it takes into account existing policy commitments and plans and assumes a modest realization of national policy intentions.[50] It is important to keep in mind that, at a global level, this scenario is based on unsustainable greenhouse emission levels: an increase in energy-related emissions by nearly 20 per cent by 2035, which corresponds to a 3.6°C increase in average global temperatures from pre-industrial times.[51] In order to provide a tangible alternative to the IEA's new baseline emissions scenario, a projection by the World Bank has also been examined below and is included in the analysis in Section 4.2.

Energy demand. On the demand side, the IEA baseline scenario predicts an 80 per cent increase in Brazil's primary demand from 2011 by 2035 (2.5 per cent/year, on average). Growth in demand is faster than in China, Russia, and South Africa. Electricity demand is expected to double, with an average annual growth rate of nearly 3 per cent. Over this period, the GDP, driven by the growing middle class, is expected to grow by 3.7 per cent/year and the population by 0.7 per cent/year. With regard to final demand per end-use sector, the IEA predicts that the current shares will be maintained: industry at 38 per cent, transport 34 per cent, and buildings 15 per cent in 2035. Demand growth in transport will slow down in comparison to the past, while that in buildings increases.

Regarding clean energy, the IEA expects Brazil's total renewables demand to double by 2035, with increases in all main sectors.[52] However, given the similarly rapid growth in demand for fossil fuels, renewables are not expected to increase their relative share of primary demand, at 43 per cent in 2035, and their share in electricity generation will drop to 80 per cent (compared to 87 in 2011). Whilst hydropower capacity keeps expanding, its share in the energy mix declines (from 14 to 12 per cent), but the shares of bioenergy (from approximately 27 to 30 per cent) and wind and solar (up to 2 per cent) increase, as does that of natural gas (see below). Altogether, the consumption of non-hydro renewables is projected to rise by nearly 90 per cent, backed by the increasing competitiveness of many renewable sources. Nuclear energy is expected to maintain its share in electricity production. In a positive development, the use of traditional biomass for cooking is projected to drop significantly, from 20 to 2 per cent over the next two decades.

Natural gas demand (from 27 bcm to 90 bcm, growing by 5.2 per cent/year) will be driven by expanding domestic production, and the fuel is expected to rise to occupy 16 per cent (from 9 per cent) of total primary demand over the period. The good news is that the share of oil is expected to decline to a third (from 41 per cent), owing to substitution by gas in industry and biofuels in transport. Coal is projected to retain its current share (5 per cent), with relatively low demand growth (1.9 per cent/year), curbed by the availability and competitiveness of natural gas and renewables.

In the IEA's electricity demand scenarios to 2035, total demand increases from 471 TWh (2011) to 834–939 TWh (2.4 to 2.9 per cent per year, on average), depending on whether more or less sustainable energy policy choices are taken.[53] In the New Policies Scenario, energy end-use in buildings drives demand growth (through increasing use of appliances and, in particular, air

[50] In terms of global trends, the scenario assumes that: global energy demand will grow by 33 per cent between 2011 and 2035, demand for oil (which maintains its status as the top energy source) will increase by 17 per cent, and demand for renewable energy (starting from significantly lower levels) will grow by 80 per cent.
[51] The UN climate convention has defined a rise in temperature of 2°C as the limit of dangerous climate change.
[52] In different scenarios, renewable energy demand is expected to grow from 116 Mtoe in 2011, to 204–225 Mtoe by 2035.
[53] High end: Current Policies Scenario. Low end: 450 Scenario, increases the chances to avoid dangerous climate change.

conditioning), and the share of electricity of total final consumption rises from 18 to 20 per cent. Despite capacity expansions, the share of hydropower in power generation is expected to fall significantly, from 81 per cent in 2011 to 62 per cent in 2035, owing to a decline in relative storage capacity of water in the system. This capacity will be largely replaced by natural gas (from 5 to 15 per cent) and wind and solar (from less than 1 to 9 per cent). Despite growing generation rates, the shares of biomass and coal in electricity will remain relatively constant (from 6 to 8 per cent and 2 per cent, respectively).

In the industry sector, the shares of biofuels and oil are expected to fall while that of natural gas increases from 12 to 20 per cent in 2011–35. In the transport sector, the IEA sees Brazil's biofuel consumption more than tripling (to 0.8 million boe/d) to meet nearly a third of domestic transport fuel demand in 2035 (up from 19 per cent in 2011). This would to lead to a levelling, followed by a slight decline, of gasoline use in passenger vehicles over the next decades. Demand for conventional diesel will keep growing, given the predominance of road transport in freight and low production rates of biodiesel.

Energy supply. As a key domestic supply side trend in the IEA's outlook, Brazil is expected to become a net oil and natural gas exporter by 2035, mainly through the exploitation of its pre-salt reserves. Oil production is expected to triple over the next two decades to 6 million bbl/d, of which 2.6 million bbl/d will be exported.[54] Together with new refinery capacity, this should enable Brazil to cover all domestic oil product needs. Natural gas production, albeit at smaller volumes, is projected to increase five-fold (from 18 bcm in 2012 to over 90 bcm in 2035, equal to a 7 per cent growth/year) and fully cover the growing domestic demand by 2035. The IEA notes, however, that production increases remain dependent on high levels of upstream investment (mainly by Petrobras), the quantity of natural gas reinjected in oil reservoirs, and the development of Brazil's onshore reserves (which include important shale gas deposits), as well as the recent local content requirements.

Brazil's biofuel production is expected to increase over three-fold, to 1 million boe/d in 2035, of which 80 per cent will be sugarcane ethanol. The IEA expects sugarcane production (both for ethanol and sugarcane) in 2035 to occupy 'only' 16 million ha and estimates that this level of expansion would not involve environmentally sensitive areas at that point. The agency predicts that an additional 20 million ha will be used for soybean production destined for biodiesel by the same year.

Another area where supply needs to be considerably expanded to meet demand is the power sector. The IEA predicts a need for 6 GW of new capacity each year until 2035, to achieve a figure that is more than twice Brazil's current capacity: from 118 GW in 2012 to 260 GW in 2035. Half of the capacity increase is expected to come from hydropower (nearly 70 GW, of which 7 GW would be small-scale), and over a fifth from natural gas and wind each (30 GW each). Even so, over 90 per cent of Brazil's wind energy potential would remain unexploited. Notably, a large majority of added capacity in wind generation expected by 2020 has already been contracted. Bioenergy and solar PV capacities are also projected to expand, albeit more moderately, from 10 to 16 GW and nearly zero to 8 GW, respectively. As a result, in 2035, wind would surpass biomass as the second most important renewable electricity source in the country. Oil, coal, and nuclear each retain a minor share in electricity generation.

Energy efficiency. The IEA projects that only a 5 per cent (20 Mtoe) deviation from a business-as-usual scenario will be attributable to energy efficiency by 2035. However, it calculates that additional energy efficiency measures[55] that are more ambitious than those in Brazil's national energy efficiency plan (see Section 3.2) could reduce final energy demand by as much as a further 11 per cent (42 Mtoe) of final demand in 2035 compared to the IEA's baseline scenario. These measures would include: building codes for new buildings, performance standards for major appliances, use of best available technologies and efficiency improvements in industry, and vehicle fuel economy standards and labelling. This would remove the equivalent of the annual production of the massive Itaipu

[54] This would be equal to one third of total global supply growth through 2035 (IEA 2013c).
[55] Implemented with already existing measures and technologies.

hydropower plant. It would also release oil for potential exports and result in lower greenhouse gas emissions.

In the transport sector, the IEA also expects new vehicle fuel efficiency standards to partially mitigate energy demand growth. The IEA's baseline scenario predicts the share of freight transport by road to decrease to from 60 to 45 per cent by 2025, which would be equal to 8 Mtoe of energy saved that year. In its optimistic scenario, the largest savings come from the transport sector, through fuel efficiency and shifting towards railroads and waterways in freight transport. The IEA projects strong electricity demand growth in buildings (3.3 per cent/year), which translates into a need to pay increasing attention to related efficiency and energy saving measures, such as appliance standards. Industrial electricity demand will grow slightly more moderately (at 2.5 per cent/year) owing to higher electricity and natural gas prices. In the industry sector, the IEA predicts that energy efficiency improvements and a shift towards less energy intensive industries will enhance energy intensity performance (consumption/output) over the next decades. In the energy efficient scenario, the additional investments required would be compensated nearly 10-fold over the next two decades, by savings in energy costs.

In the baseline scenario, the IEA expects Brazil's energy consumption per capita to rise from below to above the global average by 2035. Electricity consumption per capita, driven by rising living standards, universal access to electricity (reached in the coming years), and industrial expansion, is similarly expected to rise above the global average, to 4,150 kWh.

Greenhouse gas emissions. The IEA's baseline scenario which, as pointed out above, would take the world to 3.6°C of global warming, projects an increase by two-thirds of Brazil's energy-related CO_2 emissions over the period 2011–35, to 700 $MtCO_2$, with oil (in transport) contributing 50 per cent and natural gas (in industry and electricity generation) 40 per cent of the increase. Notwithstanding this, the carbon intensity of Brazil's economy (tonne of CO_2/US$1,000 of GDP) is expected to remain low: half that of China and only slightly above that of the European Union. A similar trend is expected in the power sector, where the carbon intensity of generation increases slightly while remaining well below the global average. The same applies to per capita emissions. In 2035, Brazil is expected to produce 4 per cent of global GDP and less than 2 per cent of energy-related CO_2 emissions. In the IEA's energy efficient scenario (see above) CO_2 emissions from energy in 2035 are estimated to be 13 per cent lower (at 610 $MtCO_2$) than the baseline scenario.

Working with a different methodology, a World Bank study from 2010 reaches a number of important conclusions on available mitigation potential in Brazil (ESMAP 2010). Set in between the IEA's baseline scenario and the Brazilian government's national energy plan PNE 2030 (which projects emissions standing at 770 $MtCO_2e$ in 2030[56]), the study's baseline scenario expects Brazil's energy-related emissions to nearly double between 2010 and 2030, reaching 735 $MtCO_2e$. In a low-carbon scenario, however, emissions would only reach 480 CO_2e per year in 2030. The largest deviations would come from energy efficiency and fuel switching demand side measures in industry – most importantly due to a switch to sustainable charcoal (around 20 per cent of the total deviation) and oven heat recovery (6 per cent) – and from supply side measures in the power generation and oil and gas sectors – gas-to-liquids production and efficiency measures in refining (8 per cent), and biomass and wind power generation (6 per cent). The transport sector is estimated to contribute to the deviation from the baseline scenario by 37 per cent. The largest reductions in this sector would come as a result of accelerated switching into ethanol in light-duty vehicles (6 per cent of the total deviation), followed by smaller reductions from shifting towards bus and metro transit in urban transport, and away from roads and airplanes in regional transport.[57] The World Bank calculates the

[56] The PNE's consumption estimates are more modest than those of the PDE but are higher than those of the IEA: its reference scenario projects total energy demand at 289 Mtoe in 2020 and 403 Mtoe in 2030. In this scenario, the PNE expects Brazil's CO_2 emissions to rise to 771 Mt in 2030. Perhaps the major difference from the two projections examined in this study is that the PNE projects a slightly higher share for renewables in Brazil's total energy supply, at 47 per cent in 2030. (EPE 2007.)

[57] The World Bank notes that the biofuel expansion projected in its low-carbon scenario is contingent on the establishment of a financial mechanism to maintain end-user prices at attractive levels.

additional cost of implementing this low-carbon scenario at around US$11bn per year throughout the two-decade period (excluding land use change and waste sectors). The additional financing for this low-carbon transition would be drawn from both public (electricity) and private (transport) sources. For comparison, the World Bank notes that loans disbursed by the BNDES in 2008 amounted to US$42bn while foreign direct investment in the same year totalled US$30bn.

Annex 4: Brazil's energy and emissions overview

Economy and demographics		
Average annual GDP growth 2000–11	3.6	%
Population growth (2012)	0.9	%
Resources/capacity		
Fossil fuels		
Proven/recoverable conventional oil reserves/resources (2012)	15.3/106	bn bbl
Proven/recoverable conventional natural gas reserves/resources (2012)	0.5/12.2	tcm
Total fossil fuel electricity generation capacity (2013)	20	GW
Clean energy		
Land area used for sugarcane harvest (2012)	8.5	m ha
Land area suitable for sugarcane production	65	m ha
Installed hydropower capacity (without and with small-scale hydro, 2013)	84/88	GW
Total exploitable hydropower potential	261	GW
Installed wind power generation capacity (2013)	4	GW
Estimated wind energy potential	350	GW
Installed biomass power generation capacity (2013)	9	GW
Nuclear energy capacity (2014)	2	GW
Total clean energy (renewables + nuclear) electricity capacity (2013)	103	GW
Energy use		
Energy supply (TPES, 2011)	270	Mtoe
Share of energy supply of global energy supply (TPES, 2011)	2.1	%
Share of renewable energy in energy supply (/TPES, 2011)	43	%
Global average share of renewable energy in energy use (/TPES, 2011)	13	%
Total final energy consumption (2011/2013)	218/251	Mtoe
Consumption of fossil fuels, excluding electricity (2011/2013)	121/134	Mtoe
Consumption of bioenergy, excluding electricity (2011/2013)	57/65	Mtoe
Final electricity consumption (2011/2013)	480/520	TWh
Share of electricity of total final consumption of energy (2011/2013)	18	%
Share of renewable energy of electricity generated (2011)	87	%
Global average share of renewable energy of electricity generated (2011)	20	%
Average annual energy consumption growth (2000–11, CAGR)	3.2	%
Average annual electricity generation growth (2000–11, CAGR)	3.9	%
Transmission and distribution losses in electricity (2013)	17.3	%
Electricity consumption per capita (2011)	2,441	kWh
Energy intensity (2011)	0.13	
Global average energy intensity (2011)	0.19	
Greenhouse gas emissions		
Energy-related greenhouse gas emissions (2012)	437	$MtCO_2e$
Average annual growth of energy-related GHG emissions (2000–11, CAGR)	3.1	%
Per capita energy-related GHG emissions (excl. LUCF, 2010)	5.96	tCO_2e
Per capita energy-related GHG emissions global average (excl. LUCF, 2010)	6.47	tCO_2e
Carbon intensity (energy intensity of economy/CO_2 intensity of energy mix, 2011)	0.36	
Global average carbon intensity (2011)	0.60	

Sources: IEA 2013a; 2013b; 2013c; EPE 2013a; 2013c; OC 2013a; World Bank 2013; WRI 2013a.
Note: Possible inconsistencies are due to the different methodologies used by each source.
Hydropower capacity includes around 6 GW from the Paraguayan share of the Itaipu plant.

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