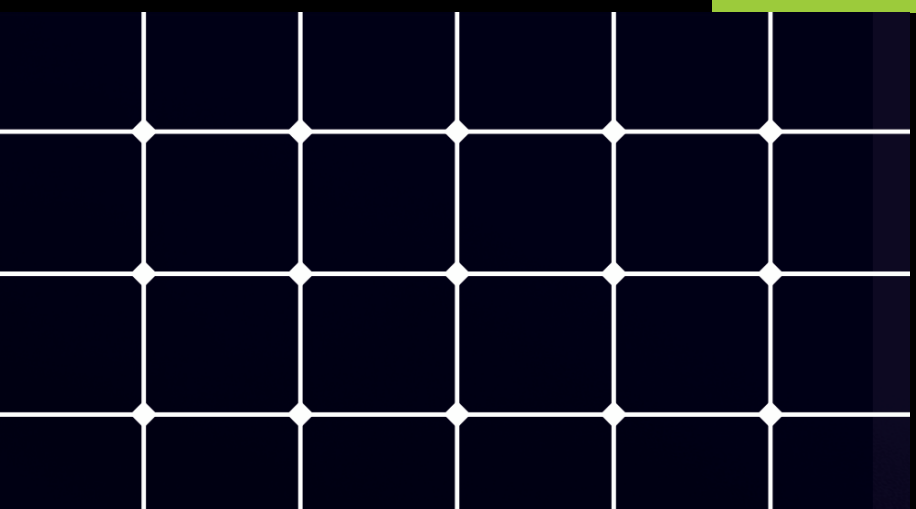
# E[R]

This is a translated summary of the original Energy [R]evolution report published in Portuguese in August 2016. For the complete version, including Methodology and Data Tables Annex, please consult the original version at www.greenpeace.org.br/revolucao

# Energy [R]evolution

For a Brazil with 100% clean and renewable energy



Brazilian scenario **2016**

GREENPEACE

# Executive Summary

In 2050 Brazil could have a 100% renewable energy mix, while creating new jobs, improving air quality and the lives of millions of people and helping to limit global temperature rise. To show that this is possible, the Energy [R]evolution 2016 proposes a path toward a new energy generation and consumption model that would meet the energy needs of Brazil in the coming decades in a cleaner and more just manner.

This future represents a step forward for the country's infrastructure, which would have a more diversified energy mix, and more autonomy for the urban population, who would generate their own energy and benefit from improved mobility in cities. At the same time, this future would ensure for traditional communities and indigenous people respect for their rights as the current hydroelectric plants proposed for the Amazon would not be built.

The Brazilian economy and society would benefit directly, since the Energy [R]evolution would provide 618,000 jobs in 2030 related only to electricity generation and the use of solar and ambient heat throughout the country. Prices for electricity would fall, with savings of around R$ 45 billion (or US$ 19.3 billion) per year in 2050. The outcome would be a lower electricity bill and the possibility of generating one's own electricity.

In recent years, Brazilians have experienced an average increase of 72% in their electricity bills[1]. Part of this increase is due to the fact that the country's model for electricity generation is based mainly on the use of hydroelectric and fossil fuel thermoelectric plants. Recently, hydroelectric plant reservoirs experienced low water levels due to a period of drought, which led to constant use of fossil fuel-fired power plants. This meant citizens had to foot the bill, as thermoelectric plants are more expensive. The Energy [R]evolution proposes a solution to this and other problems in Brazil.

This report is a global benchmark for the energy sector. Dozens of editions in other countries and five global editions have been published. The most recent global edition, released in September 2015, showed how the world could achieve 100% renewable energy and phase out the use of all fossil fuels by embarking on an energy transition. Along the same lines, the fourth edition of the Brazilian report shows how the country could transform its entire energy mix.

Since the first Brazilian edition, in 2007, the report has evolved. In 2016, the Energy [R]evolution presents energy scenarios for all sectors, including industry and transportation. And innovates by showing how the country can achieve a 100% renewable energy mix—in addition to showing in detail how a system based only on these sources would operate.

A group of specialists assisted Greenpeace Brazil in assembling this report. The general development of the scenarios was carried out by the systems analysis team at the Institute of Thermodynamic Engineering at the German Aerospace Center (DLR) in Germany—a worldwide benchmark for energy scenarios. The team at DLR worked in conjunction with a team from the Energy Planning Program at the Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (Coppe) of the Federal University of Rio de Janeiro (UFRJ).

The report was also based on a series of studies carried out in partnership with Brazilian institutions that are well recognized in their respective fields of research. The scenarios for the transport sector were developed by the Freight Transport Laboratory at Coppe/UFRJ. Scenarios for energy efficiency and energy transition for industry and other sectors were developed by a team from the International Energy Initiative (IEI) and the Graduate Program for Energy Systems Planning at the State University of Campinas (Unicamp). Finally, the structure for the Base scenario for energy and electricity was developed by Greenpeace Brazil.

1 Data refer to average rates for electricity with taxes for the residential sector between April 2013 and December 2015. ANEEL - Brazilian Electricity Regulatory Agency (2016). Relatórios de Consumo e Receita de Distribuição. Consumidores, Consumo, Receita e Tarifa Média – Região, Empresa e Classe de Consumo. Available at: bit.ly/1SZ4

## RESULTS OF THE ENERGY [R]EVOLUTION

The Energy [R]evolution 2016 presents and compares two scenarios for the Brazilian energy mix in 2050. The Base scenario reflects a continuation of government policies and current trends for the energy sector. While the Energy [R]evolution scenario is a projection developed by Greenpeace Brazil, which analyzes the country's renewable energy potential to achieve a mix that is 100% clean with zero greenhouse gas emissions.

According to the report, Brazilian energy consumption will reach 6,849 petajoules (PJ) in 2050 (or 163.59 million tonnes of oil equivalent). This is 47% less than predicted in the Base scenario, due to significant potential gains in energy efficiency. The energy transition proposed by Greenpeace Brazil also depends on greater use of renewable electricity to replace technologies that still burn fossil fuel today, primarily in the transportation sector. Among the main results of the Energy [R]evolution scenario are:

**Use of 100% renewable sources throughout the energy mix in 2050:** fossil fuels can be gradually eliminated between now and 2050. For electricity generation, it would be possible to stop using coal in 2030 and oil in 2040. Natural gas could still be used as a transition fuel and then discarded mid-century. The expansion of wind and solar energy (photovoltaic and concentrated solar power) is of special importance: they would achieve a share of 46% of electricity generation, which is more than double that forecast in the Base scenario. The installed capacity for renewable energy would rise from the current 106 gigawatt (GW) to 349 GW in 2050. Primarily in transportation and industrial sectors, eliminating the use of fossil fuels would also occur gradually, with a transition toward greater use of electricity and biofuels.

**Increase in energy efficiency:** replacing obsolete technology with more efficient options and changes in use patterns would result in gains of 47% in energy efficiency by 2050. Examples of possible measures include greater use of electricity in transportation, the use of solar heat and more efficient engines in industry, as well as improved climate control and lighting systems in buildings. Starting in 2020, the scenario proposed by Greenpeace Brazil would already be more efficient than the Base scenario. In 2050, energy efficiency for transportation and industry would reach 61% and 40%, respectively. In other sectors (residential, commercial, public and rural), efficiency would reach 38%.

**Electrification of the energy mix:** the Energy [R]evolution scenario forecasts an increase in demand for electricity in every sector as a result of the substitution of fossil fuels. In transportation and industry, the share of electricity would rise to 25% and 37% of consumption, respectively. As a result, annual demand for electricity in Brazil would rise from the current 500 terawatt-hours (TWh) to 864 TWh in 2050 –around 6% below the Base scenario. Using more electricity based on renewable sources is one of the measures that would allow the country to achieve high levels of energy efficiency and save resources, enabling the phasing out of fossil fuels and, consequently, the end of greenhouse gas emissions in the energy sector.

**Diversification and decentralization:** electricity generation in the Energy [R]evolution scenario would be more diversified and decentralized. There would still be a small increase in the number of hydroelectric plants found today, but no new projects would be necessary in the Amazon region. In 2050, hydroelectric energy would represent 45% of generation, while wind energy would rise to 25% and solar (photovoltaic and concentrated solar power) would jump to 21%. Biomass would remain at 7% of generation, and other sources, like ocean and hydrogen power, would be responsible for 2%. In addition, the current approach to electricity production would change, since a large number of consumers would begin to generate their own energy with photovoltaic panels in their homes, shops and companies and send electricity back to the grid.

**Revolution in the transport sector:** a decrease in total energy consumption in this sector could be as high as 61% in relation to the Base scenario. For this to happen, certain measures would be necessary: broader adoption of electric motors, a transition from highway freight transport to railway, improved logistics efficiency and prioritization of public as well as non-motorized transportation in urban areas. Technologies that enable the use of electricity as a source of energy will be fundamental to eliminating the use of fossil fuels. In addition, biofuels will play an important role where the use of electricity is not well suited—like in planes and certain vehicles. In the Energy [R]evolution, electricity will be responsible for 25% of total transport sector energy consumption, as compared to 1% in the Base scenario. Biofuels, whose share today is 19%, would reach 74% in 2050.

**Cheaper electricity:** eliminating the use of fossil fuels would result in significant cost savings. In 2050, the total cost of electricity supply in the Energy [R]evolution would be R$ 209 billion (US$ 89 billion) per year as compared to R$ 254 billion (US$ 108 billion) in the Base scenario. This annual savings of R$ 45 billion (US$ 19 billion) would benefit the country and consumers enormously.

**Many jobs:** among the many benefits that the Energy [R]evolution would bring to the country is a large number of jobs. In 2030, it is estimated that there will be 618,000 jobs associated with electricity generation and solar and ambient heat alone. In addition, in the scenario proposed by Greenpeace Brazil, in 2030 there would be 61 jobs for each PJ of primary energy consumed for electricity generation. In the Base scenario there would be only 57 jobs per each PJ. In the construction, manufacture, maintenance and operation of power plants, the Energy [R]evolution scenario forecasts 1,247 jobs for each installed GW in 2030, as compared to 1,093 in the Base scenario. A difference of 12%.

With undeniable social, environmental and economic gains, it is clear that the ingredient that is lacking to accelerate the energy transition for a renewable future is political will. This report by Greenpeace Brazil shows that this Energy [R]evolution is possible and overall results are shown in the next chapter. A detailed analysis about the paths for putting it into practice, as well as a complete set of data tables and methodology are available in the original Portuguese version available at www.greenpeace.org.br/revolucao[2].

**2**
Alternatively, the full original report is available at (http://bitly/2cpoVtG).

# Results

Next we present the results of the two scenarios developed for this report: (i) Base scenario, which follows the trends signaled by the Brazilian government for the energy sector for the coming decades; (ii) and the Energy [R]evolution (E[R]), which presents a roadmap for a different energy mix in 2050, one that is more efficient, 100% renewable and free of greenhouse gas emissions.

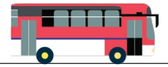
## ENERGY DEMAND BY SECTOR

In 2014, energy consumption in Brazil reached 9,027 PJ[3], of which 41% was consumed by industry. The Base scenario forecasts that demand for energy will increase by 43% to 12,904 PJ by 2050. While in the Energy [R]evolution scenario, with the phasing out of fossil fuels and gains in energy efficiency, demand would be 6,849 PJ in 2050. This is 47% less than the Base scenario and 24% less than current levels.

**3**
The final energy consumption does not include the consumption for non-energy use and consumption of the energy sector

→ **Energy demand by sector (PJ/year)**

How our energy mix will change by the year 2050 if we follow the current trend or if we follow the Greenpeace Brazil proposal.





## TRANSPORT

The transport sector has the greatest potential for efficiency gains in the Energy [R]evolution scenario. In 2050, energy consumption would fall by 61% in relation to the Base scenario. This is possible mainly due to modal shift – taking freight off the roads and transferring it to railways, for instance – and by the greater use of electricity.

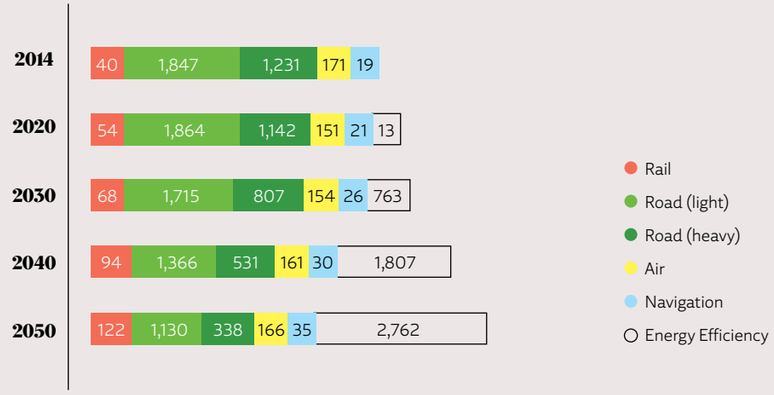
**→ Energy demand in the transport sector by type and mode (PJ/year)**

| | | 2 014 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| **Type** | | | | | | |
| Freight | Base | 1,287 | 1,311 | 1,396 | 1,567 | 1,770 |
| | E[R] | 1,287 | 1,290 | 1,097 | 674 | 420 |
| Passenger | Base | 2,021 | 1,934 | 2,137 | 2,423 | 2,784 |
| | E[R] | 2,021 | 1,942 | 1,673 | 1,509 | 1,372 |
| **Mode** | | | | | | |
| Rail | Base | 40 | 48 | 58 | 73 | 90 |
| | E[R] | 40 | 54 | 68 | 94 | 122 |
| Road | Base | 3,078 | 3,009 | 3,262 | 3,671 | 4,177 |
| | E[R] | 3,078 | 3,007 | 2,523 | 1,898 | 1,468 |
| Air | Base | 171 | 167 | 189 | 216 | 248 |
| | E[R] | 171 | 151 | 154 | 161 | 166 |
| Water | Base | 19 | 20 | 24 | 31 | 39 |
| | E[R] | 19 | 21 | 26 | 30 | 35 |
| **Total** | Base | 3,308 | 3,244 | 3,533 | 3,990 | 4,554 |
| | E[R] | 3,308 | 3,232 | 2,770 | 2,183 | 1,792 |

In the two scenarios analyzed, the demand for passenger and freight transport service is the same[4]. In the Energy [R]evolution scenario, however, the demand for road transport is reduced by improving logistic efficiency of freight transport and also migrating from motorized to non-motorized modes of passenger transportation.

**→ Energy demand and energy efficiency in the transport sector in the E[R] scenario (PJ/year)**

With energy efficiency measures it would be possible to reduce energy consumption in the transport sector by 61% by midcentury.




**→ Modal shares in freight transport**

| | | 2014 | 2020 | 2030 | 2050 |
|---|---|---|---|---|---|
| Pipeline | Base | 3% | 3% | 2% | 2% |
| | E[R] | 3% | 3% | 2% | 2% |
| Air | Base | 0.10% | 0.12% | 0.14% | 0.20% |
| | E[R] | 0.10% | 0.09% | 0.10% | 0.11% |
| Water | Base | 17% | 17% | 18% | 20% |
| | E[R] | 17% | 19% | 20% | 23% |
| Rail | Base | 25% | 26% | 27% | 31% |
| | E[R] | 25% | 26% | 31% | 46% |
| Road | Base | 55% | 54% | 52% | 47% |
| | E[R] | 55% | 52% | 46% | 28% |
| **Reduction in transport demand due to logistic efficiency** | **E[R]** | **0%** | **2%** | **4%** | **6%** |

4 Transport demand is given in tonnes/km for freight and in passenger/km for passengers.

5
Demanda de transportes, dada por tonelada/km para o transporte de cargas, e por passageiro/km para o transporte de passageiros.

→ **Modal shares in passenger transport**

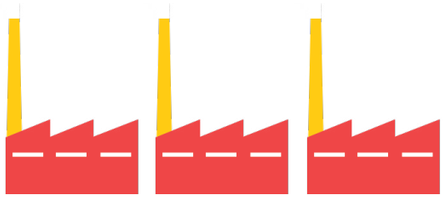
| | | 2014 | 2020 | 2030 | 2050 |
|---|---|---|---|---|---|
| Air | Base | 6% | 7% | 7% | 7% |
| | E[R] | 6% | 6% | 7% | 7% |
| Water | Base | 0.06% | 0.06% | 0.08% | 0.10% |
| | E[R] | 0.06% | 0.07% | 0.08% | 0.11% |
| Rail | Base | 3% | 4% | 4% | 4% |
| | E[R] | 3% | 5% | 7% | 13% |
| Road | Base | 91% | 90% | 90% | 89% |
| | E[R] | 91% | 88% | 86% | 79% |
| **Reduction in transport demand due to the use of non-motorized modes** | **E[R]** | **0%** | **1%** | **3%** | **6%** |

In relation to freight, logistical efficiency measures, like trip optimization, would enable a 6% reduction in transport demand in 2050[5]. In addition, with modal shifts, from road to rail, and improved energy efficiency, the energy consumption for freight transport would be 76% lower (460 PJ) in the Energy [R]evolution scenario.

For passenger transport, the Energy [R]evolution would halve the total consumption of energy compared to the Base scenario in 2050. To do so, measures would be necessary to improve urban mobility, enabling prioritization of public transportation and incentives for non-motorized transport. An increase in the use of bicycles or walking would reduce demand for passenger transport by 6%.

In 2050, road transport would still be important for passengers. That is why the adoption of electric motors would be essential for reducing overall energy consumption. In the Base scenario, following the trends of the Brazilian government, there would be 143 million vehicles (private cars, commercial vehicles, motorcycles, buses and trucks) in 2050, but only 0.2% with electric motors (around 275,000 automobiles and 53,000 buses). Another 0.3% would be hybrid vehicles, which are powered by a combination of electricity and fuel. Approximately 30% of the vehicle fleet would continue to be powered by gasoline or diesel and the rest would use ethanol or have flex engines.

In the Energy [R]evolution scenario, electricity would be responsible for 25% of total energy consumption in the transport sector. This is significant growth given its share is practically zero today. The entire fleet of road vehicles would be smaller, with anol and biodiesel, 29%. Hydrogen would provide power for 28,000 urban buses.

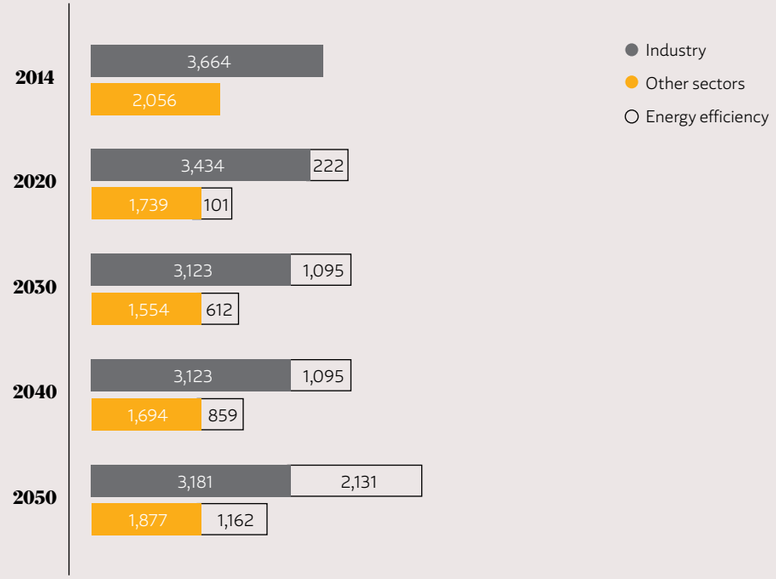


## INDUSTRY AND OTHER SECTORS

With regard to the industrial sector, the Energy [R]evolution scenario shows that it is possible to improve energy efficiency by 40%. In residential, public, commercial and rural sectors, energy efficiency would reach 38% in 2050.

→ **Energy demand and energy efficiency in the industrial sector and other sectors in the E[R] scenario (PJ/year)**

With energy efficiency measures it would be possible to reduce industrial consumption by 40% and in other sectors by 38% by midcentury.



According to the study developed by IEI and Unicamp[5] for the Energy [R]evolution report, the areas with the most potential for electricity conservation in the industry sector are lighting systems, engines and heating processes. And, in the case of thermal energy, it is the use of heating and process heating.

In the residential sector the main opportunity for conservation of electricity is found in lighting systems and for thermal energy in the heating of water and heating for food preparation. In other sectors, the main potential for conservation lies in the use of lighting, motive power (water pumping systems, for example), refrigeration, heating and process heat.

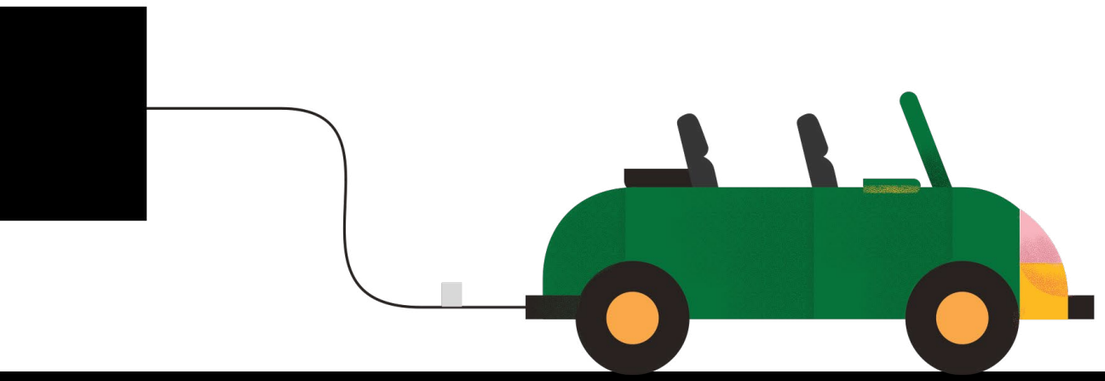
**5**
Jannuzzi, G. M. and Jantim, H. (2016). Revolução Energética 2016 - Eficiência Energética. Relatórios 1, 2 e 3. International Energy Initiative (IEI) and Programa de Pós-Graduação em Planejamento de Sistemas Energéticos da Universidade Estadual de Campinas (UNICAMP).

**→ Potential for electricity conservation (%)**

| | Industry | | Public | | Residential | | Commercial | | Rural | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Average Potential | 24 | 37 | 23 | 36 | 27 | 36 | 24 | 33 | 31 | 46 |
| Lightning | 14 | 47 | 15 | 35 | 35 | 50 | 32 | 35 | 29 | 34 |
| Refrigeration/Cooling | 10 | 20 | 35 | 31 | 30 | 35 | 14 | 31 | 15 | 35 |
| Heat Processes | 7 | 11 | - | - | 25 | 38 | - | - | 25 | 38 |
| Motive Power | 30 | 43 | 32 | 47 | 32 | 46 | 32 | 45 | 34 | 48 |
| Direct Heating | 11 | 22 | 15 | 23 | 15 | 23 | 15 | 23 | 15 | 25 |
| Electrochemical | 5 | 7 | - | - | - | - | - | - | - | - |

**→ Potential for thermal energy conservation (%)**

| | Industry | | Public | | Residential | | Commercial | | Rural | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Average Potential | 28 | 43 | 7 | 18 | 25 | 30 | 35 | 45 | 35 | 47 |

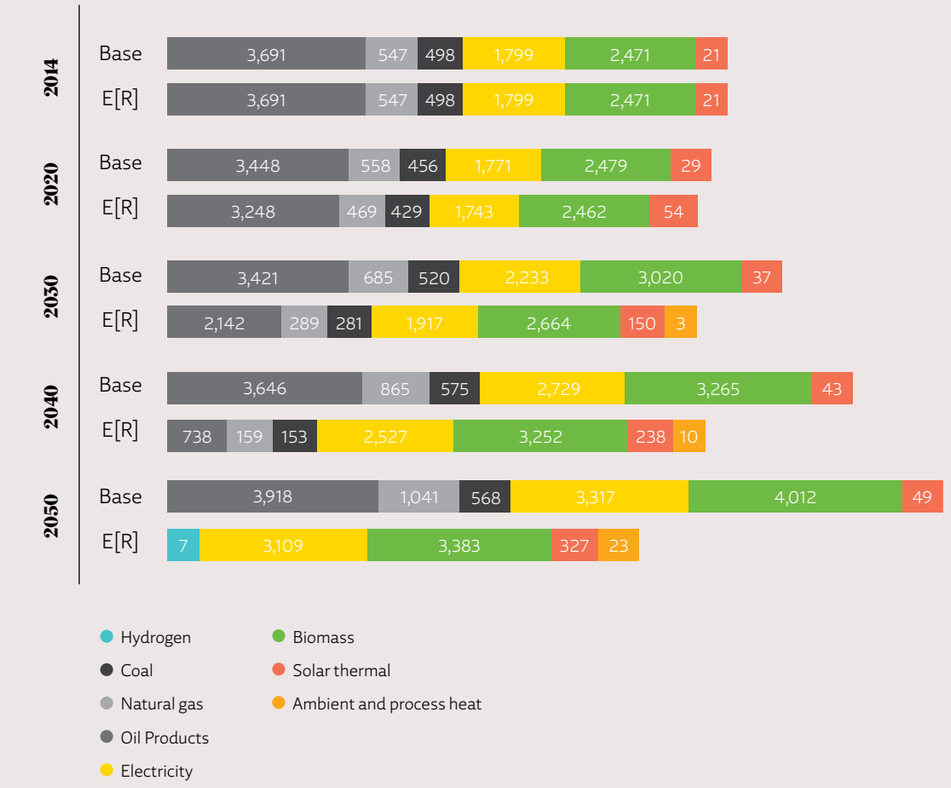


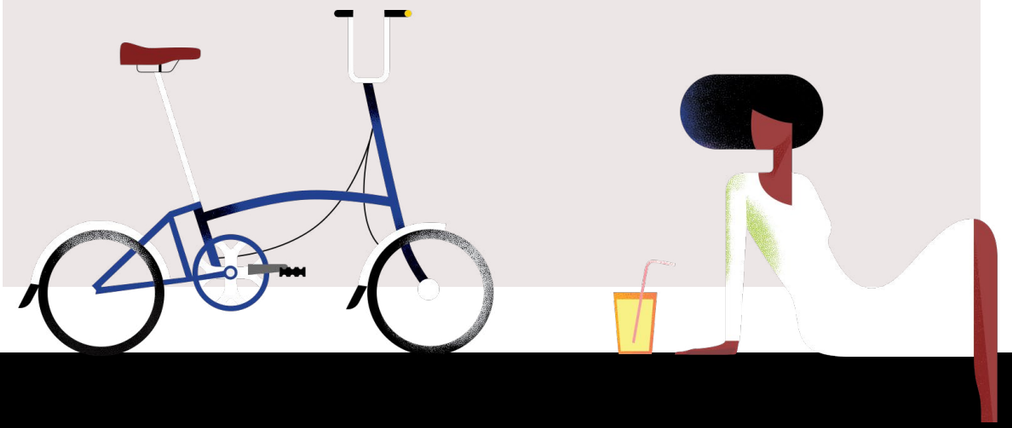
## ENERGY DEMAND BY SOURCE

The energy demand in Brazil in 2050 would be 47% lower in the Energy [R]evolution scenario. The energy sources in E[R] are also different.

**→ Energy demand by source (PJ/year)**

Consumption of different energy sources in Brazil up to 2050.



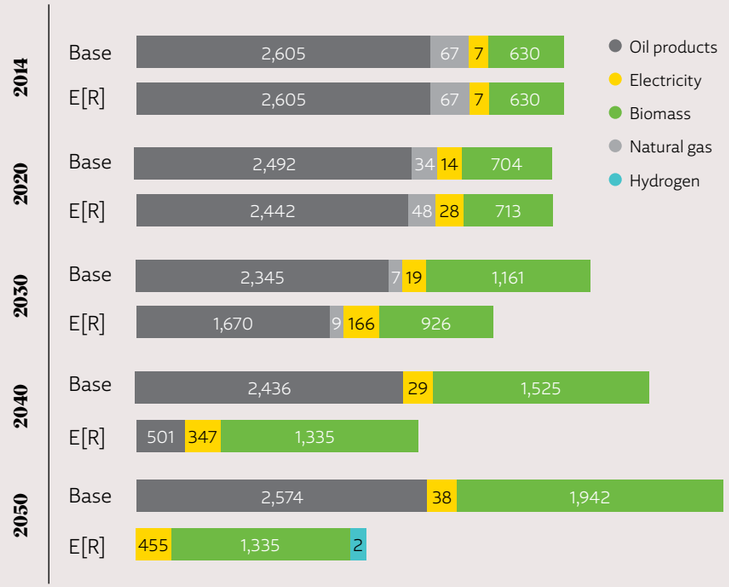
In the Base scenario, fossil fuels still make up a large share. Today, they represent 58% of total energy consumption and in 2050 would continue to supply 47% of the total. This small reduction would be offset in part by the use of electricity, whose share would rise from the current 20% to 26% in 2050. To do so will depend on the expansion of fossil fuel thermoelectric plants, in addition to nuclear plants. The use of biomass would also rise slightly, achieving a share of 31% of total consumption.

On the other hand, in the Energy [R]evolution scenario we would arrive in 2050 with 100% renewable energy, with a large increase in the use of electricity—45% of total energy consumption. With regard to biomass, which today represents 27% of the energy consumption in Brazil, the source would represent 49% in 2050. Solar thermal energy, today marginally employed in other sectors (residential and commercial), would increase its share in the Greenpeace Brazil scenario, achieving 5% of overall energy consumption in 2050. And it would be employed to a greater extent in the industrial sector, rising to 4% of the consumption of this sector.

For the transport sector, whose current consumption is based 81% on fossil sources, the Base scenario provides for continued use of these fuels, although this figure would decrease to 57% in 2050. Part of this demand would be supplied by biomass. This source would rise from the current 19% to 43% by midcentury. The use of electricity for transportation in the Base scenario is marginal, achieving a share of only 1% in 2050. In the Energy [R]evolution scenario, the use of electricity, which would rise to 25% of total consumption for the sector, would be primarily used for road transportation, with 391 PJ (or 27% of the consumption of this mode). It would also be used in the rail mode, amounting to 64 PJ or 53%. Biofuels—ethanol and biodiesel —would also have an increased share in transport energy consumption (75%). The use of hydrogen in urban passenger buses, however, would be marginal (0.1%).

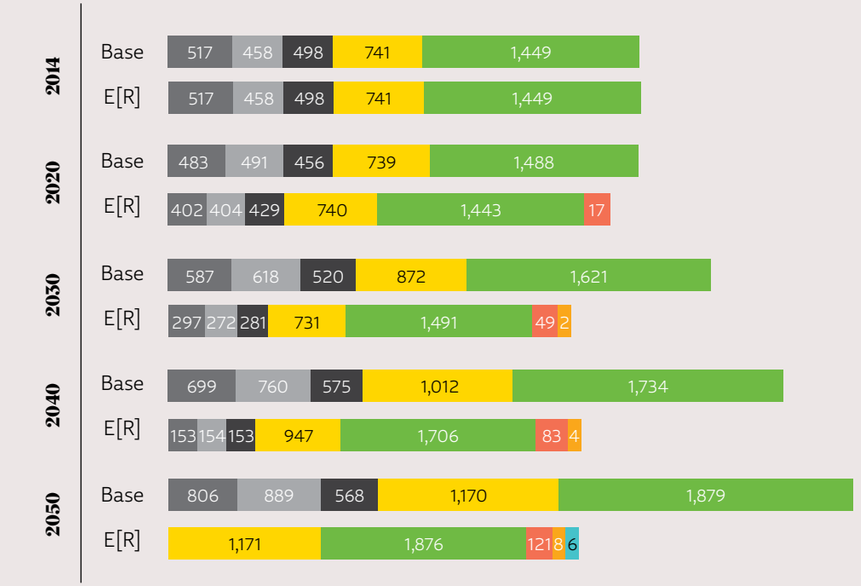
**→ Energy demand by source in transport sector (PJ/year)**

Energy consumption for the transport sector in both scenarios.




**→Energy demand by source in industry (PJ/year)**

Energy consumption in the industrial sector in both scenarios.t

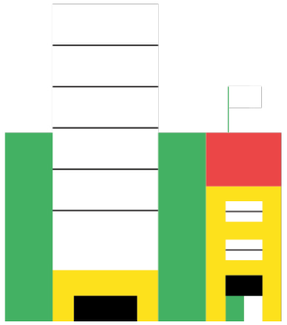



For industry, the Base scenario foresees continued use of fossil fuel, which is expected to remain in 46% in 2050. Electricity is expected to rise to 22% in 2050, only two percentage points above its current share. While biofuels are expected to top 35%.

The Energy[R]evolution foresees a very different industrial sector: fossil fuels would be replaced primarily by the use of biomass (59%), followed by renewable electricity (37%). Solar thermal energy would be responsible for 4%.

**→ Energy demand by source in other sectors (PJ/year)**

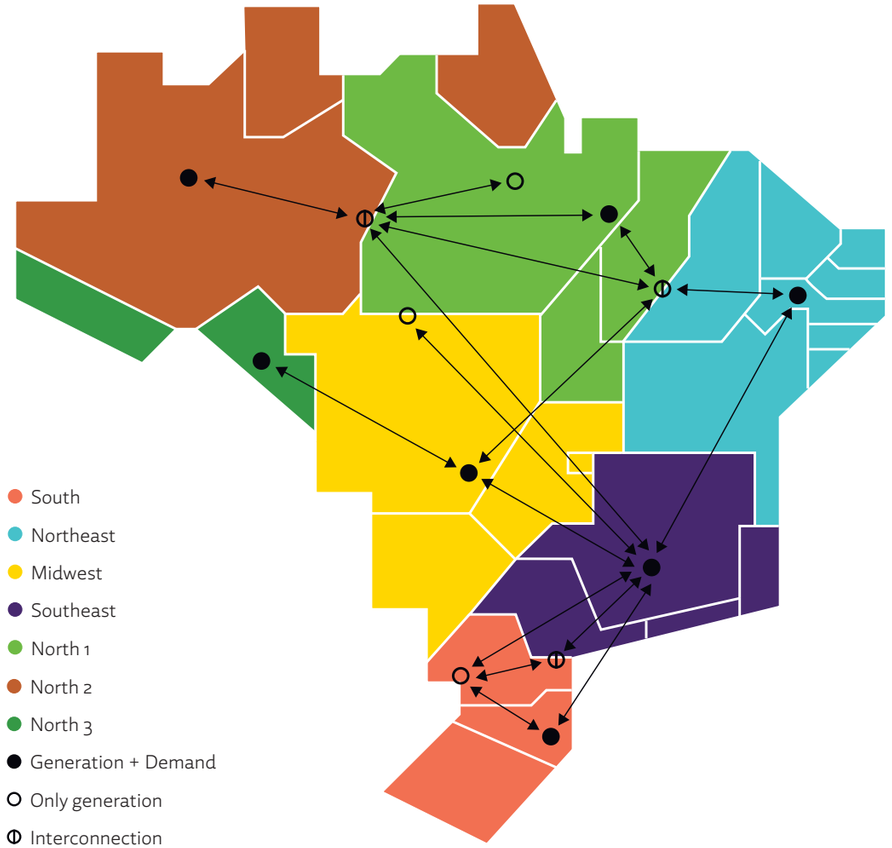
Energy consumption in the other sectors in both scenarios.

In the so-called "other sectors" (residential, commercial, public and rural), the Base scenario predicts that fossil fuels will continue to represent 34% of energy consumption in 2050, slightly below the current level of 42%. The share of electricity is expected rise from 51% to 69% in 2050. In the future of the Energy [R]evolution there will be no fossil fuels and energy demand for other sectors would be met primarily by electricity (79%). Solar thermal energy would play a more significant role (11%), complemented by biomass (9%) and marginal use of hydrogen (1%).

## ELECTRICITY

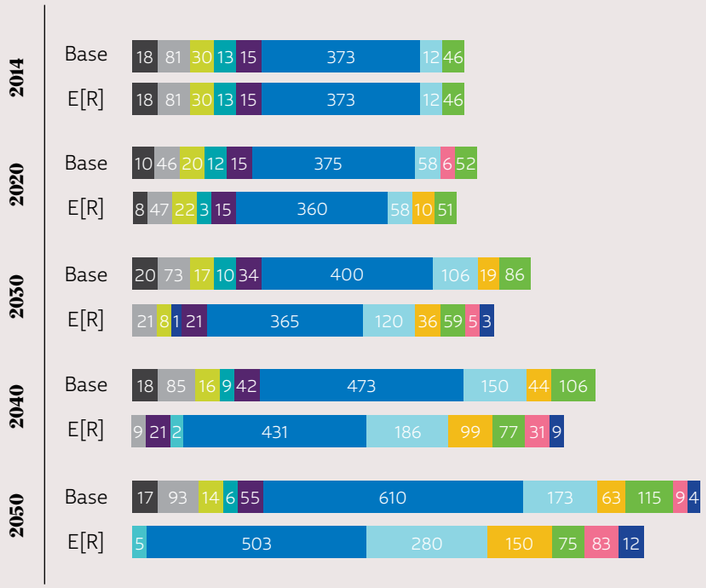
Currently, electricity consumption in Brazil is 500 TWh. In 2050, in the Base scenario this value is expected to rise to 921 TWh per year, 11% of which would come from fossil fuels. In the Energy [R]evolution, consumption would rise to 864 TWh a year, using only renewable sources with a significant share of solar and wind power. It is important to note that the difference in consumption between the two scenarios is small because in the Energy [R]evolution the electric power sector, although efficient, would replace part of the total energy demand for fossil fuels in sectors like transport and industry.




The operation of the 100% renewable electricity mix in 2050 was analyzed in spatial and temporal terms. Electricity load was examined for all regions and periods of time in order to simulate optimal supply. The model considered the availability of energy potential, transmission infrastructure and cost. A map with all regions is shown in the illustration.

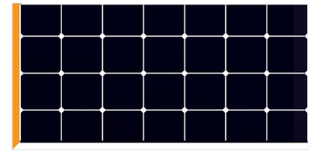
→ **Electricity generation by source (TWh/year)**

Electricity generation in Brazil up to 2050 in both scenarios.



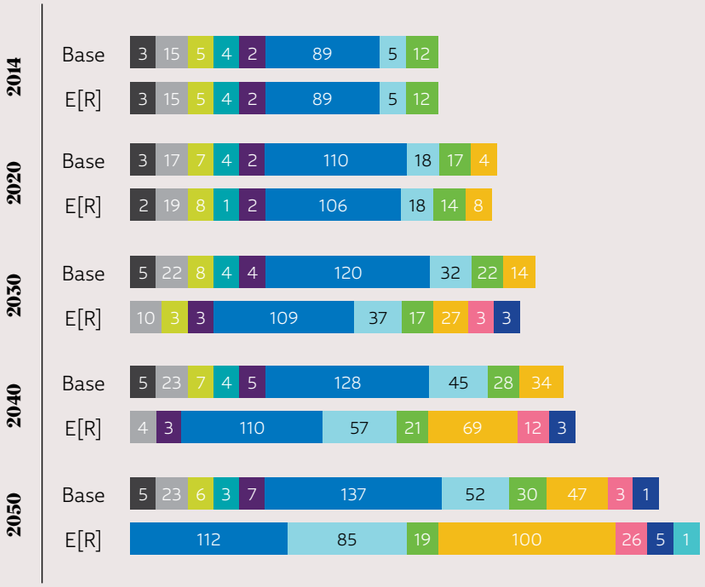

In the Energy [R]evolution scenario, solar and wind power plants would be responsible for 46% of the total electricity generation in Brazil. Concentrated solar power (CSP), which is currently not used in Brazil, and photovoltaic, which is still marginal, would rise to 6% and 14%, respectively, in 2050. Wind power would continue to rise from the current 2% to 25%.

In the Energy [R]evolution scenario, power plants in Brazil would total 349 GW of installed capacity, against 314 GW in the Base scenario, due to the characteristics of the plants that compose the generation system. This means adding 216 GW of capacity by 2050. Some of these new plants are already under construction.



→ **Installed capacity for electricity generation (GW)**

The mix of power plants is different for the two scenarios.



Concentrated solar power (CSP) plants would have 26 GW of installed capacity in 2050. In the Southeast region alone, due to its proximity to large centers of consumption, there would be around 25 GW. Other CSP plants would be located in the Northeast, where the potential for solar power is higher.

By combining large-scale plants and distributed photovoltaic systems on the roofs of Brazilians, we could achieve 100 GW of installed capacity of photovoltaic energy by midcentury. In this case, we would also have part of the installed capacity in the Southeast region (50%), followed by the Northeast (25%), but with some presence in other regions.

Wind power plants would provide 85 GW of installed capacity, with the Northeast region providing most of this capacity: 71 GW or 83%.

In 2014, Brazil already had hydroelectric plants with a total of 89 GW of installed capacity. By 2050, the Energy [R]evolution foresees 112 GW of installed capacity from this source. Around 20 GW would be from plants that are already under construction today. The Greenpeace Brazil scenario calculates that 3 GW would be added to the system from plants located in the Southern region. Unlike the plans of the government, calculations for this study show that there is no need for new hydroelectric plants in the Amazon region, which is a fragile biome and easily damaged by such projects.

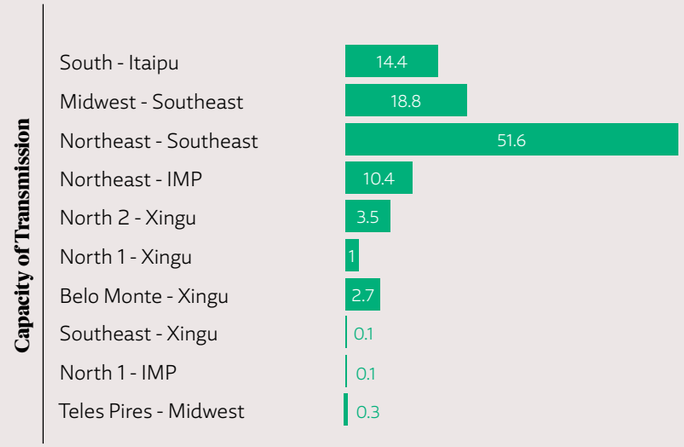
**→ Installed capacity by region in 2050 in the Energy [R]evolution scenario (GW)**

In the Energy [R]evolution scenario each region of the country would have this mix of plants operating in 2050.

| | Biomass | Hydrogen | Photovoltaic | Concentrated Solar Power | Wind | Ocean | Hydropower |
|---|---|---|---|---|---|---|---|
| South | 3.3 | 0.13 | 10.0 | 0.0 | 14.4 | 1.4 | 19.7 |
| Southeast | 10.6 | 0.44 | 50.0 | 25.0 | 0.0 | 1.2 | 7.2 |
| Midwest | 0.9 | 0.04 | 12.0 | 0.0 | 0.0 | 0.0 | 32.1 |
| Northeast | 2.7 | 0.11 | 25.0 | 0.0 | 71.1 | 0.9 | 11.0 |
| North 1 | 0.8 | 0.03 | 3.0 | 1.4 | 0.0 | 1.1 | 4.6 |
| North 2 | 0.5 | 0.02 | 0.0 | 0.0 | 0.0 | 0.0 | 10.5 |
| North 3 | 0.5 | 0.02 | 0.0 | 0.0 | 0.0 | 0.0 | 4.8 |
| Itaipu | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.4 |
| Belo Monte | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 11.2 |
| Teles Pires | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 |

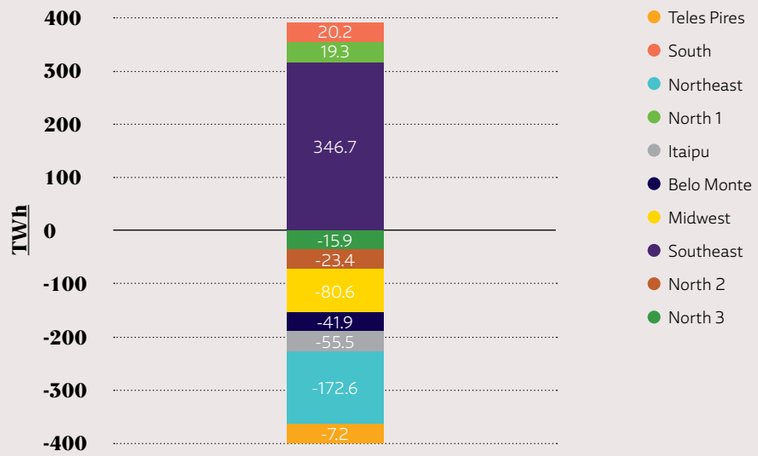
**→ Additional capacity of transmission lines in 2050 (GW)**

To ensure the flow of energy around Brazil, the transmission system will need to grow. Especially in the Northeast and Southeast regions, new transmission lines will be necessary to transport electricity coming from new wind power plants.

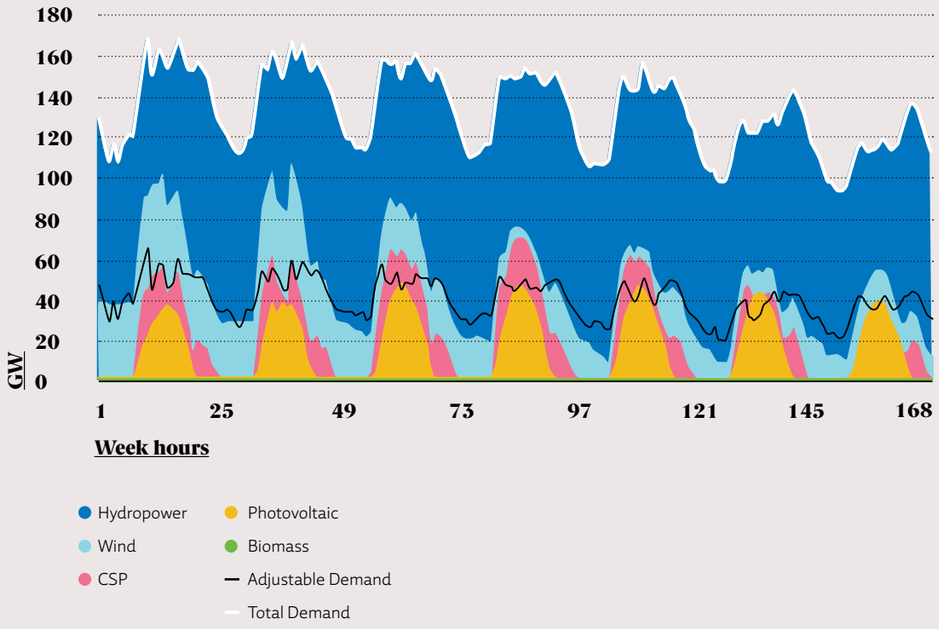



By 2050, the transmission system would need to grow to ensure that electricity could be transferred from one region to another. The greatest increase would be between the Northeast and Southeast, primarily to transmit wind power. The Southeast region, which is a large center of consumption, would continue to import electricity from other regions.

**→ Net electricity imports between regions in 2050**



→ Week with peak load

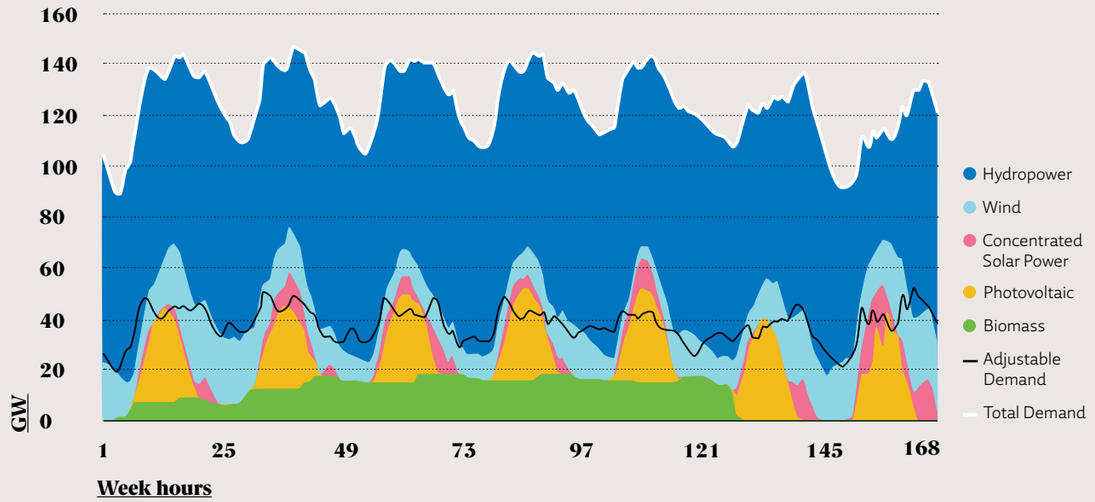



The renewable installed capacity in the Energy [R]evolution scenario was calculated to meet the country's electricity needs in various situations. The graphs below show the typical behavior of electricity supply and demand for each hour throughout a week. Each graph shows different demand conditions and different availability conditions for wind and water in reservoirs.

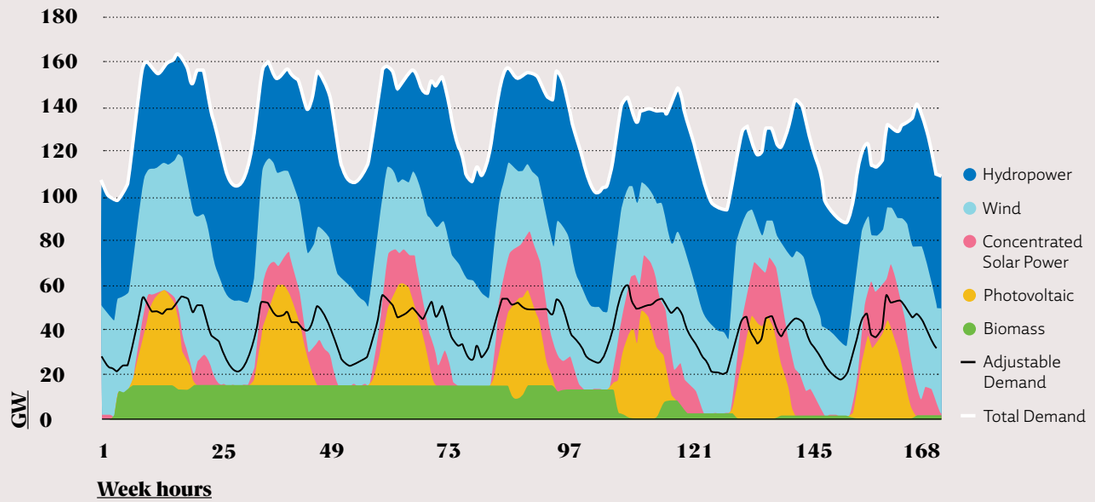
As can be seen in the graphs, electricity generation based on photovoltaic and wind power plants is prioritized and complemented by concentrated solar power plants and hydroelectric plants (which would operate in a flexible manner). At times of lower wind or lower water levels in reservoirs demand would be complemented by the use of biomass power plants.

The simulation results also show that measures for demand management can reduce the system load by up to 2.8 GW. There is also a curtailment of 25.53 TWh a year that refer to unused power generation from solar, wind, hydro and ocean sources, as their power generation in some hours of the year exceeds the demand.

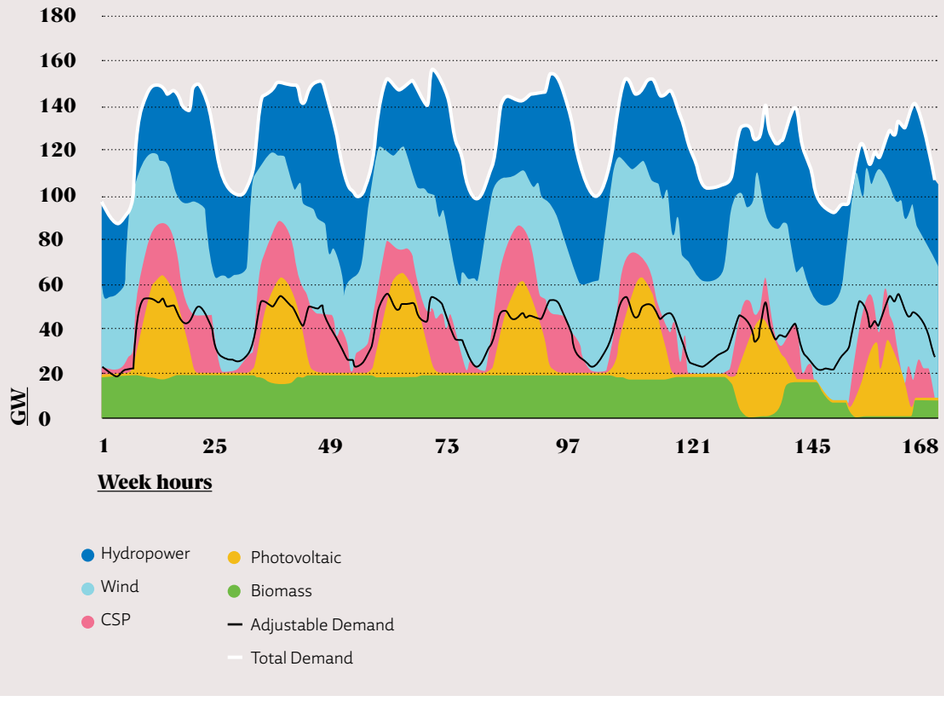
→ Week with minimum wind

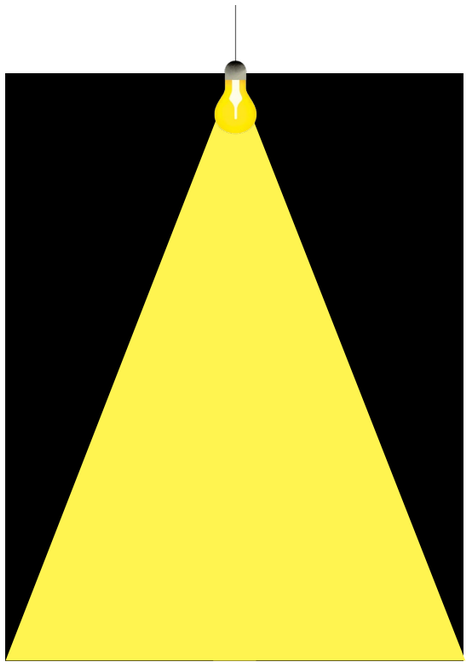



→ Week with maximum wind



→ **Week with minimum hydroelectric generation**



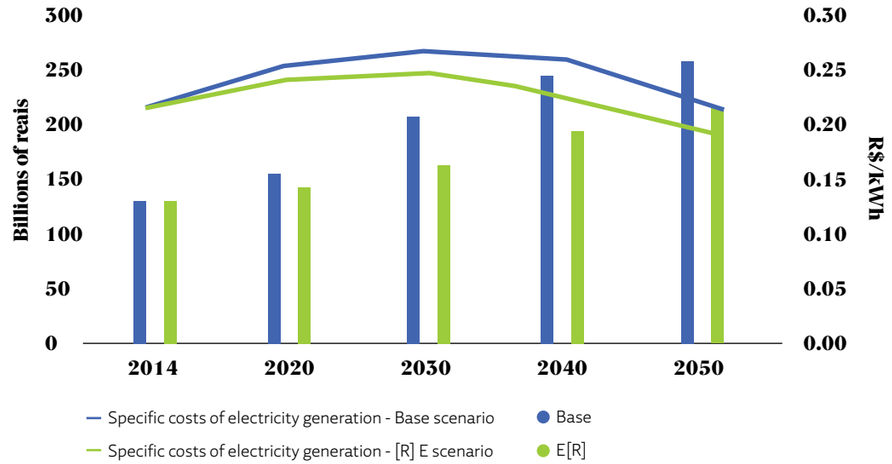
## Investments and costs of electricity generation

To expand the installed capacity for electricity generation in Brazil, the Energy [R]evolution scenario would require investments of R$ 1.747 trillion (or US$ 743 billion). This is slightly more than that needed for the Base scenario: R$ 1.697 trillion (or US$ 722 billion).

Despite the need for a larger total investment, the energy [R]evolution scenario actually saves money. This is because there is no spending on fossil fuels. This savings would be of R$ 909 billion (or US$ 387 billion) by 2050, much more than the additional investments needed to implement the new renewable power plants of the Energy [R]evolution scenario (R$ 50 billion or US$ 21.4 billion).

→ **Total and specific costs of electricity generation**

Using 100% renewable sources would reduce the total electricity generation cost in 2050. In the Base scenario, the amount would remain almost the same as today.




→ **Difference between total investments and fuel costs for electricity generation in the Base and E[R] scenarios (R$ billion)**

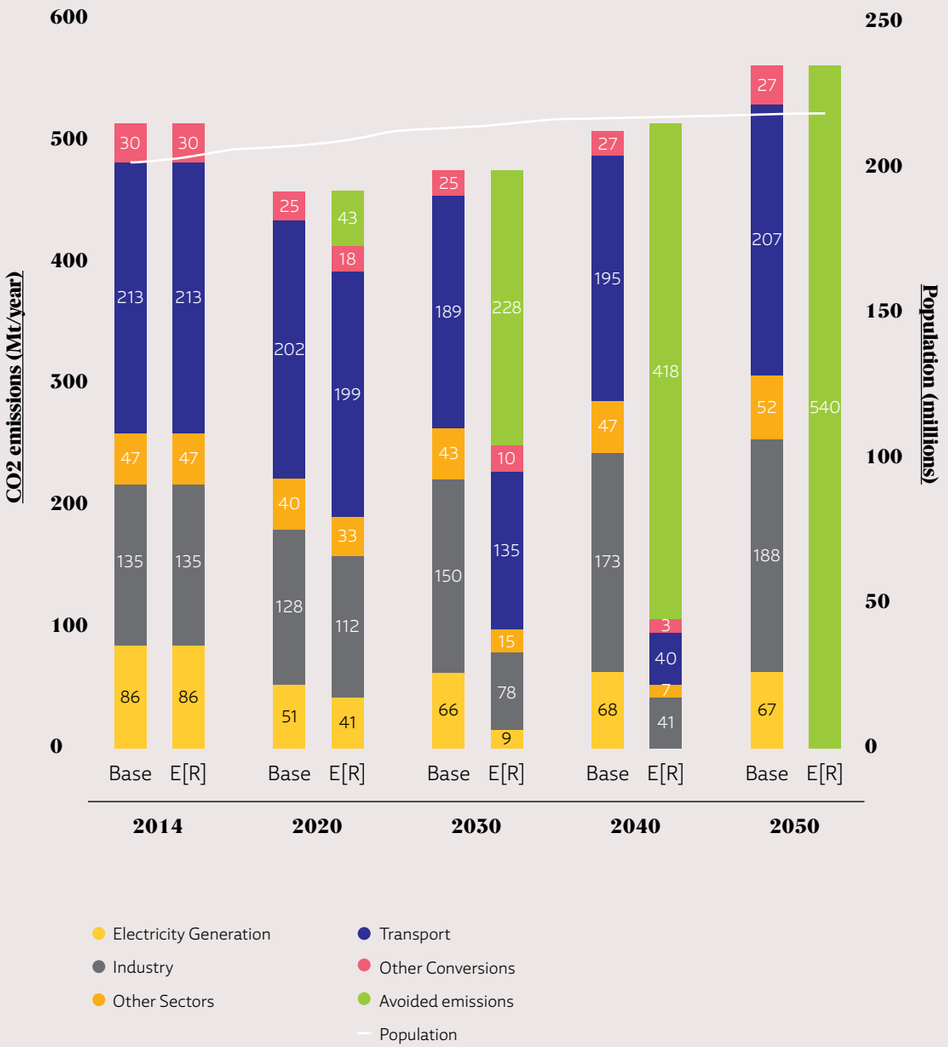
| | 2014 - 2020 | 2021 - 2030 | 2031 - 2040 | 2041 - 2050 | Cumulative 2014 - 2050 | Annual Average 2014 - 2050 |
|---|---|---|---|---|---|---|
| Investment Base scenario | 391 | 420 | 438 | 448 | 1,697 | 46 |
| Investment E[R] scenario | 360 | 388 | 503 | 496 | 1,747 | 47 |
| Difference in Investment E[R] scenario | -31 | -31 | 65 | 47 | 50 | 1 |
| Fuel savings in E[R] scenario | 3 | 136 | 331 | 439 | 909 | 25 |
| Total savings in E[R] scenario | 34 | 167 | 266 | 392 | 859 | 23 |

Having a 100% renewable mix would bring a lower total cost of electricity generation in 2050. It would cost R$ 209 billion (US$ 89 billion) a year or R$ 45 billion (US$ 19.3 billion) less than the Base scenario. In the Energy [R]evolution scenario the average cost of electricity generation in 2050 would be R$ 0.19 per kWh (or US$ 0.079 per kWh). In the Base scenario it would be R$ 0.22 per kWh (or US$ 0.092 per kWh)[6]. Currently generation costs R$ 0.21 per kWh (or US$ 0.09 per kWh).

**6**
The calculation does not take into account inflation.

### → $CO_2$ emissions up to 2050

Following the current trend, the energy sector will emit 6% more CO2 than today. The Greenpeace Brazil scenario shows that we could reduce emissions to zero.




## $CO_2$ EMISSIONS IN THE ENERGY SECTOR

If Brazil continues on the path of the government's Intended Nationally Determined Contributions (INDC) we will arrive in 2050 with an increase in CO2 emissions in the energy sector of around 6% in comparison to 2014. Around 541 million tons would have been released into the atmosphere by 2050. In the Energy [R]evolution scenario, thanks to the use of 100% renewable energy sources, emissions would fall from their current level (around 511 million tons of CO2 per year) to zero by midcentury.

### → $CO_2$ emissions in the energy sector (millions of tons per year)

| | 2014 | | 2020 | | 2030 | | 2040 | | 2050 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Base | E[R] | Base | E[R] | Base | E[R] | Base | E[R] | Base | E[R] |
| Total Emissions | 511 | 511 | 446 | 403 | 473 | 245 | 510 | 92 | 541 | 0 |
| Transport | 213 | 213 | 202 | 199 | 189 | 135 | 195 | 40 | 207 | 0 |
| Industry | 135 | 135 | 128 | 112 | 150 | 78 | 173 | 41 | 188 | 0 |
| Other Sectors | 47 | 47 | 40 | 33 | 43 | 15 | 47 | 7 | 52 | 0 |
| Electricity Generation | 86 | 86 | 51 | 41 | 66 | 9 | 68 | 1 | 67 | 0 |
| Other Conversions | 30 | 30 | 25 | 18 | 25 | 10 | 27 | 3 | 27 | 0 |
| Emissions **per capita** | 2.6 | 2.6 | 2.1 | 1.9 | 2.1 | 1.1 | 2.2 | 0.4 | 2.3 | 0 |

## JOB CREATION

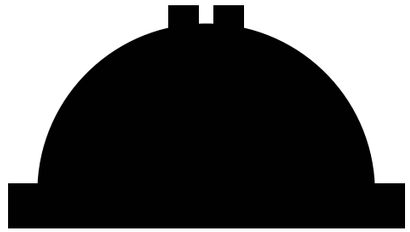
In addition to reducing CO2 admissions to zero, improving efficiency and reducing costs of electricity generation, the Energy [R]evolution would also create new jobs for Brazil. Estimates indicate that, in 2030, around 618,000 jobs would be associated with electricity generation and solar and ambient heat alone.

**→ Number of jobs in 2030 by type in the Energy [R]evolution scenario (electricity and solar and ambient heat)**

| | 2030 |
|---|---|
| Total no. of Jobs | 618,101 |
| Construction and Installation | 65,603 |
| Manufacture | 23,189 |
| Operation and Maintenance (O&M) | 176,042 |
| Supply of Fuels | 308,153 |
| Solar Thermal Energy and Ambient Heat | 45,114 |

**→ Number of jobs in the Base and E[R] scenarios**

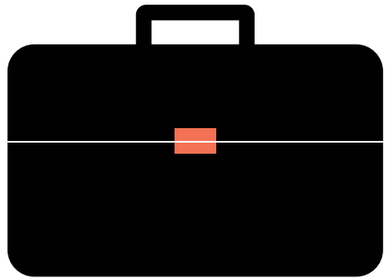
| | Base | E[R] |
|---|---|---|
| Jobs per PJ of primary energy for the supply of fuel for electricity generation | 57 | 61 |
| Jobs per installed GW of power plants | 1,093 | 1,247 |



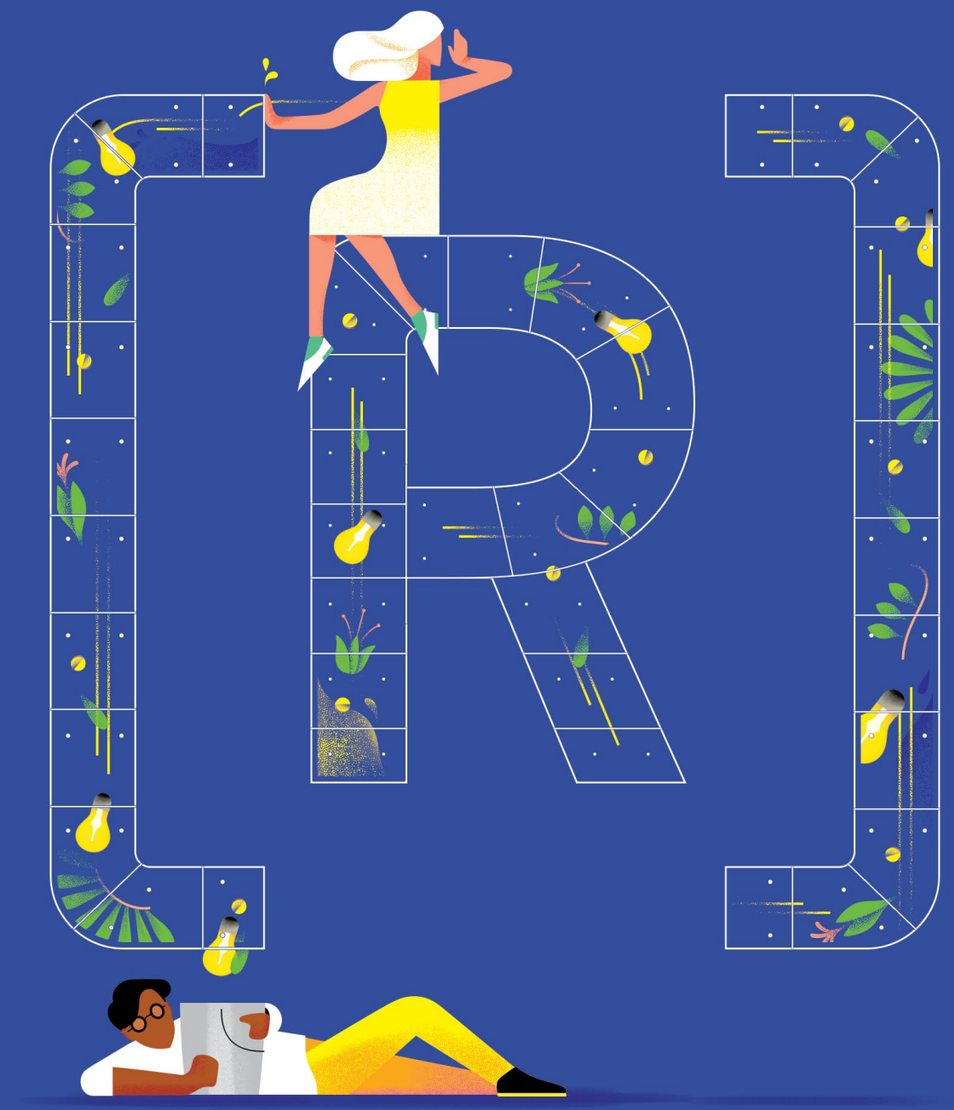
7
Primary energy consumed for electricity generation.

**→ Number of jobs in 2030 by source in Energy [R]evolution scenario (electricity and solar and ambient heat)**

| | 2030 |
|---|---|
| Total no. of Jobs | 618,101 |
| Coal | 1,528 |
| Natural Gas and Oil Products | 28,287 |
| Nuclear | 3,224 |
| Biomass | 366,794 |
| Hydro | 81,472 |
| Wind | 21,332 |
| Photovoltaic | 52,720 |
| Concentrated Solar Power | 8,255 |
| Ocean | 9,375 |
| Solar – Thermal | 43,951 |
| Ambient Heat – Thermal | 1,163 |



Analysis of job creation per PJ or GW shows that the 100% renewable scenario would create more jobs than the Base scenario. In 2030, it is estimated that 61 jobs will be created for each PJ of primary energy consumed[7]. In the Base scenario, only 57 jobs are created per PJ. With regard to construction, manufacture, maintenance and operation of power plants, in the Energy [R]evolution scenario 1,247 jobs would be created per installed GW in 2030, while the Base scenario would create 1,093 or 12% fewer jobs.



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