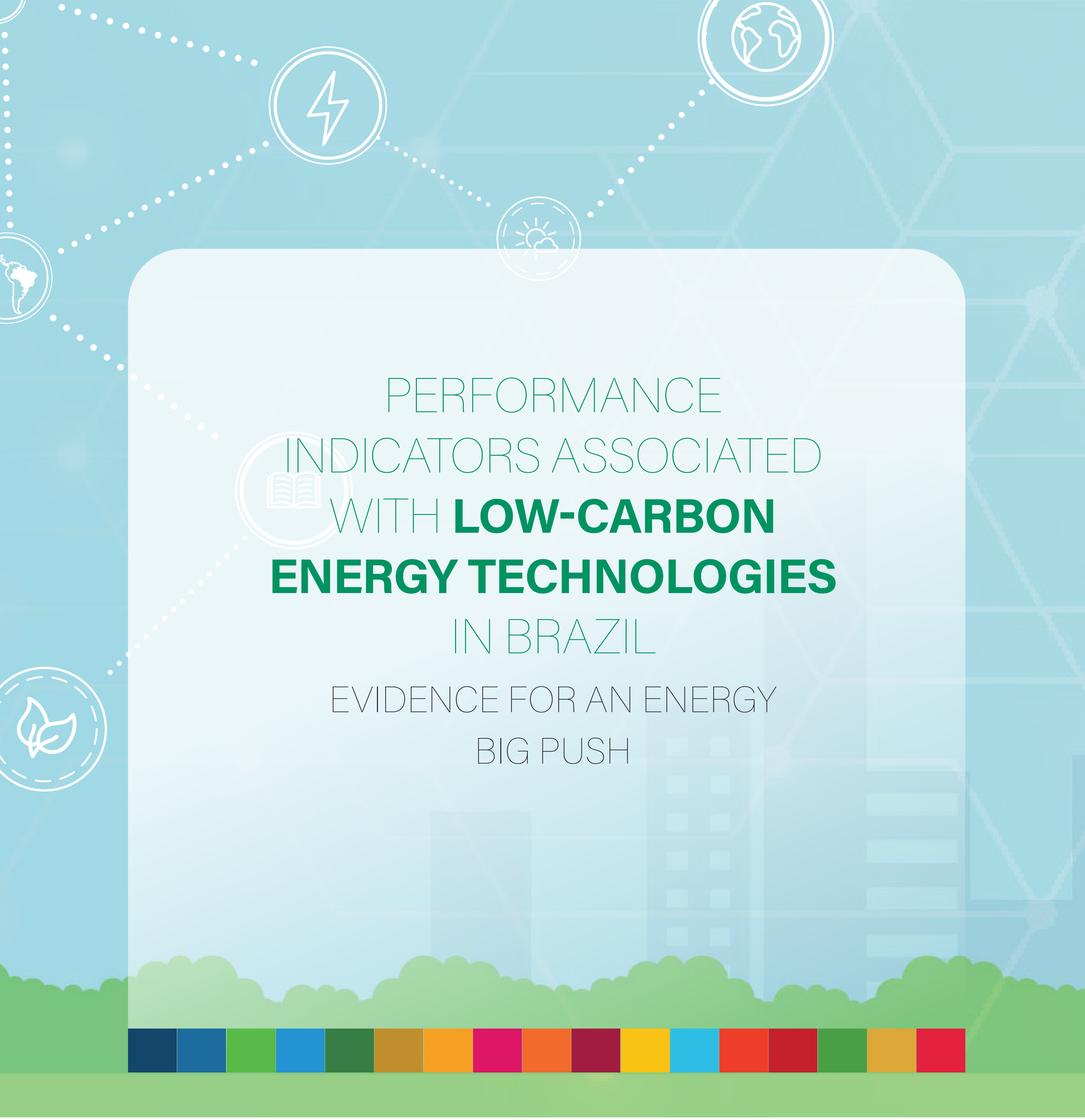

PERFORMANCE INDICATORS ASSOCIATED WITH **LOW-CARBON ENERGY TECHNOLOGIES** IN BRAZIL

EVIDENCE FOR AN ENERGY BIG PUSH

United Nations
ECLAC

cgee
Center for Strategic Studies and Management
Science, Technology and Innovation

epe
Empresa de Pesquisa Energética

german cooperation
DEUTSCHE ZUSAMMENARBEIT

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Performance indicators associated with low-carbon energy technologies in Brazil

Evidence for an energy big push

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Contents

Tables

Figures

Executive summary

This report presents the work carried out under Axis 2 of the Energy Big Push (EBP) Brazil project, which was aimed at providing a panel of techno-economic, social, environmental and political-institutional indicators to assess the performance of selected low-carbon energy technologies in Brazil. The report describes the methodology, which involved data survey and literature review, analysis of data and information collected; and the development of a set of performance indicators associated with low-carbon energy solutions. The report also presents the estimates produced for a set of indicadors that provide an overview of the potential impacts of various low-carbon energy technologies on multiple dimensions of sustainable development in Brazil.

Effective choices of energy solutions that take into account national circumstances are important and can benefit from the creation and application of evidence-based tools to guide decision-makers. A panel of indicators that contemplates a wide spectrum of dimensions of sustainable development is essential to identify possible synergistic and complementary areas for investments, follow and monitor the impacts of the investments made and, indirectly, of the policies and strategies implemented and, finally, to evaluate and improve the regulatory framework and incentive mechanisms so that they are effective in promoting investments for an Energy Big Push in Brazil.

Based on (i) the relevance of the sector with respect to economic performance, participation in energy supply and demand and environmental impacts, (ii) the potential of technologies for deployment at scale in Brazil, and (iii) future prospects regarding learning curves and relevance in energy policy and national strategic development, low-carbon energy solutions (LCES) were selected. These include transport sector, biofuels and power generation (both centralized, and mini and micro generation). For these selected LCES, 26 indicators were proposed for development under four pillars: environmental, techno-economic, social and political-institutional. Given data constraints and gaps, estimates were produced and calculated for 11 indicators. The fact that not all indicators could be estimated reveals significant data gaps, constraints and challenges for developing a comprehensive set of energy technology performance indicators for multiple dimensions of sustainable development.

In the environmental pillar, the indicators calculated covered water use, land use, greenhouse gas (GHG) emissions and non-GHG emissions. Under techno-economic pillar, estimates included the indicators of technology readiness level (TRL), capital production costs (CAPEX), operation and maintenance costs (OPEX), total costs and energy diversity. Regarding, the social pillar, the set of indicators that were calculated were job creation and income generation.

The analysis of these indicators showed that no technology outperforms others in every aspect, which suggests that a mix of technologies should be developed if multiple social, economic and environmental goals are to be achieved. This finding emphasizes the need for coordination for an Energy Big Push in Brazil.

The study of indicators revealed that there is no "one-size fits all" indicator, and some of them only allow a qualitative analysis. This finding underlines the importance of having a panel of indicators, instead of considering a single indicator only. Information provided by various indicators is often complementary across the dimensions of sustainable development. A cross-cutting analysis of diverse indicators is necessary to enable a comprehensive understanding of energy technologies performance. The present report also recommends a set of indicators that should be developed, updated and maintained, that include, in addition to the calculated indicators mentioned above: water quality and aquatic biodiversity, soil quality and terrestrial biodiversity and vulnerability and risks in the environmental pillar; efficiency of energy coversion and use, technology ownership, infrastructure requirements and supply chain readiness in the techno-economic pillar; access to electricity, directly affected population, occupational injury, illness and fatalities, impact on indigenous and traditional communities and risks to cultural, historical and archaeological heritage in the social pillar; and simplicity of environmental licensing process; compatibility with energy policy and international agreements, compatibility with existing regulatory and institutional framework in the political-institutional pillar.

As with any quantitative exercise, the quality of the estimates produced depend on the availability, robustness and reliability of the collected data and information, as well as the accuracy of the analysis method employed. In this sense, the work carried out under Axis 2 of EBP represents an advancement in reviewing and compiling multiple indicators of low-carbon energy solutions in Brazil. However, there is fertile ground for future developments in order to improve the quality, comparability and coverage of the indicators panel on low-carbon energy solutions in the country.

Preamble

Context and motivation

The climate and sustainability commitments of the Paris Agreement and the 2030 Agenda and its 17 Sustainable Development Goals have inspired several global, regional and national initiatives. In this sense, the Energy Big Push (EBP) Brazil project originated from the convergence of motivations and synergic efforts in the activities of its partners that permeate the themes of sustainable development, energy transition and international cooperation.

In 2015, a global initiative led by 24 countries and the European Union was launched, aimed at accelerating clean energy innovation, named Mission Innovation (MI). The representatives of the Brazilian government in the MI —the Ministry of Foreign Affairs (MRE in its Portuguese acronym) and the Ministry of Mines and Energy (MME in its Portuguese acronym)— mobilized the Energy Research Office (EPE in its Portuguese acronym) in order to conduct a survey of investments in research, development and demonstration (RD&D) in energy technologies to support the monitoring of innovation efforts in the energy sector in the country.

The EPE took the first steps in this direction and organized a first database of public and publicly oriented investments in RD&D, between 2018 and 2019, using the classification of the International Energy Agency (IEA). Based on this initiative, the need to incorporate other data sources and expand the time series was identified to improve the understanding of the main efforts in energy innovation in the country based on a single, structured and harmonized data set. In this context, the Centre for Strategic Studies and Management (CGEE in its Portuguese acronym) was invited as a strategic partner to design and implement a project that, in a collaborative way, would be able to build technical and institutional capacity to meet the need to expand access to strategic data for decision making in the energy sector.

The Brazilian government's need to have inputs and strategic information to accelerate the sustainable and low-carbon energy transition, fully coincides with the Big Push for Sustainability approach in the energy sector. The United Nations Economic Commission for Latin America and the Caribbean (ECLAC) has been developing this approach since 2016 to support countries in the region in building more sustainable development styles. The Big Push for Sustainability represents a coordination of policies (public and private, national and subnational, sectorial, fiscal, regulatory, financial, planning, etc.) that leverage national and foreign investments to produce a virtuous cycle of economic growth, generation of jobs and income, reduction of inequalities and structural gaps and promotion of environmental sustainability (ECLAC/FES, 2019).

Investments in the expansion, integration and diversification of clean and renewable energies represent one of the major opportunities for a Big Push for Sustainability in Latin America and the Caribbean, due to its multiple positive impacts in several areas, which are discussed in more detail the final project report. In the context of ECLAC's technical cooperation program with the German technical cooperation agency Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) to support selected countries in the region in a position to develop their strategies for implementing the 2030 Agenda, in line with the Big Push for Sustainability approach, ECLAC joined the efforts of CGEE and partners of the Brazilian government to promote a big push for investments with a focus on clean energy innovation in Brazil.

The IEA also joined efforts for an Energy Big Push in Brazil, within the scope of its Clean Energy Transition Program (CETP). This program's mission is to accelerate global clean energy transitions, mainly in major emerging economies, through activities that include collaborative analytical work, technical cooperation, training and capacity building and strategic dialogues. The program provides cutting-edge support to governments whose energy policies will significantly influence the prospects for —and the speed of— the global transition towards more sustainable energy production and use, with Brazil being one of the priority countries. The IEA's broad energy experience, mainly in analysis and survey of clean energy research and development (R&D) expenditures, clearly converges with EBP.

In 2019, based on the synergistic motivations of the partners, the EBP project kicked-off within a framework of multi-institutional collaboration at the international, regional and national level, forming a unique environment to exchange of experiences and share knowledge for an Energy Big Push in Brazil.

The Energy Big Push project

The objective Energy Big Push (EBP) project is to support the promotion of more and better public and private investments in sustainable energies, with an emphasis on innovation, contributing to an Energy Big Push in Brazil.

The project is structured in four axes. Each axis corresponds to a specific objective, as indicated below:

- Axis 1 - Development of a process for collecting, structuring and managing data on public and private investments in research, development and demonstration (RD&D) in energy;
- Axis 2 - Survey of technical, economic, social and environmental performance indicators associated with low carbon energy solutions;
- Axis 3 - Identification of strategic guidelines and key policy instruments to accelerate investments in energy innovation;
- Axis 4 - Innovative and effective communication strategy of project results, targeted at decision makers.

For each of these axes, working groups were formed, which met regularly and offered technical and data contributions to the EBP project. In addition to CGEE, EPE, ECLAC and IEA, the working groups were formed by experts of MRE, MME, Ministry of Science, Technology and Innovations (MCTI), Brazilian Electricity Regulatory Agency (ANEEL), National Agency of Petroleum, Natural Gas and Biofuels (ANP), Funding Authority for Studies and Projects (FINEP), National Council for Scientific and

Technological Development (CNPq), Brazilian Industrial Innovation Agency (EMBRAPII) and Institute for Applied Economic Research (IPEA) —see participants list in the annexes. Therefore, more than a dozen institutions, national, regional and global, have been mobilized and actively contributing to EBP, bringing the universe of energy and the universe of innovation stakeholders closer. The collaboration of each partner takes place on a voluntary basis, in an effort to value the different experiences of each participant, strengthen the collective intelligence of the group and add value to the results obtained in the project.

From the inputs and interactions of the working groups, preliminary technical reports on axes 1, 2 and 3 were generated, presenting preliminary estimates and considerations for each of these axes. The preliminary reports were presented and discussed at the Energy Big Push Workshop, held at the CGEE in October 2019. The workshop aimed to provide exchange of experiences, learning among peers and an opportunity to review and improve the preliminary results of the project. The event was attended by 47 people, including experts and representatives of the project's partner institutions (see list of participants in annex 1). The rich discussions of this workshop generated key inputs for the final reports on axes 1, 2 and 3 and for the communication and engagement activities on axis 4, as well as the final project report that summarises and integrates the results of each axis in the light of the approach of the Big Push to Sustainability.

The reports produced within the framework of the EBP are, therefore, the result of a collective effort and the contributions from several partner institutions and experts that are working on the theme. These are:

- The Axis 1 final report: Overview of energy innovation investments in Brazil: Data for an energy big push;
- The Axis 2 final report, which is the present document: Performance indicators associated with low carbon energy technologies in Brazil: Evidence for an energy big push;
- The Axis 3 final report: Incentive mechanisms for clean energy innovation in Brazil: Paths for an energy big push;
- Final EBP project report: A big push for sustainability in Brazil's energy sector: Subsidies and evidence for policy coordination.

EBP is expected to be a process of co-creating several studies and analysis to support decision-making; capacity building and learning acquired by the teams of the various agencies involved on the project on issues related to sustainable energy, innovation and investments; and, finally, the development of recommendations on the topics covered, which may serve as inputs for public policies to accelerate investments in clean energy in Brazil, with a focus on innovation.

Introduction

This report presents the work carried out within the framework of Axis 2 of the Energy Big Push (EBP) Brazil project. The main objective of EBP Axis 2 is to provide a panel of techno-economic, social, environmental and political-institutional indicators to assess the performance of low-carbon energy technologies in Brazil. This work included mapping, surveying and reviewing existing data and literature; analysis of collected data and information; and presentation of estimates for a selection of performance indicators associated with low carbon energy solutions and their respective values. Effective choices of energy solutions that take into account national circumstances are important and can benefit from the creation and application of tools to guide decision-makers. A panel of indicators can be a useful tool to support decision making, by offering evidence on the potential social, economic and environmental performance of each low-carbon energy solution. This set of evidence can help identify complementary sectors and technologies that could be the focus of an articulated and coordinated set of policies to accelerate clean energy innovation and investments, in line with a Big Push for Sustainability in the energy sector of Brazil. A panel of indicators that contemplates a wide spectrum of dimensions of sustainable development is essential to identify possible synergistic and complementary areas for investments, follow and monitor the impacts of the investments made and, indirectly, of the policies and strategies implemented and, finally, to evaluate and improve the regulatory framework and incentive mechanisms so that they are effective in promoting investments for an Energy Big Push in Brazil.

The indicators produced in this work can help to detect the appropriate combination, for the context of the Brazil, of complementary and coordinated investments for the construction of a more sustainable, resilient and low-carbon energy matrix and, at the same time, for the promotion of a more inclusive, efficient and competitive economy. In addition, an indicators panel can be a useful navigation tool for decision makers, as it allows continuous adjustments to the course of action towards the sustainability of the development it aims to achieve. As with any quantitative exercise, the quality of the estimates produced depend on the availability, robustness and reliability of the collected data and information, and on the accuracy of the analysis method employed. In this sense, the work carried out under Axis 2 of EBP is an important step in reviewing and compiling multiple indicators of low-carbon energy solutions in Brazil, which should be continuously developed in order to improve the quality and coverage of the indicators panel on low-carbon energy solutions in the country.

The methodology and preliminary estimates for the set of indicators were presented at the Energy Big Push Workshop in October 2019, in which these were subject to expert scrutiny. The content of the present report thus incorporates suggestions for improvements and feedback received from experts at the workshop, as well as inputs received over the technical meetings of the Working Group of Axis 2 of the EBP project. Based on this collaborative effort and on the criteria described in this report, the following solutions were selected and for which indicators were produced:

- Transportation light-duty vehicles, buses and trucks (hybrid, battery electric and internal combustion engine vehicles, when relevant);
- Centralized power generation: large hydro, small hydro, thermopower (forest biomass, sugarcane bagasse), solar photovoltaic, concentrated solar power (CSP), onshore wind and offshore wind;
- Mini and micro power generation: thermopower (biogas from agricultural residues) and distributed solar photovoltaic;
- Biofuels: sugarcane bioethanol, soybean biodiesel, biogas (from urban solid waste) and biokerosene.

This report is organized as follows. Besides the Preamble in which the context, motivations and a description of the EBP project are presented and this Introduction, there are four chapters. In Chapter I presents the selection exercise of low-carbon energy solutions and the process of building a panel of indicators. Chapter II describes key methodological considerations for the calculation of the estimates of a set of indicators. In Chapter III, the results for various indicators are presented in discussed. Chapter IV presents final remarks, recommendations and areas for future development.

I. Performance indicators for selected low-carbon energy solutions

This Chapter describes the selection exercise of low-carbon energy solutions and the process of building a panel of indicators. The environmental, social and economic implications of energy mix and policy should be considered in a holistic manner and reflected in institutional arrangements. Having evidence such as a panel of indicators can help policy makers consider the current and future effects of alternative energy sources, uses and production on health, equity, economy, environment, among others to support informed decision-making processes. In this sense, indicators are useful for monitoring progress towards specific country goals and to identify the factors most responsive to policy changes.

Selection of low-carbon energy solutions

For the purposes of the Energy Big Push (EBP) Brazil project, low-carbon energy solutions (LCES) are those defined by the IEA (2011) in categories 1 - Energy Efficiency, 3 - Renewable Energy Sources, 5 - Hydrogen and Fuel Cells, 6 - Other Power and Storage Technologies and 7 - Other Cross-Cutting Technologies or Research.

Following this categorization, the members of EBP Axis 2 Working Group (WG2, see annex 4 for list of participants) performed a selection of technologies for specific sectors. The selection criteria considered, among other aspects:

(i) at the sector level: current and future relevance of the sector with respect to economic performance, participation in energy supply and demand and environmental impacts (Brazil, 2015; EPE, 2018a and Rathmann (org.), 2017);

(ii) at the technology level: identified potential for deployment at scale in Brazil, future prospects regarding development and learning curves, as well as relevance in energy policy and national strategic development (EPE, 2018a and b; MME, 2018; Rathmann (org.), 2017); La Rovere and others, 2018; MCTI, 2018).

Based on these criteria, selected technologies are:

- Transportation: light-duty vehicles, buses and trucks (hybrid, battery electric vehicle (BEV) and internal combustion engine (ICE), when relevant);
- Centralized power generation: large hydro, small hydro, thermopower (forest biomass, sugarcane bagasse), solar photovoltaic, concentrated solar power (CSP), onshore wind and offshore wind;
- Mini and micro power generation: thermopower (biogas from agricultural residues) and distributed solar photovoltaic;
- Biofuels: sugarcane bioethanol, soybean biodiesel, biogas (from urban solid waste) and biokerosene.[1]

The analysis did not focus on energy distribution and storage technologies, since there is scarce data for these technologies. The impact of smart grids, for example, is rather diffuse and therefore, difficult to assess.

Building a panel of indicators

The Biodiversity International Partnership defines an indicator as a "measure based on verifiable data that conveys information about more than just itself". This means that indicators are purpose dependent —the interpretation or meaning given to the data depends on the purpose or issue of concern (BIP, 2011). Indicators extend beyond basic statistics to provide a deeper understanding of causal relationships in the energy–environment–economics nexus, and to highlight linkages that may not be evident from simple statistics. Taken together, indicators can give a picture of the whole energy system, including interlinkages and trade-offs among various dimensions of sustainable development, as well as the longer-term implications of current decisions and behaviour (Vera and Langois, 2006).

Factors determining what makes a "successful" indicator naturally depend on its purpose. In essence, underlying features of indicators include (GBEP, 2011; BIP, 2011):

- to be relevant to users' needs: an indicator should be relevant inasmuch as it should measure as closely as possible the trend of a theme or a component of a theme. It should be responsive to change in the issue of interest;
- to be scientifically valid: existence of consensual theory of the relationship between the indicator and its purpose, with agreement that change in the indicator does indicate change in the issue of concern;
- to be practical: the practicality of an indicator will contribute to the extent of its (voluntary) use, dependent on data availability, so that it can be produced regularly over time and with reasonable effort.

Usually, indicators do not provide answers and do not constitute a standard or benchmark. Nor are they legally binding. Rather, they present the right questions to ask in assessing the effect of practices and policies in meeting nationally defined goals of sustainable development.

Systematized performance indicators by pillar

Indicators proposed for measuring performance of LCES are classified into three major dimensions of sustainable development: social, economic and environmental. A fourth, cross-cutting, pillar assesses institutional feasibility. This section presents the selection of indicators.

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[1] Hydroprocessed Esters and Fatty Acids (HEFA) route.

Environmental pillar

Energy production and use leads to important anthropogenic pressures on the environment, including climate change, local atmospheric pollution, deforestation, loss of water and soil quality, among others. Many of the environmental effects from energy-related activities are long term and carry some degree of uncertainty. Indicators from the environmental pillar contemplate these aspects, as well as risks associated to human activity and natural disasters.

Indicators:

- Water use
- Impacts on water quality and aquatic biodiversity
- Land use
- Impacts on soil quality and terrestrial biodiversity
- Greenhouse gas (GHG) emissions
- Non-GHG emissions
- Vulnerability and risks

Techno-economic pillar

The techno-economic pillar assesses primarily the associated production costs of different LCES, an underlying aspect determining market allocation decisions for energy technologies. It also contemplates other aspects, such as learning curve, upstream and downstream chain effects, energy efficiency and diversity.

Indicators:

- Efficiency of energy conversion and use
- Technology Readiness Level (TRL)
- Technology ownership
- Capital production costs (CAPEX)
- Operation and maintenance costs (OPEX)
- Total costs
- Associated infrastructure requirements
- Energy diversity
- Supply chain readiness

Social pillar

Indicators from the social pillar encompass income and employment generation, which are intrinsically related to economic growth and distribution and policy support. These should nevertheless consider potential impacts on local population, workers and heritage. These are equity aspects that can undermine popular support, namely regarding energy generating projects.

Indicators:

- Job creation
- Income generation
- Access to electricity
- Directly affected population
- Incidence of occupational injury, illness and fatalities
- Respect to indigenous and traditional communities
- Risks to cultural, historical and archaeological heritage

Political-institutional pillar

Finally, there are a number of issues that are difficult to quantify or are more qualitative by nature and that need to be taken into consideration in any decision-making process and in the final formulation of major energy policies (Vera and Langois, 2006). This is fundamentally the case of indicators measuring institutional feasibility that compose the political-institutional pillar. According to IRENA (2014), one reason for which institutional feasibility tends to be evaluated qualitatively is that the criterion does not measure success, rather it helps to explain a policy's potential to succeed. In this sense, results can also be more difficult to interpret since they do not incorporate a metric benchmark against which comparisons can be made. These difficulties can make institutional feasibility harder to evaluate than other criteria for which quantitative methods are more suitable.

Indicators:

- Simplicity of environmental licensing process
- Compatibility with energy policy and international agreements
- Compatibility with existing regulatory and institutional framework

II. Methodological considerations

This chapter provides key methodological considerations regarding the escope and comprehensiveness of the calculations performed for a set of indicators (results are presented in Chapter III). The system boundaries for the computation of indicators should be clearly defined and stated in order to allow an adequate monitoring and comparison across low-carbon energy technologies.

The selection of indicators for which estimates were produced was based on applicability, the availability and quality of data considerations, as well as on the relevance of indicators.

Some indicators can be easily quantified, subject to data availability. Others involve a certain degree of subjectivity or imply such high data requirements and specific assumptions that can only be assessed qualitatively. In such cases, a qualitatively scale is usually applied. As previously stated, indicators of the political-institutional pillar can only be assessed through a qualitative approach, which is out of the scope of this study.

Environmental pillar

Water use

This indicator allows to assess direct water requirements for energy production and use of a given technology. It can be applied to power generation and biofuels. For power generation plants (centralized and mini/micro), water use depends on the type/source and null values are expected for some technologies. For biofuels, the indicator comprises water use for biofuel production itself (i.e. crop irrigation is excluded). This indicator is not applicable to transportation and energy distribution and storage technologies, as water requirements during the operation phase can be considered negligible.

Table 1
Water use indicators

Description	
(1) Volume of water required for the production and processing of energy per unit of energy output or installed capacity (2) Volume of water required in the production per unit of output	
Measurement Units	
(1) m^3/MW	(2) m^3/unit
(1) m^3/MWh	
(1) m^3/MJ	

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Land use

This indicator allows to understand land requirements for energy production and use of a given technology. Energy generation plants occupy land through their installed capacity (facilities and equipment). Hence, this indicator is applicable to centralized power generation technologies and biofuels. Land requirements for micro and mini power generation can be considered negligible, since projects are usually implemented in areas already occupied with human activities (e.g. rural communities, roofs).

Table 2
Land use indicators

Description
(1) Total area of land used for the production and processing of energy per unit of energy output or installed capacity
Measurement Units
(1) hectares/MW (1) hectares/MJ

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Greenhouse gas emissions

This indicator comprehends the direct greenhouse gas (GHG) emissions due to energy production and use of a given technology. Emission factors depend on the energy source employed, i.e. fuels, biomass, and electricity. Ideally, emission factors should be sensitive to regional and processing specificities.

The GHGs covered are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). Values of GHGs other than CO_2 should be converted to CO_2 equivalent (CO_2e).

Indirect emissions regarding the lifecycle of the assets/activities (e.g. during production, processing, transport, disposal, etc.) are out of the scope of the present analysis, as their assessment requires a complex methodology, strongly dependent on the formulation of assumptions, scenarios and heavy data requirements. However, data is presented when available for comparison purposes.

This indicator is applicable to transportation (operation phase only), power generation technologies and biofuels.

Table 3
GHG indicators

Description
(1) Emissions of GHG from the production and processing of energy per unit of energy output
Measurement Units
(1) tons CO_2e/MWh (1) tons CO_2e/MJ

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Non-GHG emissions

This indicator allows to analyse the direct non-greenhouse gas emissions due to energy production and use of a given technology. Non-GHGs covered are: particulate matter of 2,5 micrometers in diameter ($P.M._{2,5}$), particulate matter of 10 micrometers in diameter ($P.M._{10}$), carbon monoxide (CO particulate matter of 2,5 micrometers in diameter, nitrous oxides (NO_x), suphur dioxide (SO_2) and aldehydes (RCHO).

Non-GHGs are primarily related to local air pollution, which originate from different sources and present undesirable effects, described below:

- $P.M._{2,5}$, P.M.10 (energy generation, transport): respiratory diseases
- CO (transport, energy generation): reduces the amount of oxygen that can be transported in the blood stream to critical organs like the heart and brain
- NO_x (energy generation, transport, agriculture): respiratory diseases, acid rain, photochemical smog
- SO_2 (transport): respiratory diseases, acid rain
- RCHO (transport, especially bioethanol): carcinogenic composts, respiratory diseases

Indirect emissions regarding the lifecycle of the assets/activities (e.g. during production, processing, transport, disposal, etc.) are out of the scope of analysis, as their assessment requires a complex methodology, strongly dependent on the formulation of assumptions and heavy data requirements.

This indicator is applicable to transportation (operation phase only) and power generation technologies. However, for the power generation technologies that were analysed, emissions were considered negligible. For biofuels, non-GHG emissions are not assessed, given that these are mostly related to field burning (Violante, 2018), which is out of the scope of analysis and becoming outdate practice. Emissions from biofuel combustion are accounted for within the transportation sector.

Table 4
Non-GHG indicators

Description	
(1) Emissions of non-GHG air pollutants from the production and processing of energy per unit of energy output (2) Increased occurrence of respiratory diseases by unit of energy output	
Measurement Units	
(1) tons/MWh	(2) qualitative scale
(1) tons/MJ	

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Techno-economic pillar

Technology readiness level (TRL)

This indicator measures the technical feasibility of a given technology at the global level. It measures whether applications are at the experimental or demonstration phases (low readiness) or if large-scale, nearly commercial stages have been achieved (high readiness), see table 5.

Within a given technology, options and routes at different TRL levels can be found (for example, solar PV and graphene organic thin film solar PV are both comprised within the same category but found at different stages at their learning curves). In this case, the analysis should consider the most advanced option, that is, the one with the highest TRL.

The TRL is applicable to all LCES, except for smart grids, since it involves a package of different technologies and would require a complex methodology, strongly dependent on the formulation of assumptions and heavy data requirements.

Table 5
TRL indicator

Description
(1) Maturity level of a given technology relative to its development cycle
Measurement Units
(1) scale from 1 to 9, being: TRL 1 - Basic principles observed and reported TRL 2 - Technology concept and/or application formulated TRL 3 - Analytical and experimental critical function and/or characteristic proof-of-concept TRL 4 - Component and/or breadboard validation in laboratory environment TRL 5 - Component and/or breadboard validation in relevant environment TRL 6 - System/subsystem model or prototype demonstration in a relevant environment TRL 7 - System prototype demonstration in an operational environment TRL 8 - Actual system completed and qualified through test and demonstration TRL 9 - Actual system proven through mission operation

Source: Created by the authors based on internal communication with the International Energy Agency (IEA).

Capital production costs (CAPEX)

This indicator comprises capital expenditures (CAPEX) for a given technology: investments in capital goods (machinery, equipment and any type of physical capital). It often indicates the upfront costs required to deploy a given technology.

Cost reductions are expected for many of the selected LCES in future, namely for those at initial stages of their learning curves. A complete assessment requires costs to be presented for current and future levels. Current levels should cover the most recent data available (e.g. from 2015 to 2019). Future costs target the period of 2025 to 2030. This indicator is applicable to all the selected LCES.

Table 6
CAPEX indicators

Description
(1) Total capital requirements per unit of energy output or installed capacity (2) Total capital requirements per unit of output
Measurement Units
(1) \$/MW (1) \$/MJ (2) \$/unit

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Operational costs (OPEX)

This indicator refers to operational expenditures (OPEX) for a given technology: maintenance expenses, labour, fuel, among others. Given that OPEX is strongly dependent on the price of energy commodities, only current levels were defined (most recently available data). This indicator is applicable to all the selected LCES.

Table 7
OPEX indicators

Description	
(1) Total annual operational costs per unit of energy output (2) Total annual operational costs per unit	
Measurement Units	
(1) $/MWh	(2) $/unit
(1) (2) $/MJ	

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Total costs

This indicator allows to assess the total cost of deployment of a given technology.[2] For each category, it is defined by a different methodology, namely (i) Levelized Cost of Electricity (LCOE) for power generation technologies; (ii) Total Cost of Ownership (TCO) for transportation technologies; and (iii) Levelized Cost of Fuel (LCOF) for biofuels. These methodologies are detailed in annex 7.

Table 8
Total cost indicators

Description	
(1) Total (annualized) costs per unit of energy output (2) Total (annualized) costs per unit	
Measurement Units	
(1) $/MWh	(2) $/unit
(1) (2) $/MJ	

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Energy diversity

This indicator describes the potential contribution of a given technology to energy security, measured by diversification of supply sources. It is applicable to power generation[3] and biofuels for 2018 by computing a concentration index[4] that contrasts scenarios with and without the energy source (allocating the related fractions to the most likely alternative use). It considers that power generation technologies replace natural gas thermopower. For biofuels, it was considered that ethanol replaces gasoline and biodiesel replaces diesel.

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[2] This indicator cannot be expressed as the simple sum of CAPEX and OPEX. It requires a more complex methodology, which takes into account several variables such as annualization factors, assumptions on capacity factor (for power generation technologies), lifespan and discount rates, among others.

[3] Except large hydroelectricity, which accounts for a major share of the Brazilian energy matrix and cannot be considered an alternative source.

[4] Herfindal-Hirschman index.

Social pillar

Job creation

This indicator captures gross direct job generation related to a given technology, including both temporary (fixed-term contract) and permanent (indefinite) employment. It does not capture indirect or induced jobs, given that this would require sophisticated methods and assumptions. Jobs related to research and development are not contemplated either. It is applicable for power generation and biofuels, subject to data availability.

Table 9
Job creation indicators

Description		
(1) Direct jobs created during construction peak (2) Direct jobs created during operation phase (incl. maintenance) (3) Direct jobs created during production		
Measurement Units		
(1) jobs/MW	(2) (3) jobs/MJ	(3) jobs/unit

Source: Created by the authors based on information from EBP Axis 2 Working Group.

Income generation

Finally, this indicator measures changes in both wage and non-wage income due to the deployment of a technology. It relates to the potential forward linkages it entails, promoting economic development. It considers direct income generation (actual earnings), as well as indirect and induced income.[5] However, the scope is delimited to local effects. It was assessed for a few power generation technologies, subject to data availability.

Table 10
Income generation indicators

Description
(1) Direct impact on income related to the deployment of a technology (2) Indirect impact on income related to the deployment of a technology (3) Induced impact on income related to the deployment of a technology
Measurement Units
(1) (2) (3) $/MW

Source: Created by the authors based on information from EBP Axis 2 Working Group.

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[5] Expenditures effectively related to the project are known as the direct impact (e.g. onsite construction workers, equipment manufacturers, security personnel, etc.). Spinoff economic effects throughout the value chain that occur as a result of these expenditures are the indirect impact (e.g. construction equipment suppliers, legal and accounting services). The induced impact is related to expenditures made by workers` earnings that are supported by direct and indirect impacts (e.g. housing, restaurants, services in general).

III. Results and discussion

A quantitative assessment was carried out to produce estimates for 11 of the 26 indicators initially presented in Chapter I. When relevant or applicable, figures for the reference technology that can be potentially replaced by the low-carbon energy solutions (LCES) are shown (e.g. natural gas thermopower plants, or fossil-fulled internal combustion engine —ICE— vehicles), for comparison purposes. Monetary indicators are presented in US$ dollars, at 2018 constant values.[6]

Data is obtained from diverse sources, which employ different methodologies and assumptions. The interpretation of results should take this into account. The results presented in the present Chapter were validated by a team of experts on the Energy Big Push Workshop held in Brasilia on the 30th and 31st of October 2019.

Power generation

Water use

For thermopower (biomass) and CSP, water is directly consumed for the cooling process during operation phase. In Solar PV, water use is primarily related to panel cleaning. For hydro (large or small) generation, water is not directly consumed by the plants and losses are due to the water natural cycle, i.e. evaporation process from the reservoirs. For wind (onshore or offshore), there is no water withdrawal (IRENA/WRI, 2018).

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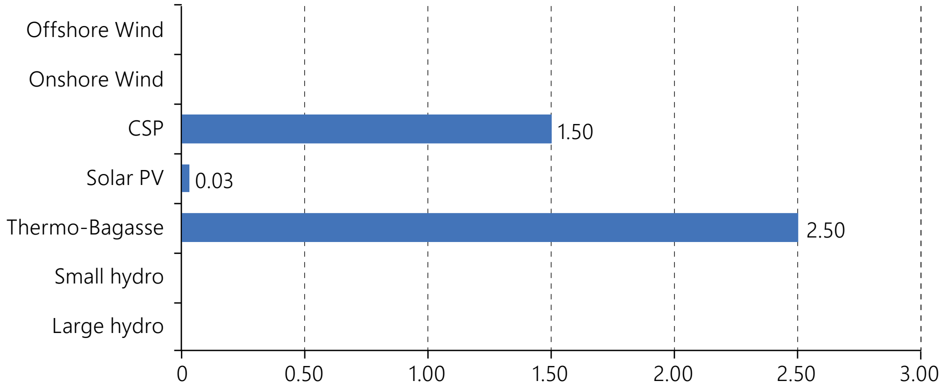
[6] Average exchange rate (2018): 3,65 BRL/USD (Banco Central do Brasil, 2019).

Figure 1
Water use for centralized power generation technologies
(In m^3/MWh)

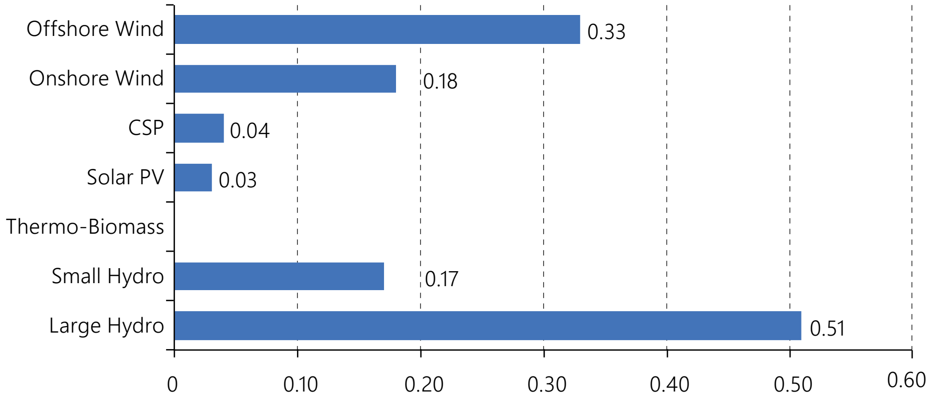


Source: Created by the authors based on Agência Nacional de Água (ANA), *Manual de Usos Consuntivos da Água no Brasil*, Superintendência de Planejamento de Recursos Hídricos (SPR), Brasília, 2019; and Bukhary, Saria, Sajjad Ahmad and Jacimaria Batista, "Analyzing land and water requirements for solar deployment in the Southwestern United States", *Renewable and Sustainable Energy Reviews*, vol. 82, 2018.

Land use

Energy generation plants occupy land through their installed capacity (facilities and equipment). In the case of hydropower plants, flooded land turned into reservoirs is computed. For thermopower plants that run on biomass, land requirements associated with energetic crops should be considered as well. For solar and wind technologies, land requirements are related to the equipment (panels and turbines) installation and spacing. For wind energy, specifically, spacing depends on the turbines' size and arrangement, so an average value for existing projects was used as reference.

Figure 2
Land use for centralized power generation technologies
(In km^2/MW)

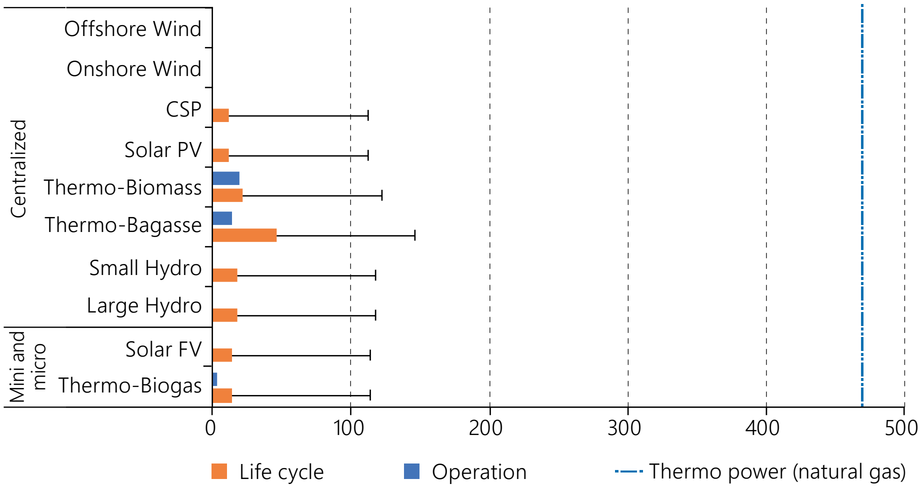


Source: Created by the authors based on Bukhary, Saria, Sajjad Ahmad and Jacimaria Batista, "Analyzing land and water requirements for solar deployment in the Southwestern United States", *Renewable and Sustainable Energy Reviews*, Elsevier, vol. 82, 2018; Musial, Walt and others (2016), *Offshore Wind Energy Resource Assessment for the United States*, National Renewable Energy Laboratory (NREL), Golden, CO; Empresa de Pesquisa Energética (EPE), *Nota Técnica EPE 026/2018 – Análise socioambiental das fontes energéticas do PDE 2027*, Rio de Janeiro, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), November; and Simsek, Yeliz, David Watts and Rodrigo Escobar (2018), "Sustainability evaluation of Concentrated Solar Power (CSP) projects under Clean Development Mechanism (CDM) by using Multi Criteria Decision Method (MCDM)", *Renewable and Sustainable Energy Reviews*, vol. 93, October.

Greenhouse gas emissions

Some energy sources do not generate GHG emissions during operation, however, when considering their entire life cycle, emissions are not negligible. Thus, when available, data are shown both for emissions during operation and life cycle. Life cycle GHG emissions were available for centralized power generation technologies in the Renewable Energy Sources and Climate Change Mitigation Special Report of the IPCC (2006). For comparison, direct emissions from the operation of natural gas thermal power plants are also shown.

Figure 3
GHG emissions for centralized power generation technologies
(In gCO_2e/GWh)



Source: Created by the authors based on Edenhofer Ottmar e outros (eds.), *Renewable energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change*, Cambridge, United Kingdom, IPCC, 2011; and Intergovernmental Panel on Climate Change (IPCC), *IPCC Guidelines for National Greenhouse Gas Inventories*, Prepared by the National Greenhouse Gas Inventories Programme", Eggleston, Simon and others (Eds.), Institute for Global Environmental Strategies (IGES), Japan, 2006.

Technology readiness level

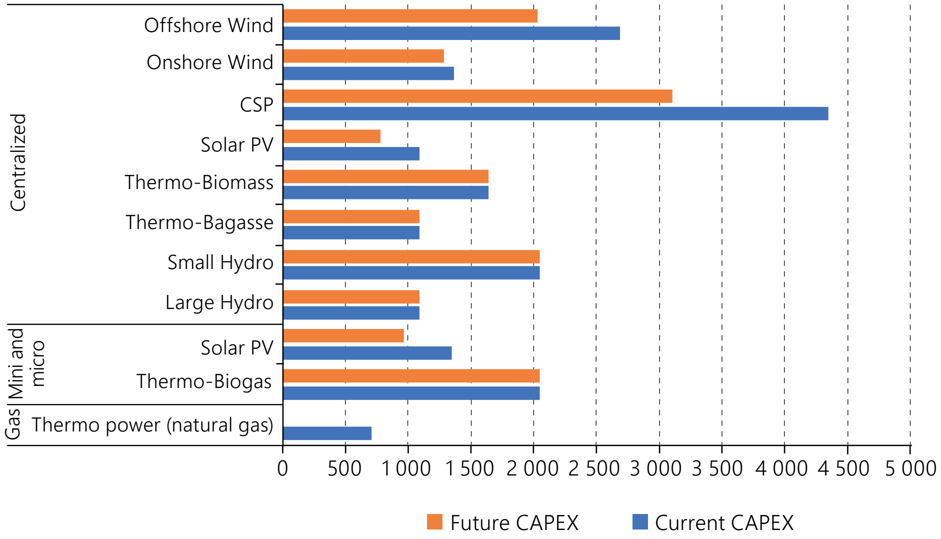
For all power generation technologies analysed, the TRL considered was 9, the highest, as defined according to internal communication with the International Energy Agency (IEA). This means that all selected technologies are at a mature stage of technological development.

Capital production costs (CAPEX)

For power generation, data is presented both in current costs (most recent available data) and future estimates (comprising the period of 2025 to 2030), as cost reductions are expected for some technologies in the near term.

For comparison, costs regarding natural gas thermal power plants are also shown. Currently, this source has a lower CAPEX than every other source. In the near future, only centralized solar PV would be competitive in relation to natural gas in terms of capital costs.

Figure 4
CAPEX for power generation technologies
(In US$/kW)

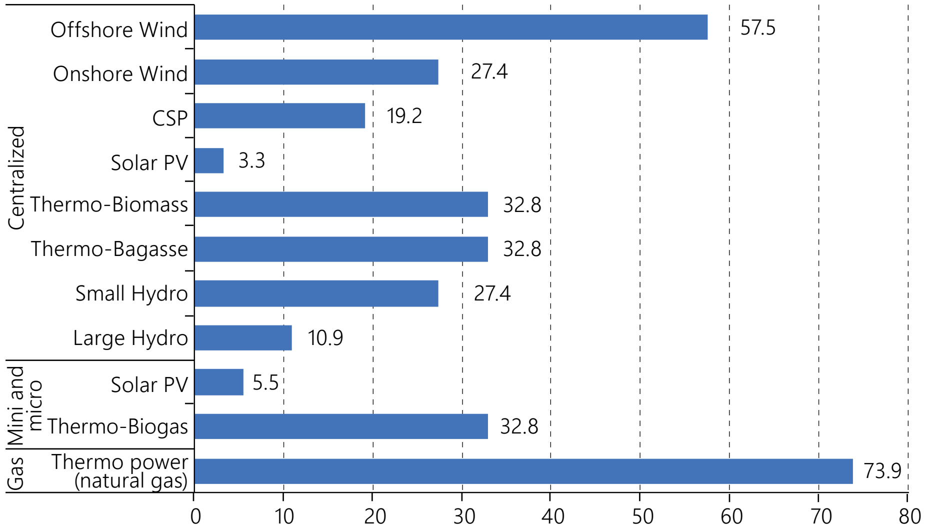


Source: Created by the authors based on Empresa de Pesquisa Energética (EPE), *Estudos Para a Expansão da Geração - Custo Marginal de Expansão do Setor Elétrico Brasileiro Metodologia e Cálculo – 2017*, Brasília, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), 2017; and Empresa de Pesquisa Energética (EPE), *Nota Técnica PR 07/18 - Premissas e Custos da Oferta de Energia Elétrica no Horizonte 2050*, Rio de Janeiro, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), November, 2018.

Operational costs (OPEX)

For comparison, operational cots regarding natural gas thermal power plants are also shown. Even though natural gas in cheaper in terms of the CAPEX, its OPEX is significantly higher than every other source examined, mainly due to fuel costs.

Figure 5
OPEX for power generation technologies
(In US$/kW/year)

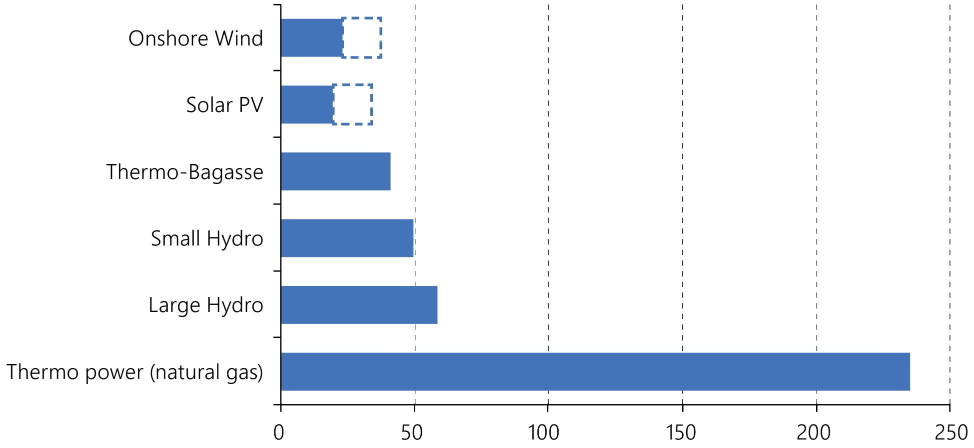


Source: Created by the authors based on Empresa de Pesquisa Energética (EPE), *Nota Técnica PR 07/18 - Premissas e Custos da Oferta de Energia Elétrica no Horizonte 2050*, Rio de Janeiro, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), November, 2018.

Total costs

For power generation LCES, total costs are presented in terms of the Levelized Cost of Electricity (LCOE; see annex 7 for details). The range in wind and solar PV is due to the fact that costs vary regionally, being lower in the Northeast region and higher in the South regions of Brazil. For comparison, total costs regarding natural gas thermal power plants are also shown. Natural gas costs are thus higher than the costs of the other analysed sources.

Figure 6
LCOE for centralized power generation technologies
(In US$/MWh)



Source: PSR, *Custos e Benefícios das Fontes de Geração Elétrica: Caderno de Geração*, Instituto Escolhas, August, 2018.

Energy diversity

Table 11
Contribution to energy diversity in 2017
(In percentages)

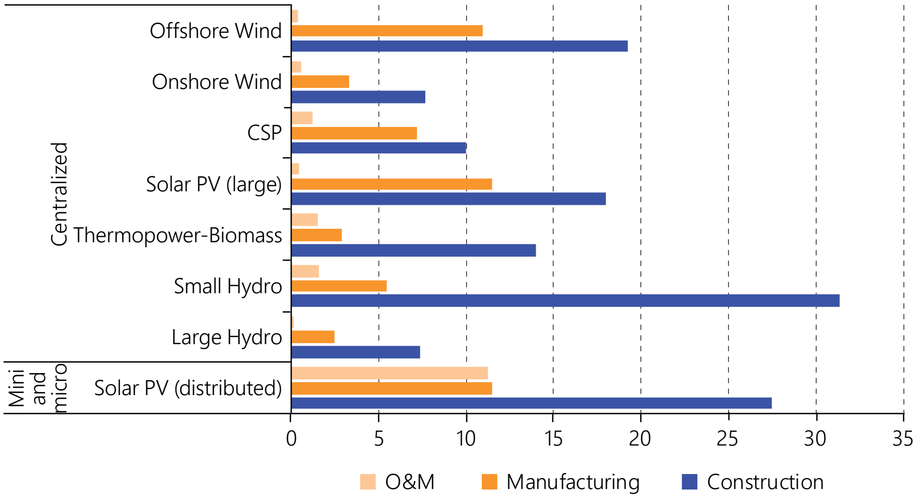
Power generation	Percentage of the power generation in the year
Centralized power generation	
Large hydro	not applicable
Small hydro	1.2
Thermopower (bagasse)	1.9
Thermopower (biomass)	0.3
Solar PV	0.2
CSP	not applicable
Onshore wind	2.5
Offshore wind	not applicable
Mini and micro power generation	
Thermopower (biogas)[a]	0.00
Solar PV	0.02

Source: Created by the authors based on Empresa de Pesquisa Energética (EPE), *Balanço Energético Nacional 2018: Relatório síntese*, ano base 2017, Brasília, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), 2018.
[a] Estimated.

Job creation

For power generation, jobs are presented for construction, manufacturing and operational phases. In the "sugar and alcohol" sector, power cogeneration units do not aggregate an expressive amount of direct jobs, since this activity is associated to the production of sugar and ethanol. Distributed solar power is a great source of jobs, especially in operations and maintenance (O&M) activities, because the activity is geographically diffuse.

Figure 7
Job creation for power generation technologies
(In jobs/MW or jobs/MW/year)



Source: Created by the authors based on Greenpeace, *Revolução Energética - Rumo a um Brasil com 100% de energias limpas e renováveis*, Rio de Janeiro, 2016; International Energy Agency (IEA), *World Energy Investment*, Paris, 2017; Empresa de Pesquisa Energética (EPE), *Nota Técnica EPE 026/2018 – Análise socioambiental das fontes energéticas do PDE 2027*, Rio de Janeiro, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), November; 2018; and International Renewable Energy Agency (IRENA), *Renewable Energy and Jobs: Annual Review 2019*, June, 2019.
Note: O&M stands for operations and maintenance.

Income generation

The direct, indirect and induced income generation were assessed for four power generation categories, according to data availability: large hydropower, solar photovoltaic, forest biomass thermopower and onshore wind.[7]

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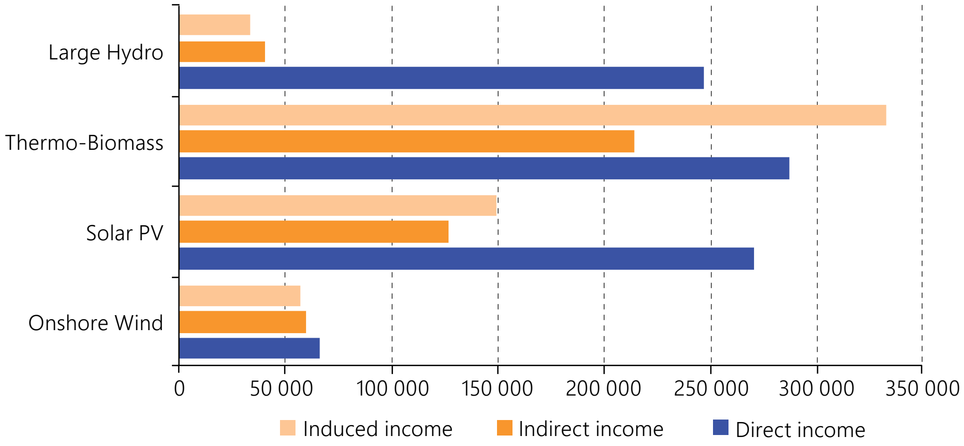
[7] Computations were performed using the Jedi model, which applies locally specific data for power generation projects as follows: data for the United States for hydropower, data for Mexico for solar PV, data for Colombia for wind and data for South Africa for biomass. Results should be interpreted taking this into consideration.

Figure 8
Income generation for centralized power generation technologies
(In thousand US$/MW/year)



Source: Created by the authors based on Companhia Ambiental do Estado de São Paulo (CETESB), "Emissões Veiculares no Estado São Paulo - Fator de Emissão 2018" [online], https://cetesb.sp.gov.br/ veicular/relatorios-e-publicacoes/, 2019.

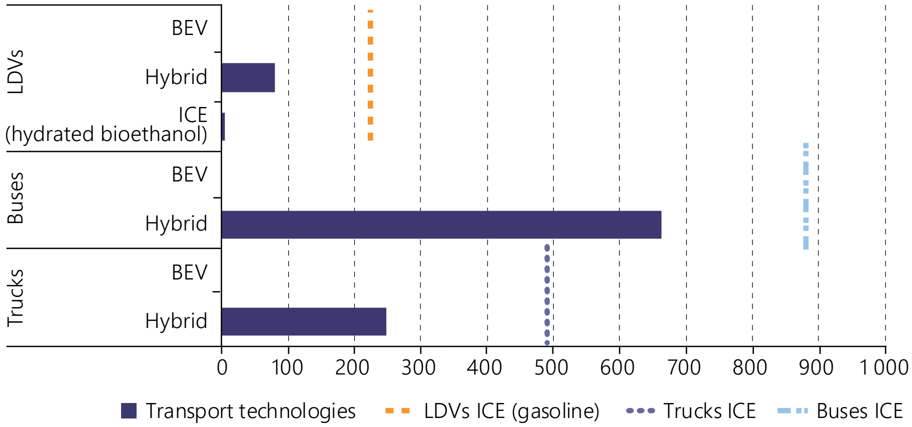
Transportation

Greenhouse gas emissions

For transportation technologies, the following premises were considered: hybrid vehicles require, in average, 50% less fuel[8] than the correspondent ICE vehicles; CO_2 emissions from bioethanol are zero, accounting for the biomass lifecycle; tailpipe emissions from battery electric vehicles (BEVs) are zero. Even though the grid emission factor may be computed in extended-scope analyses, this approach was not followed given the uncertainty regarding the grid emissions factor.

Even though trucks and buses run on diesel in Brazil, fuel consumption for trucks is lower than from urban buses, mainly due to the differences in driving conditions (e.g. stops, traffic).

Figure 9
GHG emissions for transportation technologies
(In gCO_2e/km)



Source: Created by the authors based on International Renewable Energy Agency (IRENA), *Renewable Energy and Jobs: Annual Review 2019*, June, 2019.
Note: LVDs stands for ligh-duty vehicles, BEV for battery-electric vehicles and ICE for internal engine combustion vehicles.

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[8] It depends on other factors, such as the type of hybrid vehicle, driving behavior and range.

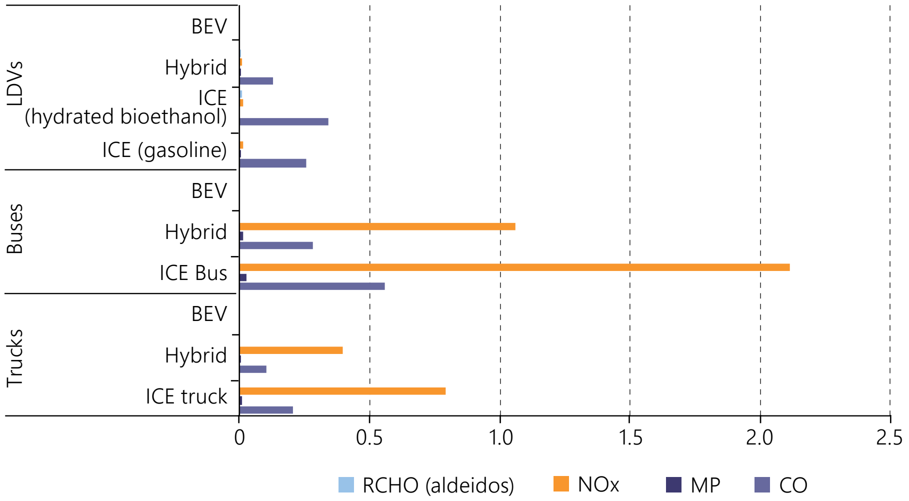
Non-GHG emissions

For transportation technologies, the main air pollutants analysed were carbon monoxide (CO), particulate matter (PM), nitrous oxides (NOx) and aldehydes (RCHO).

Among the assessed fuels, PM and aldehydes emissions are negligible. For ICE vehicles running exclusively on hydrated bioethanol, CO is the most expressive pollutant. For hybrid diesel vehicles, NOx is the most important source of air pollution.

For comparison, emission values for ICE conventional vehicles running on gasoline and diesel are also shown. For gasoline vehicles, CO is the most significant pollutant, but emissions are lower than for hydrated bioethanol ICE vehicles. And for diesel vehicles, NOx is the most significant pollutant, especially for urban buses.

Figure 10
Non-GHG emissions for transportation technologies
(In g/km)



Source: Created by the authors based on International Renewable Energy Agency (IRENA), *Renewable Energy and Jobs: Annual Review 2019*, June, 2019.
Note: LVDs stands for ligh-duty vehicles, BEV for battery-electric vehicles and ICE for internal engine combustion vehicles.

Technology readiness level (TRL)

The TRL for transportation technology was also defined according to internal communication with the International Energy Agency.

Table 12
Technology Readiness Level (TRL) for transportation technologies

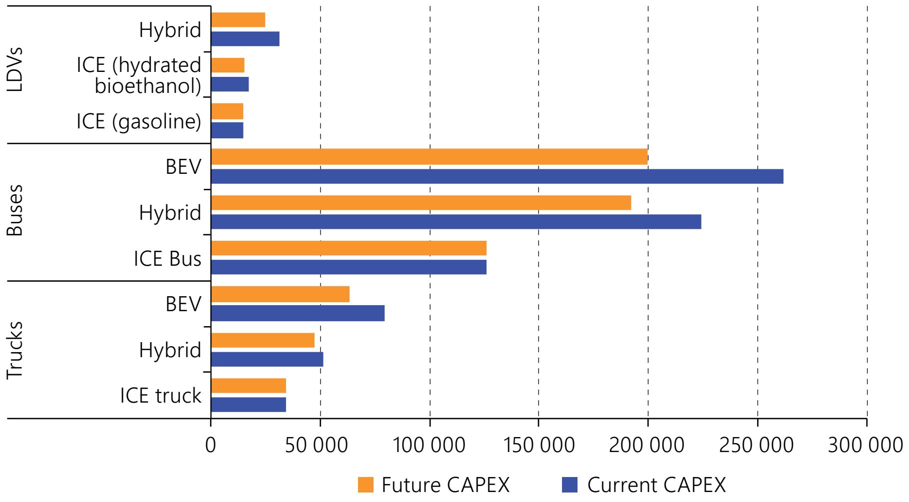
LCES	TRL
Hybrid LDV	9
BEV LDV	9
ICE LDV	9
Hybrid Bus	9
BEV Bus	8
Hybrid Truck	8
BEV Truck	8

Source: Created by the authors based on internal communication with IEA.
Note: LVDs stands for ligh-duty vehicles, BEV for battery-electric vehicles and ICE for internal engine combustion vehicles.

Capital production costs (CAPEX)

For vehicles, data is presented both in current costs (most recent available data) and future estimates (comprising the period of 2025 to 2030). For comparison, CAPEX values for ICE vehicles are also shown. For all cases, CAPEX for conventional ICE vehicles is currently lower than the CAPEX for the assessed alternative technologies. However, reductions are expected for some technologies, especially for those currently with TRL 8 (see Chapter II).

Figure 11
CAPEX for transportation technologies
(In thousand US$/vehicle)

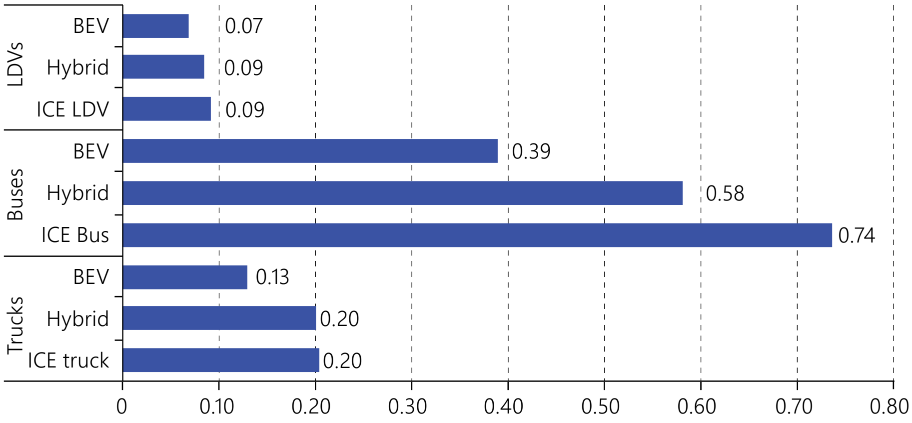


Source: Created by the authors based on C40, *Low carbon technologies can transform Latin America's bus fleets*, C40 Cities, Climate Leadership Group, Clinton Foundation, Inter American Development Bank, July, 2013; Delft, *Zero emissions trucks: An overview of state-of-the-art technologies and their potential*, Stuttgart, July, 2013; Docklands Light Railway (DLR), *Project Report: Alternative Transport Technologies for Megacities*, German Aerospace Centre, Institute of Vehicle Concept, Stuttgart, February, 2015; Greenpeace, *Dossiê Ônibus Limpo: Benefícios de uma transição para combustíveis renováveis na frota de São Paulo*, São Paulo, August, 2016; International Council on Clean Transportation (ICCT), *PROMOBE: Avaliação Internacional de Políticas Públicas para Eletromobilidade em Frotas Urbanas*, Brasília, Agência Alemã de Cooperação Internacional/Ministério da Indústria, Comércio Exterior e Serviços (GIZ/MDIC), November, 2019; and Union of Concerned Scientists (UCS), "Electric Vehicle Batteries: Materials, Cost, Lifespan" [online] https://www.ucsusa.org/resources/ev-batteries, 2018.
Note: LVDs stands for ligh-duty vehicles, BEV for battery-electric vehicles and ICE for internal engine combustion vehicles.

Operational costs (OPEX)

For comparison, OPEX values for ICE vehicles are also shown. For all cases, OPEX for conventional ICE vehicles is higher than the OPEX for the assessed alternative technologies. This is due to higher fuel expenses and also to the higher maintenance requirements of ICE vehicles when comparing to BEVS for example, which have fewer components than ICE.

Figure 12
OPEX for transportation technologies
(In US$/km)

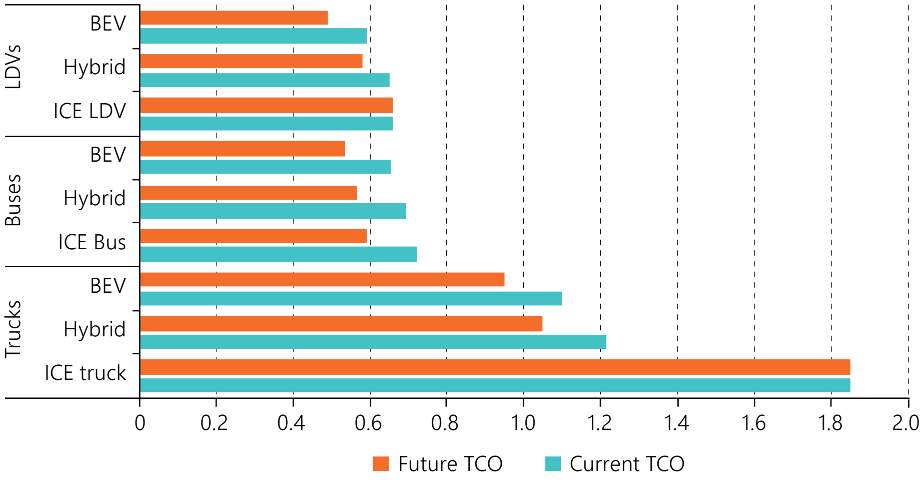


Source: Created by the authors based on International Council on Clean Transportation (ICCT), *PROMOBE: Avaliação Internacional de Políticas Públicas para Eletromobilidade em Frotas Urbanas*, Brasília, Agência Alemã de Cooperação Internacional/Ministério da Indústria, Comércio Exterior e Serviços (GIZ/MDIC), November, 2019; Union of Concerned Scientists (UCS), "Electric Vehicle Batteries: Materials, Cost, Lifespan" [online] https://www.ucsusa.org/resources/ev-batteries, 2018; and International Energy Agency (IEA), *World Energy Outlook 2018*, IEA, Paris, 2018.
Note: LVDs stands for ligh-duty vehicles, BEV for battery-electric vehicles and ICE for internal engine combustion vehicles.

Total costs

For transportation LCES, total costs are presented in terms of the Total Cost of Ownership (TCO; see annex 7 for details). In terms of TCO, hybrid and electric vehicles are currently more competitive than ICE vehicles, mainly due to the lower OPEX, as shown previously. Moreover, reductions are yet expected.

Figure 13
TCO for transportation technologies
(In US$/km)



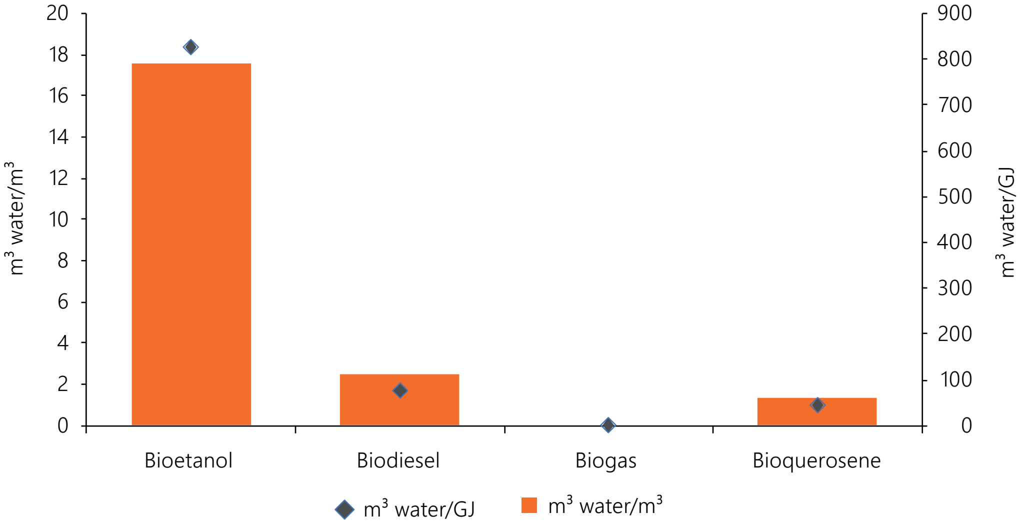
Source: Created by the authors based on International Council on Clean Transportation (ICCT), *PROMOBE: Avaliação Internacional de Políticas Públicas para Eletromobilidade em Frotas Urbanas*, Brasília, Agência Alemã de Cooperação Internacional/ Ministério da Indústria, Comércio Exterior e Serviços (GIZ/MDIC), November, 2019; Hagman, Jeans and others, "Total cost of ownership and its potential implications for battery electric vehicle diffusion", *Research in Transportation Business & Management*, vol. 18, March, 2016; Lajunen, Antti and Timothy Lipman, "Lifecycle cost assessment and carbon dioxide emissions of diesel, natural gas, hybrid electric, fuel cell hybrid and electric transit buses", *Energy*, vol 106, July, 2016; and International Energy Agency (IEA), *IEA G20 Hydrogen report: Assumptions*, Paris, 2019.
Note: LVDs stands for ligh-duty vehicles, BEV for battery-electric vehicles and ICE for internal engine combustion vehicles.

Biofuels

Water use

Only water use for biofuel processing during industrial phase was considered. Irrigation during the agricultural phase was not computed, due to a great diversity of crops and Brazilian agricultural practices that rarely uses irrigation for feedstock production for biofuels.

Figure 14
Water use for biofuels technologies
(In m^3 water/GJ and m^3 water/m^3 biofuel)



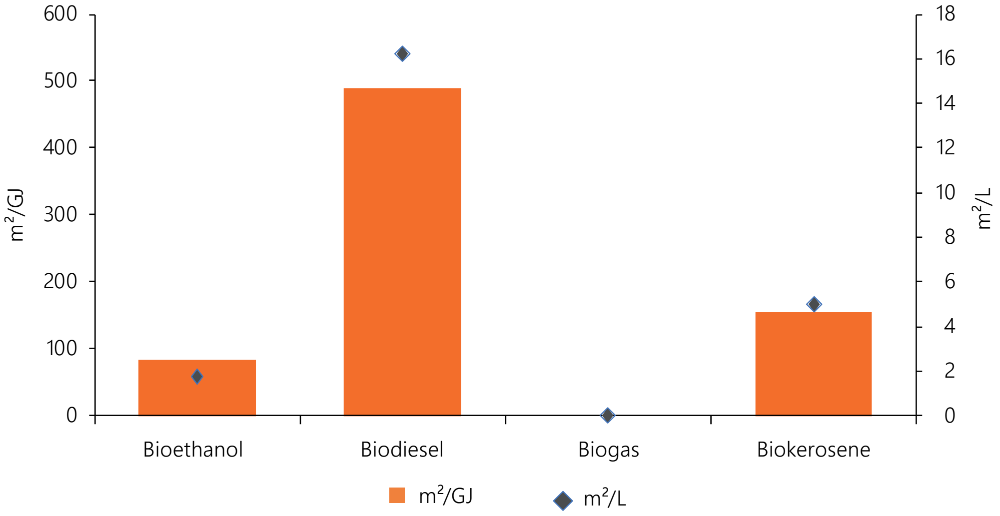
Source: Created by the authors based on Agência Nacional do Petroleo, Gás Natural e Biocombustíveis (ANP), "RenovaCalc 2019" [online], www.anp.gov.br › images › Consultas_publicas › CP10-2018_Calculadora, 2019.

Land use

For biofuels, land use is primarily related to agricultural crops dedicated to (non-residual) biomass supply. However, it is necessary to take into account that biofuels are co-products of agricultural crops in Brazil, which in the case of soybeans or corn, for example, are extracted concurrently, without competing with the production of the protein for food use.

Land requirements for biodiesel are higher than for bioethanol because the productivity of sugarcane cultures is much higher (ten times higher) than of soybeans, main raw material for the production of biodiesel in Brazil. Also, the amount of biokerosene is higher than the amount of biodiesel produced from soybean. For biogas, land requirements are null, as the source is residual.

Figure 15
Land use for biofuels technologies
(In m^2/GJ and m^2/L)

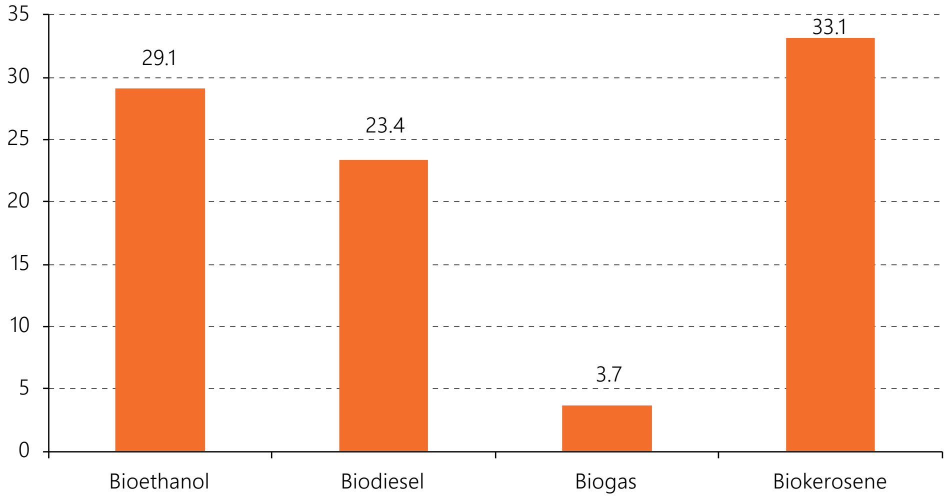


Source: Created by the authors based on Agência Nacional do Petroleo, Gás Natural e Biocombustíveis (ANP), "RenovaCalc 2019" [online], www.anp.gov.br › images › Consultas_publicas › CP10-2018_Calculadora, 2019.

Greenhouse gas emissions

For biofuels, agricultural and industrial processing phases were considered (emissions from combustion are accounted within the transportation sector). Emissions from field burning in agriculture are out of the scope of this indicator and becoming an outdate practice.

Figure 16
GHG emissions for biofuels technologies
(In gCO_2e/MJ)



Source: Created by the authors on Agência Nacional do Petroleo, Gás Natural e Biocombustíveis (ANP), "RenovaCalc 2019" [online], www.anp.gov.br › images › Consultas_publicas › CP10-2018_Calculadora, 2019.

Technology readiness level

The TRL was defined according to internal communication with the International Energy Agency (IEA).

Table 13
Technology Readiness Level (TRL) for biofuels technologies

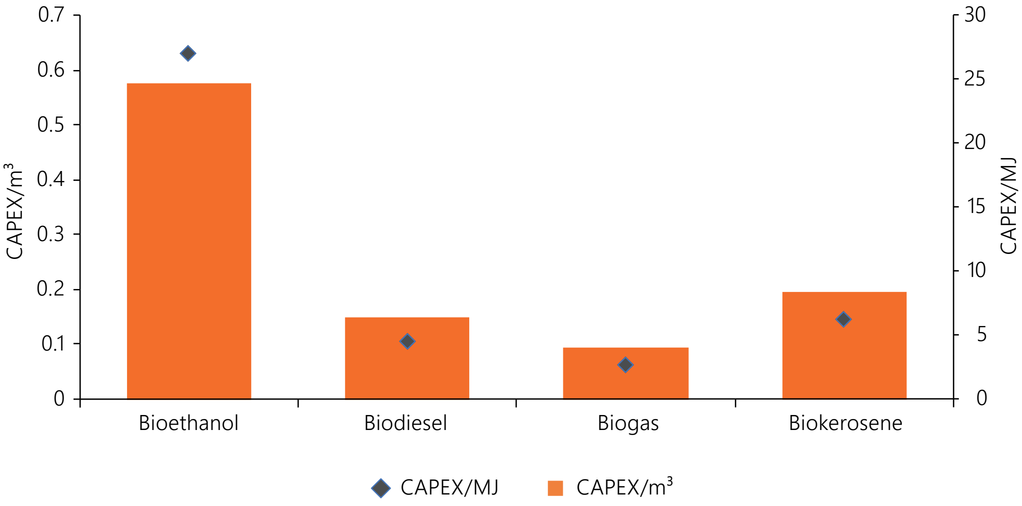
LCES	TRL
Bioethanol	9
Biodiesel	9
Biogas	9
Biokerosene	8

Source: Created by the authors based on internal communication with IEA.

Capital production costs (CAPEX)

For biofuels, there were no future estimates of cost evolution due to data gaps.

Figure 17
CAPEX for biofuels technologies
(In US$/MJ and US$/m³)

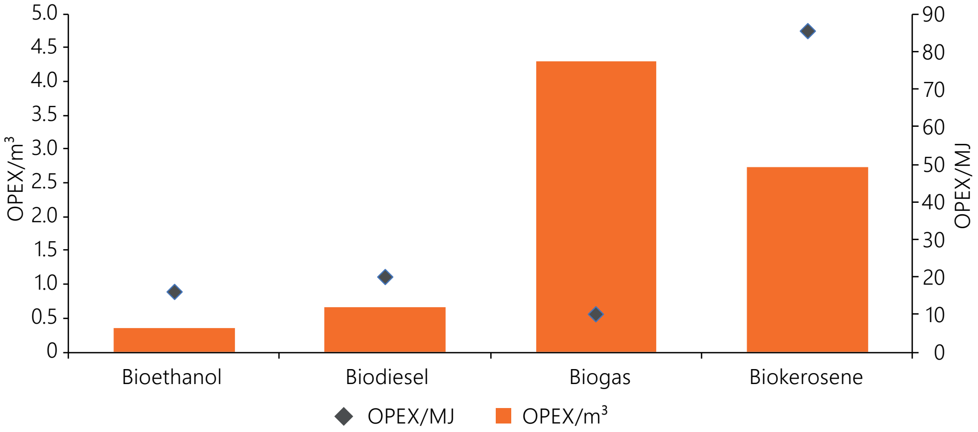


Source: Created by the authors based on Carvalho, Francielle, "Evaluation of the Brazilian Potential for Producing Aviation Biofuels through Consolidated Routes", *Masters dissertation*, Programa de Pós-graduação em Planejamento Energético, COPPE, Universidade Federal do Rio de Janeiro, February, 2017; Régis Rathmann (org.), *Modelagem integrada e impactos econômicos de opções setoriais de baixo carbono*, Ministério da Ciência, Tecnologia e Inovações (MCTI), ONU Meio Ambiente, Brasília, 2017; and Empresa de Pesquisa Energética (EPE), *Nota Técnica EPE 019/2018 – Estudo sobre a Economicidade do Aproveitamento dos Resíduos Sólidos Urbanos em Aterro para Produção de Biometano*, Rio de Janeiro, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), August, 2018.

Operational costs (OPEX)

Lower OPEX values for bioethanol, biodiesel and biogas are due to the fact that the inputs for biofuel production are coproducts of other activities (e.g. soybean protein and agricultural residues).

Figure 18
OPEX for biofuels technologies
(In US$/MJ and US$/m³)

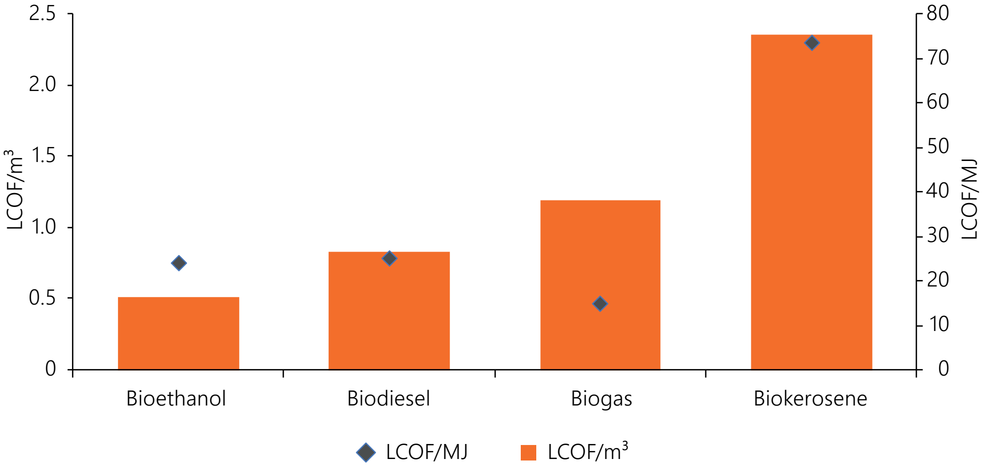


Source: Created by the authors based on Carvalho, Francielle, "Evaluation of the Brazilian Potential for Producing Aviation Biofuels through Consolidated Routes", *Masters dissertation*, Programa de Pós-graduação em Planejamento Energético, COPPE, Universidade Federal do Rio de Janeiro, February, 2017; Régis Rathmann (org.), *Modelagem integrada e impactos econômicos de opções setoriais de baixo carbono*, Ministério da Ciência, Tecnologia e Inovações (MCTI), ONU Meio Ambiente, Brasília, 2017; and Empresa de Pesquisa Energética (EPE), *Nota Técnica EPE 019/2018 – Estudo sobre a Economicidade do Aproveitamento dos Resíduos Sólidos Urbanos em Aterro para Produção de Biometano*, Rio de Janeiro, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), August, 2018.

Total costs

For biofuels, total costs are presented in terms of the Levelized Cost of Fuel (LCOF; see annex 7 for details).

Figure 19
LCOF for biofuels technologies
(In US$/MJ and US$/m³)



Source: Created by the authors based on Carvalho, Francielle, "Evaluation of the Brazilian Potential for Producing Aviation Biofuels through Consolidated Routes", *Masters dissertation*, Programa de Pós-graduação em Planejamento Energético, COPPE, Universidade Federal do Rio de Janeiro, February, 2017; Régis Rathmann (Org.), *Modelagem integrada e impactos econômicos de opções setoriais de baixo carbono*, Ministério da Ciência, Tecnologia e Inovações (MCTI), ONU Meio Ambiente, Brasília, 2017; and Empresa de Pesquisa Energética (EPE), *Nota Técnica EPE 019/2018 – Estudo sobre a Economicidade do Aproveitamento dos Resíduos Sólidos Urbanos em Aterro para Produção de Biometano*, Rio de Janeiro, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), August, 2018.

Energy diversity

Table 14
Contribution to energy diversity in 2018
(In percentages)

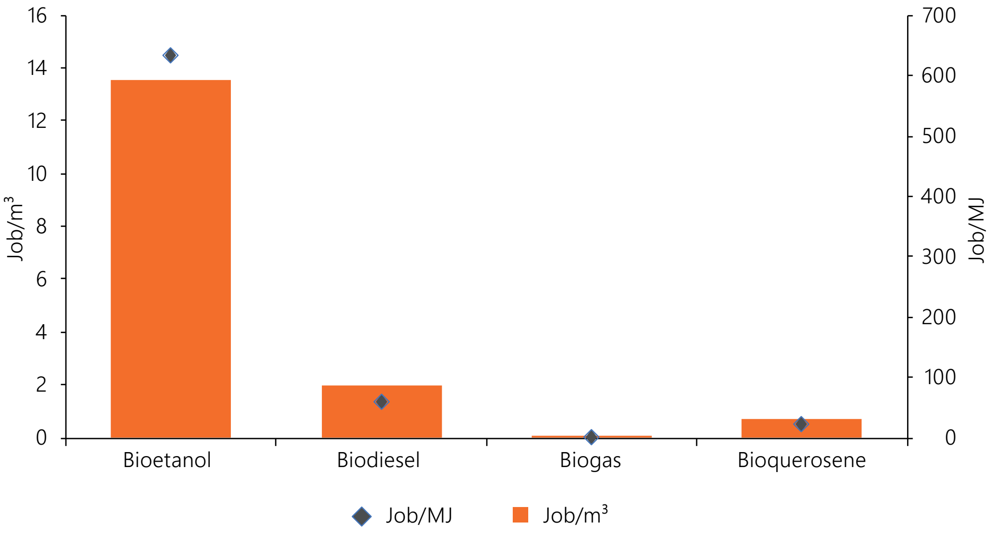
Biofuels	Percentage for the energy matrix in the year
Bioethanol	28.1
Biodiesel	11.5
Biogas	n.a.
Biokerosene	not applicable

Source: Created by the authors based on Empresa de Pesquisa Energética (EPE), *Balanço Energético Nacional 2018: Relatório síntese, ano base 2017, Brasília*, Ministério de Minas e Energia/Empresa de Pesquisa Energética (MME/EPE), 2018.

Job creation

For biofuels, the agricultural and biofuel processing phases are considered aggregately. According to REN21 (2019), for bioethanol, agricultural and biofuel processing are considered. However, for biodiesel, the phases considered are not specified. Hence, different assumptions in this sense may explain the differences in job creation values. Nevertheless, it is known that soybean cultivation is less intensive in human resources than sugarcane. For biogas, job creation was considered negligible because jobs are associated to the landfill activity.

Figure 20
Job creation for biofuels technologies
(In job/MJ and job/m³)



Source: Created by the authors based on Agencia Nacional do Petroleo, Gás Natural e Biocombustíveis (ANP), "RenovaCalc 2019" [online], www.anp.gov.br › images › Consultas_publicas › CP10-2018_Calculadora, 2019; REN21, *Renewables 2019 - Global Status Report*, Paris, 2019; and Wei, Max, Shana Patadia e Daniel Kammen, "Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?", *Energy Policy*, vol. 38, ed. 2, February, 2010.

IV. Final remarks, recommendations and future developments

This study presents a set of performance indicators for selected low-carbon energy technologies in Brazil. The exercise sought to contemplate all dimensions of sustainable development by considering indicators from different pillars: environmental, techno-economic, social and political-institutional.

Estimations were carried out for 11 of the 26 initially proposed indicators, based on feasibility, availability and quality of data, as well as the particularities of the Brazilian context. The finding that not all indicators could be estimated reveals significant data gaps, constraints and challenges for developing a comprehensive set of energy technology performance indicators on multiple dimensions of sustainable development. In addition, not every indicator is applicable to every technology, which illustrates comparability challenges.

The main findings of this study, endorsed by experts and stakeholders on the Energy Big Push Workshop in October 2019, reveal that there is no "one-size fits all" indicator, and some of them only allow a qualitative analysis. In addition, potential interlinkages among indicators and how these might differ under joint uptake of multiple technologies simultaneously should be considered. The isolated analysis of one indicator alone may lead to misinterpretation. Information provided by different indicators is often complementary across the dimensions of sustainable development, which underlines the importance of having a panel of indicators, instead of considering single indicatos. A cross-cutting analysis of diverse indicators is necessary to enable a comprehensive understanding of energy technologies performance.

Another key finding of the present study is that the panel of indicators considered showed that no technology outperforms others in every aspect, which suggests that a mix of technologies should be developed if multiple social, economic and environmental goals are to be achieved. This finding emphasizes the need for coordination for an Energy Big Push in Brazil.

As with any quantitative exercise, the quality of the estimates produced depend on the availability, robustness and reliability of the collected data and information, as well as the accuracy of the analysis method employed. In this sense, the work carried out under Axis 2 of EBP represents an advancement in reviewing and compiling multiple indicators of low-carbon energy solutions in Brazil. However, there is fertile ground for future developments in order to improve the quality, comparability and coverage of the indicators panel on low-carbon energy solutions in the country.

Other indicators were identified as relevant for policy design and should be considered as an area for future development. These include intermittency and reliability of energy sources, co-benefits, potential pressure on land use, skills requirements for technology deployment, innovation metrics, as well as time and space dimensions of indicators. In addition, indicators may be further enhanced by considering all stages of energy production and use. A life-cycle assessment that takes into account the agricultural phase (if applicable), supply chain and discard/decommissioning is underlying to cover all relevant aspects of decision-making. These are, however, beyond the scope of this phase of the project.

The relevance of indicators is another topic raised by experts. The relevance of indicators many vary according to the decision-making process that they inform. Methods such as multicriteria analysis and Delphi questionnaires for qualitative assessments may be important tools to identify priorities.

Considering the aspects above, a major priority for action is to further identify the existing data gaps and harmonization requirements to improve and expand indicators quantification. Better cohesion of data sources is key to ensure intercomparability among technologies and allow for international comparability. A detailed diagnosis would allow pinpointing the institutions in charge of providing such data on a regular basis, in order to keep track of progress. In this sense, it would be convenient to increase the number of institutions engaged in the process, which can contribute to it.

Finally, it is important to identify mechanisms capable of ensuring the continuity of indicator development, outreach and adoption. Given the fast pace of innovation and technological development in the energy sector, cost reductions and efficiency gains are expected for some technologies in the mid-term, as well as other developments that require continuously updating the indicators.

A well-conceived panel of indicators, firmly grounded on robust data, can be a useful navigation tool for decision makers, by providing evidence that can help continuously adjust the course of action towards the sustainability of the development that they aim to achieve. Such a panel of indicators is vital to inform the appropriate combination, for the context of the Brazil, of complementary and coordinated investments for an Energy Big Push in Brazil, that helps build more sustainable, resilient and low-carbon energy matrix and, at the same time, promotes more inclusive, efficient and competitive economy.

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Annex 7
Total cost assessment methodology

1. Total costs for power generation are expressed as the Levelized Cost of Electricity (LCOE):

$$LCOE = \frac{IC \bullet FRC}{CF} + \frac{FOMC}{CF} + VOM + HR * FC$$

Where:

LCOE - levelized cost of electricity (US$/MWh)

IC - capital cost

FRC - annual capital recovery factor

CF - capacity factor

FOM - fixed operational costs

VOM - variable operational costs

HR - utility heat rate

FC - fuel cost

2. Total costs for transportation are expressed as the Total Cost of Ownership (TCO) of a single vehicle:

$$TCO = \left(PP - RP\right) + FC\left(TKD\right) + \left(\frac{rP}{1 - \left(1 + r\right)^{-N}} N - P\right) + IC + MR + T - S$$

Where:

TCO - total cost of ownership for the proprietorship (US$/km)

PP - purchasing price

RP - resell price (in the end of the ownership period)

FC - fuel cost per kilometre

TKD - total kilometres driven

r - monthly interest rate

P - amount borrowed (if applicable)

N - number of monthly interest payments (if applicable)

IC - insurance cost

MR - maintenance and repair costs

T - taxes

S - subsidies

3. Total costs for biofuels are expressed as the Levelized Cost of Fuel (LCOF):

$$LCOF = \frac{\frac{IC}{T.\sum_{1}^{t}(1+tx)^{t}} + \frac{FOM + VOM}{\sum_{1}^{n}(1+tx)^{n}}}{\frac{C}{\sum_{1}^{n}(1+tx)^{n}}}$$

Where:

LCOF - levelized cost of fuel (in US$/litre or m3)

IC - capital cost

FOM - fixed operational costs

VOM - variable operational costs

tx - discount rate

C - annual generation capacity (litres)

T - construction time

N - lifespan

Annex 8
Assumptions for power generation technologies

Table A1
Construction time and lifespan power generation technologies (years)

Technology	Construction time	Lifespan
Large Hydro	5	30
Small Hydro	3	30
Thermopower-Biomass	2	20
Solar PV (large)	2	20
CSP	3	20
Onshore Wind	3	20
Offshore Wind	3	20
Solar PV (distributed)	1	20

Source: Created by the authors.

Today, Brazil and many countries around the world are seeking to stimulate economic recovery and improve people's quality of life. In this context, the Economic Commission for Latin America and the Caribbean (ECLAC) of the United Nations has been developing the Big Push for Sustainability, a renewed approach to support the efforts of the countries of the region to design more sustainable development models, by coordinating policies to promote investments that will transform existing models.

The ECLAC office in Brasilia and the Center for Strategic Studies and Management (CGEE), in conjunction with various partners, developed the Energy Big Push Brazil project, which provides evidence to promote innovation investment for a sustainable energy transition in Brazil. This publication aims to enhance readers' understanding of the environmental, social and economic performance of different low-carbon energy technologies in the power generation, transportation and biofuels sectors, contributing to an energy big push in Brazil.

ECLAC

Economic Commission for Latin America and the Caribbean (ECLAC)
Comisión Económica para América Latina y el Caribe (CEPAL)
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