Climate Change Management

Walter Leal Filho
José Baltazar Salgueirinho de Andrade Guerra *Editors*

Water, Energy and Food Nexus in the Context of Strategies for Climate Change Mitigation

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Climate Change Management

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José Baltazar Salgueirinho de Andrade Guerra
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Preface

It is widely known that matters related to water, energy and food are interrelated, especially in a context of sustainable development and against the background of a changing climate. There is a perceived need to foster an integrated understanding of them and to adapt institutional frameworks, so that they be better understood.

This need has been highlighted for many years. Paradoxically, despite the number of recommendations and suggestions made in respect of the consideration of water, energy, food, sustainable development and climate change, little progress has been achieved. These items are still seen and being tackled in separate. This states of affairs suggest that specialist publications are needed, in order to move things forward in a more systematic way.

One of these basics needs is to acknowledge that it is necessary to address the fragmented nature of the handling of these issues, in research efforts as a whole, and in teaching in particular. Improvements are needed not only in respect of ways to cater for an integrated emphasis of these themes in the curriculum, but also on how to handle and promote issues related to sustainable development, water, energy, food and climate change at multiple levels (e.g., industry, academia, community) with a focus on the many interplays and interlinkages. Also, the development of flexible means to consider and understand them is greatly needed.

A sustainability transition in the WEF nexus involves improving resilience of all its components, which include land-use, trade, energy production and water management. Understanding the science of these connections is not enough, however, because changes of policy, legal frameworks and regulatory compliance act to influence and re-orient the system in subtle interrelated ways. Such changes, therefore, need to be extremely well informed by science in order not to lead to unintended consequences (e.g., generating energy poverty with emissions reduction policy, barring access to water with pricing policies, destruction of ecosystems due to land policy for creating jobs, etc). Thus, a qualified science-policy dialogue can become crucial for informing effective policy-making and environmental law that reach stated objectives.

Consistent with the perceived need for action in this field, the book *Water, Energy and Food Nexus in the Context of Strategies for Climate Change Mitigation* has been prepared by the Centre for Sustainable Development (Greens), from the University of Southern Santa Catarina (Unisul), in the context of the project BRIDGE—Building Resilience in a Dynamic Global Economy: Complexity across scales in the Brazilian Food-Water-Energy Nexus, funded by Newton Fund, Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC), Coordenação de Aperfeiçoamento de Pessoal de Nível superior (CAPES), National Council for Scientific and Technological Development (CNPq) and the Research Councils United Kingdom (RCUK).

The experiences gathered in the book will useful to those interested at or working in the field of water, food, sustainable development and climate change, and may support current and future efforts towards innovation on the one hand, and teaching and research practice on the other.

Enjoy the reading.

Spring 2021

Walter Leal Filho
José Baltazar Salgueirinho de Andrade Guerra

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Chapter 1
Phosphorus Removal from Municipal Wastewater by Electrocoagulation Associated with Biological Treatment

Hioná Valéria Dal Magro Follmann, Caroline Rodrigues, Emerson Souza, Flávio Rubens Lapolli, and María Ángeles Lobo-Recio

Abstract The phosphorus present in wastewater is a global concern, given the environmental problems that its excessive presence in aquatic environments can cause, such as deterioration of water quality, eutrophication and loss of aquatic life. Thereby, its removal becomes highly desirable. Thus, the main purpose of this study was to evaluate the efficiency of the electrocoagulation process in the removal of the phosphorus present in municipal wastewater. This study was developed on a bench scale, using an electrocoagulation reactor associated with biological treatment, equipped with an aluminum anode and a stainless-steel cathode. In parallel, a bioreactor with no electric current was operated (control), for comparison purposes. The results showed that the phosphorus removal in the electrocoagulation reactor was 100% after 7 h. The phosphorous decay over time shows probable first-order kinetics. In the control reactor, the removal was 40.75% after the same operation time. The electric current application did not impair the biological process, providing an increase in NH_4^+-N and COD removal. Thus, electrocoagulation is proven to be an efficient

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technological method for the removal of phosphorus from municipal wastewater, with its application possible in association with biological processes.

Abbreviations

BOD	Biological oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
EBPR	Enhanced biological phosphorus removal
PAO	Phosphate accumulating organisms
TSS	Total suspended solids

Introduction

Phosphorus is usually found in wastewater as orthophosphate (the soluble form), polyphosphate and organic phosphate (Irdemez et al. 2006). The release of these effluents into watercourses can generate serious problems of pollution, especially eutrophication, due to the excessive assimilation of orthophosphate by algae, bacteria and plants (Correll 1998).

Biological processes are widely used in municipal wastewater treatment. However, there are some disadvantages in phosphorous removal, such as a long period of treatment and low phosphorus removal (Kim et al. 2010). The removal via cellular synthesis represents about 10–20% of the overall process efficiency (Metcalf and Eddy 2014). Meanwhile, the Enhanced Biological Phosphorus Removal, known as EBPR, is difficult due to inherent process limitations: it requires intermittence between anaerobic and aerobic environments (Nguyen et al. 2016). In anaerobic conditions, phosphate accumulating organisms (PAO's) release intracellular phosphate, and under aerobic conditions, they absorb a greater amount of phosphorus than that required for their metabolism, resulting in a low phosphorus effluent and a polyphosphate-rich sludge (Oehmen et al. 2007). Although this biological process is reasonable, the requirement of different environments and the maintenance of some parameters - such as temperature close to 20 °C, low nitrate content in the anaerobic stage and minimum ratio of soluble BOD:P of 15:1- can make the operation difficult (Kim et al. 2010; Zheng et al. 2014).

Therefore, it is necessary to search for other technologies regarding phosphorus removal. The electrocoagulation process has been used as an alternative, presenting advantages to conventional treatments, such as ease of operation and reduced sludge production (Omwene et al. 2018). The electrochemical reactions that occur at the anode and cathode, using an aluminum anode, are described in Eqs. 1.1 and 1.2, and the reaction between the ions released by the electrodes is described in Eq. 1.3

(Missaoui et al. 2013). Equations 1.4 and 1.5 describe the reactions involved in the phosphorus removal by electrocoagulation (Wei et al. 2012).

At the anode:

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^{-} \quad (1.1)$$

At the cathode:

$$2H_2O_{(l)} + 2e^{-} \rightarrow 2OH^{-}_{(aq)} + H_{2(g)} \quad (1.2)$$

In solution:

$$Al^{3+}_{(aq)} + 3H_2O \rightarrow Al(OH)_{3(s)} + 3H^{+}_{(aq)} \quad (1.3)$$

$$Al^{3+} + PO_4^{3-} \rightarrow AlPO_{4(s)} \quad (1.4)$$

$$3Al^{3+} + 2PO_4^{3-} + 3H_2O \rightarrow (AlOH)_3(PO_4)_{2(s)} + 3H^{+} \quad (1.5)$$

In the electrocoagulation process, the coagulant ions are released by the anode, usually Al^{3+}, and they may react with the soluble phosphate ($PO_4{}^{3-}$), giving rise to an insoluble species ($AlPO_4$), that is easily sedimented (Eq. 1.4) (Attour et al. 2014). Moreover, the $Al(OH)_3$ formed during the process (Eq. 1.3), due to the reaction between the metal ions (Al^{+3}) and the hydroxyl ions (OH^{-}) produced by the cathode (Eq. 1.2), react with $PO_4{}^{3-}$, which precipitates into $(AlOH)_3(PO_4)_2$ (Eq. 1.5) (Wei et al. 2012). In addition, the high surface area of $Al(OH)_3$ contributes to the adsorption of soluble phosphorus species (Bani-Melhem and Smith 2012).

A significant advantage of electrocoagulation is that it does not depend on the control of several parameters, such as temperature, organic matter and absence of nitrate, that on a real scale are difficult to control. Besides that, it can be associated with the biological process in a single reactor, not requiring an additional unit for phosphorus removal (Alshawabkeh et al. 2004). However, it is necessary to apply low intensity currents and intermittent exposure modes in order to avoid damage to the biomass (Bani-Melhem and Elektorowicz 2011).

In this sense, the present study aimed to evaluate the $PO_4{}^{3-}$-P removal from municipal wastewater by electrocoagulation associated with biological treatment. This removal over time was evaluated in order to determine the required time for efficient removal, as well as to perform the kinetic study.

Materials and Methods

Experimental Unit

In this study, two reactors were used on a bench scale of 1 L capacity each with an air diffuser installed at each base, in order to maintain aerobic conditions and ensure adequate mixing in the reactors. One reactor, named the electrobioreactor, was equipped with a pair of electrodes of dimensions 5.65 × 13.9 cm, spaced apart by 5 cm. The anode was made of flat aluminum plates with 46.335 cm^2 of useful area; the cathode consisted of a thin stainless-steel screen. This reactor was connected to a digital power supply (PS-A305D) to control the applied current density, with a voltage varying from 0 to 30 V and a current from 0 to 5 A, and a timer for setting the exposure mode. The second reactor, named the control, was operated in parallel without electric current application, for comparison purposes. Figure 1.1 shows the representation of the experimental unit used in the study.

Mixed Liquid

The mixed liquid was collected from an aeration tank of an activated sludge system of a municipal wastewater treatment station located in Florianópolis, Brazil. The samples were sedimented to remove the supernatant in order to maintain the suspended solids contents at about 5000 mg L^{-1}, and were standardized for the initial phosphate concentration to approximately 5 mg L^{-1}, by adding potassium dihydrogen phosphate (KH_2PO_4).

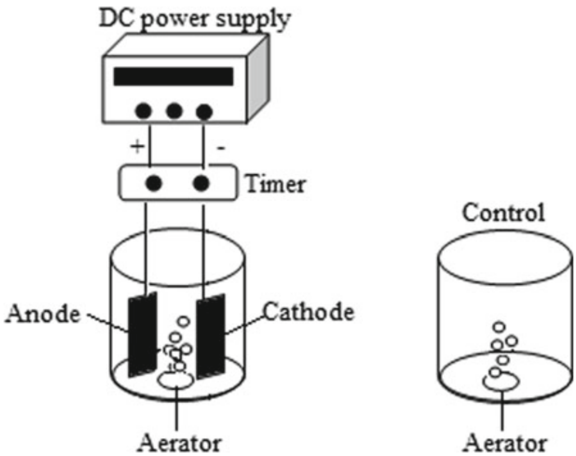

Fig. 1.1 Representation of the electrocoagulation unit used in this study for phosphorus removal

Table 1.1 Analytical methods for characterization of wastewater before and after treatments

Parameter	Method	Equipment
PO_4^{3-}-P	Molybdovanadate acid[a]	Spectrophotometer Hach 5000
NH_4^+-N	Salicylate method[a]	
COD	Reactor digestion method[a]	
Al^{3+}	Aluminon[a]	
TSS	Gravimetric[a]	Benchtop oven
pH	Potentiometric	pH meter thermo fisher
DO	Polarographic sensor	Oximeter YSI-55
Conductivity	Amperometric	Probe Hanna HI-991300

[a]Adapted from (APHA 2012)

Experimental Procedure

Both reactors were inoculated with 800 mL of mixed liquid each, starting the process under complete mixture and constant aeration and temperature (8.63 mg L^{-1} DO and 17.4 °C, respectively). The electrobioreactor was operated under a current density of 10 A m^{-2} and an exposure mode of 6′ON/18′OFF (Battistelli et al. 2019). At specified time intervals (1, 2, 3, 4, 5, 6 and 7 h), a 10 mL aliquot was taken from both reactors and filtered under vacuum through a cellulose acetate membrane (0.45 μm of pore diameter) for PO_4^{3-}-P analysis. After 7 h, the filtrate was also analyzed for the concentrations of NH_4^+-N and COD, in order to evaluate whether the electric current application impaired the biological treatment process, and for the soluble Al^{3+} concentration in order to evaluate the release of aluminum after the electrocoagulation process. These analyses were made according to the *Standard Methods of Water and Wastewater* (APHA 2012) and are summarized in Table 1.1.

Kinetic Study

In the case of a mixed liquid being treated in a batch reactor, at constant temperature and volume, presenting a decay of PO_4^{3-}-P concentration, these experimental data can be interpreted: a rate equation is achieved if a reasonably linear fit is obtained (Levenspiel 1999). This way, in the integral method of analysis, a particular form of rate equation (Eq. 1.6) is estimated and should yield a straight line, after an appropriate integration and mathematical manipulation (Eq. 1.7).

$$-\frac{dC}{dt} = k_n C^n \tag{1.6}$$

Table 1.2 Equations of n^{th}-order kinetic models

n	Linear regression
0	$C = C_0 - kt$
0.5	$\sqrt{C} = \sqrt{C_0} - 0.5kt$
1	$\ln C = \ln C_0 - kt$
1.5	$\frac{1}{\sqrt{C}} = \frac{1}{\sqrt{C_0}} + 0.5kt$
2	$\frac{1}{C} = \frac{1}{C_0} + kt$

$$\frac{1}{C^{n-1}} = \frac{1}{C_0^{n-1}} + (n-1)k_n t, \text{ for } n \neq 1 \quad (1.7)$$

where C is the concentration at time t, C_0 is the initial concentration, k_n is the kinetic constant, n is the reaction order. The order of the reaction refers to the empirically found rate expression, which can have a fractional value (Levenspiel 1999). Table 1.2 describes the equation of each model tested.

Results and Discussion

Table 1.3 shows the characterization of the standardized mixed liquid used in the present study.

The initial concentrations of phosphorus and TSS were standardized in order to maintain the same conditions in the control and in the electrobioreactor. The pH and conductivity were not adjusted, because the values were desirable for the electrocoagulation process. The DO was measured in order to maintain adequate conditions for the aerobic process in the control. The temperature was kept constant during the process to perform the kinetic study of the phosphorus removal. Al^{3+} concentration was measured in order to evaluate the release of soluble aluminum

Table 1.3 Physical–chemical characterization of standardized mixed liquid

Parameters	Unit	Initial values
PO_4^{3-}-P	mg L^{-1}	4.73
NH_4^+-N	mg L^{-1}	15.0
COD	mg L^{-1}	97.0
Al^{3+}	mg L^{-1}	0.003
pH	–	6.08
DO	mg L^{-1}	8.63
Conductivity	μS cm^{-1}	1202
Temperature	°C	17.4
TSS	g L^{-1}	5.42

after the electrocoagulation process, and NH_4^+-N and COD were measured in order to analyze whether the electric current application improved or impaired the biological process of treatment.

Figure 1.2 demonstrates the behavior of the PO_4^{3-}-P removal over time in comparison between the electrobioreactor and the control. In the control reactor, no favorable environments to the EBPR process (no intermittence between anaerobic and aerobic phases) led to only 40.75% removal, probably attained via cellular synthesis (assimilatory metabolism). Meanwhile, the application of the electric current in the electrobioreactor, under intermittent exposure mode, provided an excellent PO_4^{3-}-P removal efficiency, with removal of 100% after 7 h of electrocoagulation.

This high efficiency is due to the interaction of the Al^{3+} released by the anode with the soluble PO_4^{3-} present in the effluent, which generates insoluble species (Eq. 1.4) (Mollah et al. 2004). In addition, the adsorption of soluble PO_4^{3-} by the metal hydroxides formed during the electrocoagulation process must be also taken into account (Bani-Melhem and Smith 2012). The increase of soluble Al^{3+} concentration from 0.003 to 0.43 mg L^{-1} (Table 1.4), being an increase of over 143 times, validates the satisfactory result of PO_4^{3-}-P removal.

The high Al^{3+} concentration is due to the initial pH of the process (pH 6.08). At an appropriate pH, the anode releases metal species in the solution, and these species

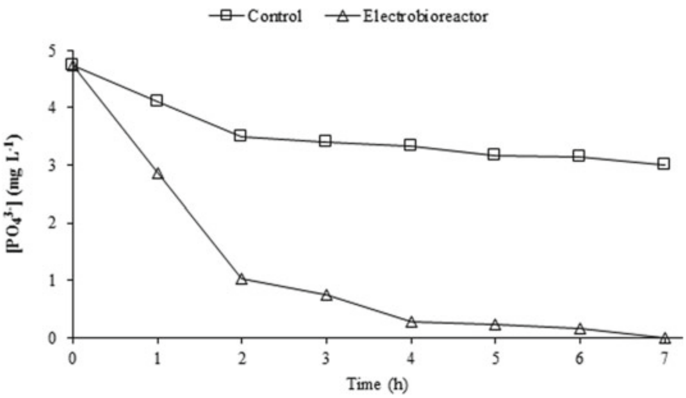

Fig. 1.2 Phosphorus removal over time, without electric current application (control) and with electric current application (current density = 10 A m^{-2} and exposure mode = 6′ON/18′OFF)

Table 1.4 Al^{3+}, NH_4^+-N and COD after 7 h with (electrobioreactor) and without (control) electric current application (current density = 10 A m^{-2} and exposure mode = 6′ON/18′OFF)

	NH_4^+-N concentration (mg L^{-1})	NH_4^+-N removal (%)	COD concentration (mg L^{-1})	COD removal (%)	Al concentration (mg L^{-1})
Control	14.1	6	89.0	9.2	0.003
Electrobioreactor	10.7	28.67	69.0	28.87	0.43

form hydroxides (Elabbas et al. 2016). At an acidic pH, the aluminum is mostly in the form of Al^{3+} and $Al(OH)_3$ (Bassala et al. 2017); the formation of $Al(OH)_3$ occurs specifically in the pH range of 6–8, and playing the role of a coagulant, provides an efficient removal of phosphorus. After 7 h of electrocoagulation, the pH dropped to 5.69 due to the electrochemically produced protons at the anode (Bassala et al. 2017).

After 7 h of electrocoagulation, the electric current application improved the biological process. The control presented removal of 6% of $NH4^+$-N and 9.2% of COD, while the electrobioreactor provided 28.67% and 28.87% for $NH4^+$-N and COD, respectively (Table 1.4). This increase may be due to the electro-stimulation process. The electric current application stimulates the metabolism and activity of microorganisms (Wei et al. 2011) from the transmembrane potential that occurs with the current application, which allows the transport of nutrients through the bacteria cytoplasmic membrane and increases its permeability (Zhang et al. 2014).

Kinetic Study for Phosphorous Removal

Related to the $PO_4{}^{3-}$-P concentration decay during the treatment time in the standardized mixed liquid, the kinetics were tested, and each one of their linear fits are shown in Table 1.5.

The first-order kinetics ($n = 1$) presented the highest coefficient of determination ($R^2 = 0.9097$), followed by the kinetics of order $n = 0.5$ ($R^2 = 0.9023$). Visually, it can be observed that the first-order graph (Fig. 1.3a) matches with most of the experimental data, much more than the half-order kinetics graph (Fig. 1.3b). Levenspiel (1999) suggested that integral analysis should be attempted first (because of its higher accuracy), and if not successful, the differential method can be tried, being useful in more complicated situations. Thus, due to the proximity of R^2 values, and only as a tiebreaker criterion, the differential method was checked, that is ruled by Eq. 1.8:

Table 1.5 $PO_4{}^{3-}$-P decay kinetics in the standardized mixed liquor treated in the electrobioreactor operated under the studied conditions

Order (n)	R^2	Linear regression	k	k unit
0	0.7367	$C = 3.31 - 0.5879t$	0.5879	$mg\ L^{-1}\ h^{-1}$
0.5	0.9023	$\sqrt{C} = 1.8609 - 0.2733t$	0.5466	$mg^{0.5}\ L^{-0.5}\ h^{-1}$
1	0.9097	$\ln C = 1.7731 - 0.7534t$	0.7534	h^{-1}
1.5	0.5651	$\frac{1}{\sqrt{C}} = -0.8953 + 0.9613t$	1.9226	$L^{0.5}\ mg^{-0.5}\ h^{-1}$
2	0.3927	$\frac{1}{C} = -16.252 + 8.8386t$	8.8386	$L\ mg^{-1}\ h^{-1}$

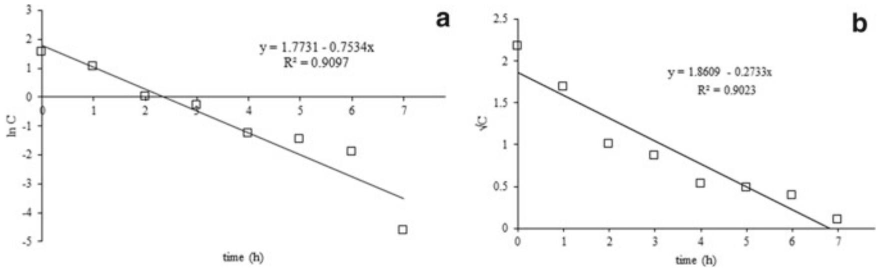

Fig. 1.3 Test for the integral method rate equation for **a** first-order and **b** half-order

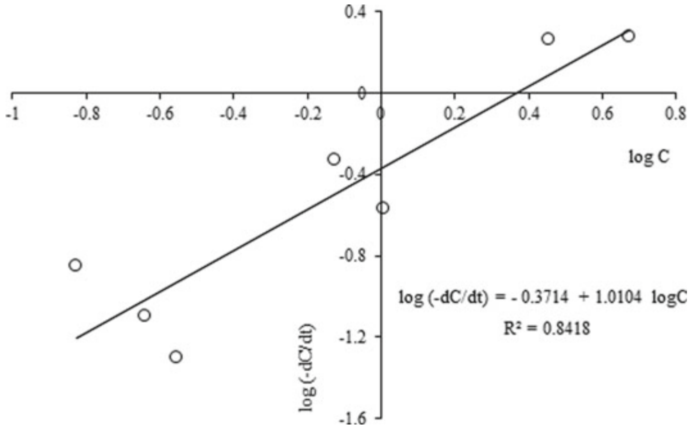

Fig. 1.4 Graph for rate nth-order determination by the differential method

$$\log\left(-\frac{dC}{dt}\right) = \log K + n\log C \tag{1.8}$$

As can be seen in Fig. 1.4, the differential method plot provided $n = 1.0104$ ($R^2 = 0.8418$), meaning that we have the minimum background necessary to suggest that the PO_4^{3-}-P decay over time in the electrocoagulation reactor probably follows first-order kinetics. Further studies are being carried out in order to determine the kinetic parameters more precisely.

Conclusion

This study demonstrated the potential of the electrocoagulation process in the removal of phosphorus present in municipal wastewater, showing the possibility of obtaining 100% removal after 7 h of treatment with 10 A m^{-2} electric current density and

6′ON/18′OFF exposure mode. The kinetic studies suggested that, under the tested conditions, the PO_4^{3-}-P decay over time probably follows first-order kinetics.

The presence of Al^{3+} ions in the electrobioreactor increased after 7 h, providing efficient removal of phosphorus. In the control reactor, the absence of Al^{3+} and of favorable conditions for the development of EBPR caused a much lower phosphorus removal (40.75%), and this removal refers only to the assimilatory metabolism. In addition, the application of an adequate current density and exposure time stimulated the activity of microorganisms, providing increased removal of NH_4^+-N and COD.

The electrocoagulation process was shown to be an effective technological method for phosphorus removal that can be applied in association with the biological process, thus providing a superior quality to the treated municipal wastewater.

In order to verify the influence of different current densities, modes of exposure and pH, a 2^3 factorial design is being carried out in regards to phosphorus removal by electrocoagulation.

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Chapter 2
Evaluating Gaseous Emissions and Performance of a Spark-Ignited Non-road Engine Fueled with Gasoline, Ethanol and Adulterant Blends

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Abstract Some concerns regarding the depletion of non-renewable sources of energy along with the environmental damage resulting from their use have motivated the search for alternative fuels. Ethanol is a renewable and important energy alternative for Otto-cycle engines. In such context, this study proposes the evaluation of carbon monoxide (CO) and total hydrocarbons (THC) concentrations and the performance of a spark-ignited non-road engine fueled with gasoline types A and C (GC, with 27% ethanol) and kerosene as adulterant in different proportions. Quality parameters of the fuel blends were also evaluated. The results revealed some difficulties in the identification of gasoline adulteration, relating to the current legal parameters in the conditions of mixtures and tests used in the study. Regarding the gaseous emissions, the addition of the adulterant resulted in an increase of the CO and THC concentrations to 74% and 78%, respectively, in gasoline type C with 30% adulterant, when compared to gasoline C free of adulterant. The addition of ethanol to the gasoline resulted in a reduction of the CO and THC concentrations to 64% and 56%, respectively, in relation to the pure gasoline (without ethanol), evidencing greater combustion efficiency due to the presence of the oxygenated fuel (ethanol).

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Introduction

Nowadays, energy demand is mainly supplied by fossil fuels, which greatly contribute to the deterioration of air quality. This fact, along with the successive oil crisis, has promoted a search for alternative fuels (Lin et al. 2010; Schirmer et al. 2017) such as ethanol.

Ethanol can be used both as a vehicle fuel and as a gasoline additive, aiming at octane enhancement (Schifter et al. 2013; Walter 2009). In addition, its properties (such as greater heat of vaporization and antiknock characteristics) are advantageous, since they can improve engine efficiency and increase compression ratios (Lin et al. 2010).

Currently in Brazil, the commercialized gasolines are types A and C. Gasoline type A is pure, that is, without the addition of ethanol and is sold only by producers and importers. Gasoline type C contains the addition of anhydrous ethyl alcohol (AEA) and is the gas sold to the final consumers (ANP 2016). The literature shows that both the content of the ethanol added to the gasoline and the engine operation parameters (such as the loads applied) directly influence gas emissions (Schirmer et al. 2017). In general, the presence of ethanol in the blend reduces carbon monoxide (CO) and hydrocarbon emissions (HC) (Schirmer et al. 2017; Masum et al. 2015; Gravalos et al. 2013; Lin et al. 2010; Ribeiro et al. 2018; Yao et al. 2013).

According to the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP, in Portuguese), there are several norms regulating gasoline, which set forth fuel specifications all over the country. Gasoline that is not in compliance with the specifications set forth by the ANP is considered a non-compliant product, known as adulterated.

The adulteration of gasoline is generally obtained through the addition of solvents such as kerosene, benzene, turpentine, diesel, etc. or even excess anhydrous ethyl alcohol (AEA), since these products represent lower prices and lower tax charges when compared to gasoline (Babu et al. 2017; Kalligeros et al. 2003; Obodeh and Akhere 2010; Oliveira et al 2004). The use of adulterated gasoline might provoke damage to the engine as well as increase the pollutant gas emissions to the atmosphere, due to the alterations of the gasoline physicochemical properties such as density, vapour pressure and distillation curve (Fonseca et al. 2007; Gawande and Kaware 2013; Takeshita 2006). Kerosene, for example, being a heavier compound than gasoline (therefore, more difficult to burn), tends to result in an increase in fuel consumption, poor atomization, engine corrosion, reduction in octane quality, and general wear. In addition to reducing the engine performance, the irregular burning of kerosene-added gasoline increases emissions of gases such as CO, NO_x and HC. Also, a characteristic odor is noticed when the gasoline-kerosene blend is used (Tharby 2002; Gawande and Kaware 2013; Takeshita 2006). Tharby (2002) highlights the damage that might occur to engines using adulterated gasoline, such as problems in the fuel injection system, valves, spark plugs, oxygen sensors, etc. even in cases when adulterants are used in small proportions.

Olanyk et al. (2014) evaluated the effect of the addition of different percentages (10, 20, 30 and 40% v/v) of "rubber solvent" to type A gasoline on the performance and emissions of a single-cylinder engine with a volumetric displacement of 196 cm^3 and a four-stroke cycle. Those authors verified an increase in fuel mass consumption of up to 7% with the gradual addition of adulterant, as well as a rise in CO and HC concentrations of 38% and 16%, respectively.

Obodeh and Akhere (2010) investigated the effect of gasoline adulterated with kerosene in the proportions of 10, 20, 30, 40 and 50% v/v (and pure gasoline, as a basis for comparison) on the emissions and performance of an Otto-cycle engine, four-stroke and four-cylinders. The results showed an increase in the exhaustion emissions as the kerosene content in the blend was increased (ranging from 21.7 to 53% CO, from 23.4 to 57.1% HC and from 2.4 to 8.25% particulate matter) and in specific fuel consumption (34–36%) when compared to pure gasoline.

While the use of blends of oxygenated fuels in small spark-ignition non-road engines has been widely studied, little research has been developed in relation to the use of adulterated fuels in this category of engines. Gravalos et al. (2013) pointed out that non-road gasoline engines differ from other automotive engines in relation to technical specifications, which might imply differences related to these engines' emissions and performance with the use of different fuels and their mixtures.

In this context, this study proposes the evaluation and comparison of gas emissions and mass and brake specific consumptions of a small spark-ignited non-road engine fuelled with kerosene (as adulterant) added to type C (with 27%v/v AEA) gasoline, which operated under different conditions of load applied to the engine.

Material and Methods

Fuel Blends, Properties and Experimental Apparatus

The tests were carried out with gasoline type A (pure), type C (Brazilian commercial gasoline, currently with 27% anhydrous ethyl alcohol—AEA) and kerosene, purchased from a chemical industry. To verify the effects of AEA and kerosene on fuel consumption and gas emissions, the following fuel blends were used: Gasoline C (GC); Gasoline C with 15% kerosene as adulterant (GC_{15}); Gasoline C with 30% kerosene as adulterant (GC_{30}) and Gasoline A (GA). Some properties of the fuels used are presented in Table 2.1.

Some of the main fuel quality parameters as specified by Resolution no 40/2013 of the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP) were also determined in the laboratory, as follows: color, visual aspect, density, distillation curve, final boiling point (FPB) and residue, according to the methods and specifications presented in Table 2.2. Such parameters are directly associated with the combustion quality and, therefore, the gas emissions resulting from the burning of the fuel blends investigated.

Table 2.1 Fuel properties of gasoline, ethanol and kerosene (Chang et al. 2008; Koç et al. 2009; Shoba et al. 2011)

Fuel property	Gasoline	Ethanol	Kerosene
Chemical formula	C_4 to C_{12}	C_2H_5OH	C_{10} to C_{16}
Density at 15 °C (kg L^{-1})	0.69–0.79	0.79	0.80
Upper heating value (cal g^{-1})*	Type A: 7,564 Type C: 6,882	–	10,978
Research octane number	88–100	108.6	–
Motor octane number	80–90	89.7	–

*Determined by Method DIN 51,900

Table 2.2 Gasolines "A" and "C" quality control characteristics

Characteristic	Method	Specifications	
		Gasoline A	Gasoline C
Color	Visual	From colorless to yellowish, if dye free	From colorless to yellowish, if dye free
Aspect	NBR 14,954	Clear and impurity free	
Density (Kg m^{-3})	NBR 7148	Take notes	
Distillation (°C)			
10% evaporated, max	ASTM D-86	65.0	
50% evaporated, max	ASTM D-86	120.0	80.0
90% evaporated, max	ASTM D-86	190.0	
FPB, maximum	ASTM D-86	215.0	
Residue, max. (%vol)	ASTM D-86	2.0	

Source ANP (2013)

The engine-generator used was a single cylinder, four-stroke cycle with a volumetric displacement of 196 cc and maximum power of 6.5 hp (4.85 kW), with carburetor, coupled to a generator with maximum operating power of 2.5 kW (TG2800 model, Toyama brand) (Toyama 2018).

For the variation of the loads applied to the engine-generator, an energy dissipation panel of 10 halogen lamps (with 0.3 kW each one) was used (Olanyk 2013). During the operation, the loads were measured with a digital clamp multimeter.

The concentrations of total hydrocarbons (THC) and carbon monoxide (CO) were measured using a PC-MULTIGAS gas analyzer (by NAPRO). The analyzer specifications are shown in Table 2.3.

Table 2.3 Automatic gas analyzer (Napro 2018) specifications

Características	THC (ppm)	CO (%vol)
Maximum measuring range	2000	15
Resolution	1	0.01
Detector	NDIR[1]	NDIR

[1]Non-dispersive infrared

Combustion Assays Varying the Fuel Blends and the Loads Applied to the System

The combustion tests evaluated the THC and CO concentrations and fuel consumption as a function of the different fuel mixtures (GC, GC_{15}, GC_{30}, GA) and the loads applied to the system (2.0, 1.5, 1.0, 0.5 and 0 kW), pursuant to the Brazilian Norm ABNT NBR ISO 8178-4 (ABNT 2012).

The throttle of the engine was adjusted in the totally open region during the tests, following manufacturer's instructions, characterizing, therefore, a lean mixture condition. Prior to each test, the engine was heated for approximately 20 min at 2.0 kW. All the measurements were carried out in triplicate, generating a total of six emission reports for each condition of load × mixture evaluated. The temperature of the exhaustion gases was measured every 30 s with an infrared thermometer (Minipa brand). The data regarding CO and THC gas concentration were obtained with the software PC-MULTIGAS, installed in a portable computer connected to the system.

The fuel mass consumption (Mc) (g min^{-1}) was determined (in triplicate) by the variation of the fuel mass in each test for a period of fifteen minutes of working engine. From the mass consumption and the power (P) dissipated by the energy dissipation panel coupled to the generator (kW), it was possible to obtain data regarding the brake specific fuel consumption (bsfc) (g $(kWh)^{-1}$), using Eq. 2.1 (Masum et al. 2015).

$$\text{bsfc} = (\text{Mc}) \cdot P^{-1} \quad (2.1)$$

Statistical Analysis of the Experiment

The mean results obtained in triplicate for the CO and THC concentrations were statistically analyzed using the software Action Stat (Estatcamp 2014). Initially, the Bartlett test was applied to verify the variance homogeneity. After homogeneity was observed, the variance analysis (ANOVA) was carried out, followed by the Scott-Knott test, at 5% probability level, for the comparison of means between the treatments.

Table 2.4 Quality control data of the gasolines A, C and mixtures with adulterant (kerosene)

Parameter	GA	GC	GC_{15}	GC_{30}	ANP
Density at 20 °C (kg m^{-3})	725.6[a]	741.8	749.1	751.8	730–770
Distillation (ºC)					
10% evaporated	59.45	54.94	59.80	65.53	65
50% evaporated	94.95	74.31	77.11	97.88	80
90% evaporated	160.70	151.59	175.02	178.64	190
FPB (°C)	199.65	186.15	195.65	197.65	215
Residues (%)	1.90	1.20	1.60	1.34	2.00
Aspect	C.I.F.[b]	C.I.F.[b]	C.I.F	C.I.F	C.I.F
Color	CY[c]	CY[c]	CY	CY	CY

[a]Not specified for gasoline A (ANP 2011)
[b]Clear and impurity free
[c]Colorless and yellowish

Results and Discussion

Fuel Quality Parameters

Table 2.4 presents the results of the parameters destined to verify the quality of the fuels under investigation, according to Resolution ANP n. 40/2013 (Table 2.2).

The density values in the commercialized gasoline “C” must be between 730 and 770 kg m^{-3}, pursuant to the norms for fuel commercialization determined by the regulating agency (ANP 2011). Table 2.4 shows that all density values for Gasoline C and its blends with the adulterant (kerosene) are within the band determined by ANP. Regarding gasoline A, since the mandatory percentages of anhydrous ethyl alcohol (AEA) in the commercialized gasoline “C” have been varying in values by 20% v/v since the 1990s, the density of the type A gasoline was expected to be below the standards set forth for gasoline C, mainly for not containing AEA in its composition (794 kg m^{-3} density, according to Broustail et al. 2011).

Distillation curves represent a relevant parameter in the evaluation of fuel mixture volatility. When compared to gasoline, ethanol shows lower vapor pressure, higher latent heat of vaporization and a lower boiling point; therefore, when they are mixed, the formation of azeotropic mixtures occurs, implying variations in the final boiling point (FPB) and the temperature bands of distillation curves (Andersen et al. 2010; Bielaczyc et al. 2013; Koç et al. 2009; Silva et al. 2008). When kerosene is added to gasoline, the mixture volatility is reduced and the boiling point increases, which might hamper the burning of the fuel mixture, damaging the engine over time and increasing the emission of unburned hydrocarbons and particulate material in the exhaustion gases (Gwillian et al. 2004). Such behavior is observed in Table 2.4: when the amount of kerosene added to the GC increases, the distillation temperatures gradually increase; in the formulation containing 30% kerosene, the maximum values established are exceeded for the distillates of 10 and 50% evaporation. It seems relevant to mention that Fonseca et al. (2007), when studying the adulteration of type C gasoline (≅24% AEA) with kerosene mixed in different proportions (2, 4, 6, 10 and 20% in volume), observed that all maximum values specified were exceeded corresponding to distillates of 10, 50 and 90%, for the mixtures with 20% kerosene.

The parameters of color and visual aspect indicate the presence of contaminants and materials in suspension in the fuel. The current ANP Resolution 40/2013 determines a "colorless to yellowish" color and a "clear and impurity free" aspect. The addition of AEA to type A gasoline gives the mixture a yellowish aspect, which was observed in the blends investigated; even so, the visual analysis showed that even the samples with kerosene were within the requirements. Also, none of the mixtures showed the presence of impurities.

Regardless of the parameter evaluated (visual aspect, FPB, distillation curves, density), some difficulty was found in identifying adulteration in the gasoline, mainly regarding lower adulterant concentrations. In this study, for example, the values obtained for GC_{15} were within the technical specifications and only some values were in excess when the kerosene added to type C gasoline reached 30%. Also, considering that the variations of each one of these parameters depend on the adulterant characteristics (many of them presenting physicochemical characteristics very close to those of the gasoline), a revision of the parameters set forth in the ANP 40/2013 seems to be advisable, or even the adoption of other parameters/analyses that might be able to identify fuel adulteration with lower levels of adulterant concentration.

Exhaust Emissions—CO and THC

Figures 2.1 and 2.2 show, respectively, the concentrations of carbon monoxide (CO) and total hydrocarbons (THC) by varying the fuel blends and loads applied to the engine-generator.

Figures 2.1 and 2.2 show that the samples with AEA (GC, GC_{15} and GC_{30}) presented lower CO and THC concentrations, when compared to the GA samples. AEA has 35% oxygen in its composition and a stoichiometric air–fuel ratio lower than the gasoline (mainly composed of hydrocarbons); in this case, a greater content

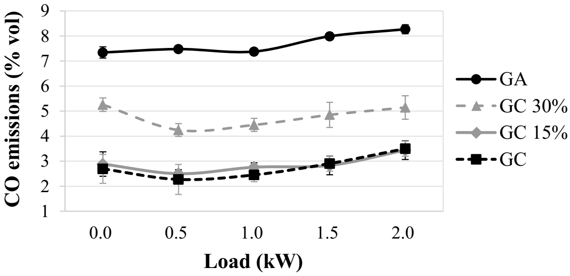

Fig. 2.1 Carbon monoxide emissions (%) in lean mixture conditions

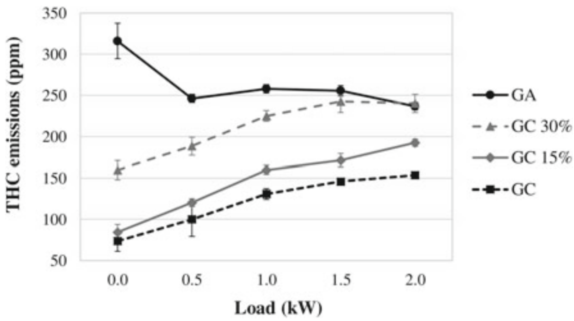

Fig. 2.2 Total hydrocarbons emissions (ppm) in lean mixture conditions

of oxygen in mass in the fuel contributed to the oxidation of THC to CO_2, which can be considered an effect of the pre-mixed oxygen to the fuel in liquid phase (KOÇ et al. 2009). Moreover, the addition of AEA promotes an improvement in the combustion balance and efficiency due to the reduction of hydrocarbons heavy fractions and a better evaporation of the AEA-gasoline mixtures, since the latent heat of vaporization and the octane number of the AEA-gasoline mixtures are commonly higher than that of the pure gasoline (type A) (Schifter et al. 2018; Turner et al. 2011). Other studies investigating types of engines and varied operation conditions also verified a reduction in CO emissions and hydrocarbons with ethanol addition to the gasoline (Elfasakhany 2015; Gravalos et al. 2013; Koç et al. 2009; Nwufo et al. 2017; Ribeiro et al. 2018; Schirmer et al. 2017).

As expected, the variance analysis revealed statistically significant differences in CO and THC emissions, considering the load and fuel used (p-value = $7.71E^{-24}$, for CO and p-value = $1.14E^{-24}$, for THC). The results of the mean comparison test are presented in Tables 2.5 and 2.6 for all treatments.

Regarding fuel adulteration, the statistical analysis pointed out that the addition of 30% keronese to Type C gasoline significantly increased the CO emissions when compared to pure type C gasoline (for all loads investigated). In relation to THC emissions, the 30% adulterant addition resulted in an increase in emissions, mainly in greater load conditions applied to the engine (1.0, 1.5 and 2.0 kW). The addition of kerosene to the gasoline reduced the volatility and the fuel mixture octane number, mainly due to an increase in the heavy fractions of hydrocarbons (which present a trend to remain in their liquid phase), as well as an increase in the mixtures; these aspects might cause the phenomenon called engine knocking, resulting in damage to the engine and higher levels of CO and THC emissions (Gawande and Kaware 2013; Gwillian et al. 2004; Heywood 1988; Sinha and Shivgotra 2012). Also, with the increase in the hydrocarbon heavy fractions of the fuel mixtures, there is a possibility of carbon deposits in the spark system, engine piston and valve. In general, adulterating gasoline with kerosene causes problems related to the fuel detonation, due to alterations in volatility, formation and accumulation of residues in the engine cylinders, incomplete burning of hydrocarbons, and reduction in the engine efficiency (Dahadha et al. 2013; Heywood 1988; Fonseca et al. 2007).

Table 2.5 Mean concentrations of CO (statistical analysis)

Treatments (blends and loads)	CO emissions (%vol)*	Standard error
$GA_{2.0}$	8.27 a	0.14
$GA_{1.5}$	7.99 a	0.10
$GA_{0.5}$	7.43 b	0.07
$GA_{1.0}$	7.41 b	0.07
$GA_{0.0}$	7.37 b	0.13
$GC_{30,\ 0.0}$	5.26 c	0.20
$GC_{30,\ 2\cdot 0}$	5.14 c	0.35
$GC_{30,\ 1.5}$	4.85 c	0.40
$GC_{30,\ 1.0}$	4.45 d	0.21
$GC_{30,\ 0.5}$	4.24 d	0.22
$GC_{2.0}$	3.50 e	0.23
$GC_{15,\ 2.0}$	3.44 e	0.29
$GC_{\ 1.5}$	2.91 f	0.23
$GC_{15,\ 0.0}$	2.89 f	0.38
$GC_{15,\ 1.5}$	2.83 f	0.28
$GC_{15,\ 1.0}$	2.76 f	0.13
$GC_{0.0}$	2.69 f	0.45
$GC_{15,\ 0.5}$	2.50 f	0.13
$GC_{1.0}$	2.45 f	0.21
$GC_{0.5}$	2.27 f	0.45

*The means followed by the same letter did not differ statistically one from another, at a 5% level of probability

Regarding the behavior of CO and THC concentrations as a function of the load variation, the increase in the load applied to the engine results in the admission of a greater fuel volume (per time) in the engine cylinder (increase in the fuel mass consumption), in order to supply the demand for more rotation of the engine axis and greater intensities in the generator magnetic field (Barakat et al. 2016; Olanyk 2013). Indeed, an increasing trend in CO and THC emissions was observed with the load increase in the system operation.

Performance of the Engine-Generator Set

The mass consumption and brake specific fuel consumption values are presented in Figs. 2.3 and 2.4, respectively, for all the blends and loads evaluated.

Figures 2.3 and 2.4 show that the mass consumption and bsfc results did not vary much as a function of different formulations of gasoline type A and type C with the

Table 2.6 Mean concentrations of THC (statistical analysis)

Treatments (blends and loads)	THC emissions (ppm)*	Standard error
$GA_{0.0}$	316.06 a	17.63
$GA_{1.0}$	257.83 b	4.33
$GA_{1.5}$	255.56 b	4.85
$GA_{0.5}$	246.28 b	4.29
$GC_{30,\ 1.5}$	242.44 b	9.99
$GC_{30,\ 2.0}$	240.28 b	8.99
$GA_{2.0}$	236.83 b	3.50
$GC_{30,\ 1.0}$	225.00 b	5.47
$GC_{15,\ 2.0}$	192.61 c	3.41
$GC_{30,\ 0.5}$	188.39 c	8.29
$GC_{15,\ 1.5}$	171.22 d	6.06
$GC_{15,\ 1.0}$	159.89 d	4.03
$GC_{30,\ 0.0}$	159.61 d	8.65
$GC_{2.0}$	153.72 d	1.75
$GC_{1.5}$	145.94 d	1.56
$GC_{1.0}$	130.83 e	4.88
$GC_{15,\ 0.5}$	120.33 e	3.70
$GC_{0.5}$	100.11 f	15.70
$GC_{15,\ 0.0}$	84.44 f	8.04
$GC_{0.0}$	73.61 f	10.14

*Means followed by the same letter did not differ statistically one from another, at a 5% level of probability

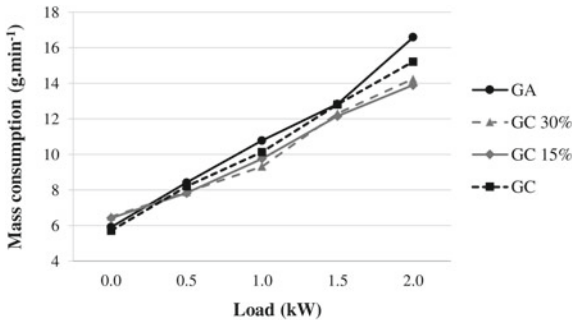

Fig. 2.3 Variation of mass consumption (Mc) as a function of the fuel blend and the load applied to the engine-generator

adulterant. When AEA is added to the gasoline, the fuel consumption is affected, due to the lower calorific value of the oxygenated compounds in relation to hydrocarbons (Gibbs et al. 2009; Wu et al. 2004). According to Channiwala and Parikh (2002), the calorific value of liquid fuels depends directly on their elemental base (chemical

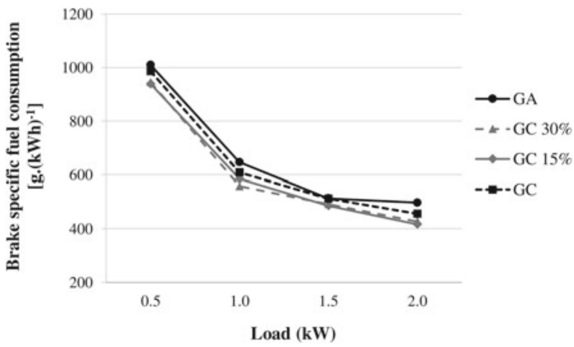

Fig. 2.4 Variation of brake specific fuel consumption (bsfc) as a function of the fuel blend and the load applied to the engine-generator

composition), and carbon and hydrogen are the greatest contributors to the generation of heat in the combustion. Costagliola et al (2016) and Hsieh et al (2002) highlighted that despite ethanol's lower heating value, its addition to the gasoline provokes a leaning effect, which results in better use of the fuel to generate energy in the engine. In this study, the low variability in fuel consumption as a function of the blends might be explained by the compensation of the improvement in the combustion efficacy due to the leaning effect, in relation to a lower energy content of the blends with different proportions of AEA.

The trend of increase in mass consumption with the increase in the load applied to the engine, for all blends investigated, might be justified by the demand for higher torques from the engine axis and higher intensities of the magnetic field of the generator in higher load conditions (Barakat et al. 2016; Olanyk 2013), which demand greater fuel volume. Figure 2.4 shows, in all blends investigated, a reduction in *bsfc* with the increase in the load applied to the engine. When the fuel mass consumption increases as a function of the increase in the load, there is a trend towards a better thermodynamic use of the fuel and a reduction in *bsfc*.

Conclusions

The following conclusions can be drawn based on our tests:

The presence of anhydrous ethyl alcohol (AEA) in gasoline (commercially available in Brazil in the 27% proportion) resulted in a significant reduction in CO and THC concentrations to 64% and 56%, respectively, when compared to pure gasoline (type A, ethanol free), therefore evidencing greater combustion efficiency with the presence of oxygenated fuel (ethanol) in the blend.

Taking into consideration the test conditions adopted in this study (type of adulterant, engine, loads, etc.) as well as the current specifications set forth by the fuel regulating Brazilian agency (ANP), the legal parameters to detect fuel adulteration were seen to present limitations, mainly regarding lower concentrations of adulterant. Thus, from the legal standpoint, it seems relevant to consider the adoption of more restrictive limits or even the inclusion of other analysis parameters, so that the adulteration can be more easily detected.

The addition of kerosene to type C gasoline resulted in an increase in the CO and THC concentrations of up to 74% and 78%, respectively (this fact was observed for higher percentages of adulterant).

In the test conditions adopted, fuel consumption was seen to be more sensitive to the load variations applied than to the type of fuel used.

Further studies should be developed on emission and consumption tests with higher loads applied to the engine, as well as the adoption of other adulterants, to evaluate the influence of these factors in the system's general performance.

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Chapter 3
The Impact of Climate Change on Hydroelectric Resources in Brazil

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Abstract In the coming decades, higher temperatures and significantly reduced rainfall are projected for various semi arid regions due to Global Warming. The objective of this study is to estimate the impact of climate change on hydroelectric production in various river basins across South America. Three different downscaled global climate models are used to estimate the percentage changes in rainfall and streamflow by the 2030s and 2080s under a high emission scenario in comparison to baseline data from the end of the twentieth century. While rainfall is projected to increase slightly over the Uruguay River basin, rainfall over the Amazon and Brazil's northeast region is expected to decline. Specifically, it was found that due to climate change, streamflow in the São Francisco River, the Tocantins River and Parnaiba River is projected to decline by 52%, 31% and 32%, respectively, in the coming 3 decades compared to data from 1961–1990. Moreover, one of the three climate models indicated that the São Francisco and Parnaiba rivers' streamflow and hydroelectric production could potentially cease in the second half of the twenty-first century. Despite some inconsistencies amongst the long-term projections from the 3 different climate models, the results of this research are important in the context of regional climate change and energy resource planning.

Introduction

While climate change mitigation will require the use of more renewable energy, renewable resources can be affected by various aspects of regional climate change. As well as impacting air temperature, climate change is already influencing rainfall, wind speeds, storm intensities and drought frequencies as well as various aspects of agriculture and the environment. Climate change projections indicate that there will

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be diminishing precipitation and more severe droughts in Northeast and Northwest Brazil, Southwest Australia, Southwest USA, the Mediterranean (Jenkins and Warren 2015) and various regions in Africa (Gan et al. 2016). In particular, streamflow in semi arid regions is vulnerable to more frequent and intense prolonged droughts due to climate change (de Jong et al. 2018).

Hydrological projections specifically for Brazil's northeast (NE) region and the São Francisco River basin, which are experiencing their worst drought in history, indicate that the water balance and agricultural production will continue to deteriorate in the coming decades (Marengo and Bernasconi 2015; Neto et al. 2016; Marengo et al. 2016). Consequently, hydroelectric generation from the basin could decrease dramatically as a result (de Jong et al. 2018). However, the impact of climate change on other river basins in the South American region requires more in-depth research. The objective of this study is to determine the impact of climate change on the long-term streamflow and natural energy flow projections for the São Francisco River, Tocantins River, Parnaiba River and Uruguay River basins in order to quantify possible changes in each basin's hydroelectricity production.

Originality of This Study Compared to Previous Works

Typically, analysis in previous studies makes use of one climate model with only 3 monthly time series projections (Ruffato-Ferreira et al. 2017), which can give some insight into seasonal rainfall variations, but such studies are dependent on the idiosyncrasies of the specific climate model used. Therefore, in order to overcome this knowledge gap, the present study uses 3 global climate models with a monthly temporal resolution. Additionally, the data is downscaled using a regional climate model with a horizontal resolution of 20 km in order to more precisely estimate future rainfall across specific basins. Previous studies that project future rainfall typically focus on large regions and use models with coarse horizontal resolutions that may not capture climate variations that occur on a local scale. Yet long-term trends in average rainfall can vary substantially from one location to another in the same country.

The majority of electricity in South America is generated from renewable energy, and yet to date there are only a handful of studies that examine the impact of climate change on renewable energy resources (such as wind and solar) in the region (de Jong et al. 2019). To our knowledge, there are only a few previous studies that examine climate change impacts on hydroelectric resources in various basins across the South American region, but these studies only focus on Brazil and are limited to one or two climate models. Given that the large majority (more than 80%) of Brazil's electricity is generated from renewable sources (MME 2018), this study begins to fill the knowledge gaps and is an important step to better enable overall energy resource planning in the region.

Hydroelectricity in the Northeast Region

A recent study by Ruffato-Ferreira et al. (2017) found that the São Francisco, Amazon, Tocantins-Araguaia, and the North and Northeast Atlantic basins are projected to experience a declining water balance under both the RCP4.5 and RCP8.5 emissions scenarios. Moreover, the São Francisco is the most vulnerable basin in the country to water scarcity (Ruffato-Ferreira et al. 2017).[1] However, that study also only used one climate model (the HADGEM2/Eta model).

Various other studies indicate that rainfall over Brazil's São Francisco river basin and the mostly semi arid NE region as a whole has already declined due to climate change (de Jong et al. 2018; Maisonnave 2018; Jornal da Unicamp 2018). Moreover, annual streamflow in the São Francisco basin has been below its long-term average every year since 1992, and from 2015–2017 streamflow was at least 60% below the long-term average due to the recent drought impacting the basin (de Jong et al. 2018). Based on the IPCC climate models with high emissions scenarios and the historical trend during the last 30 years, it was estimated that there could be a decline in average rainfall over the São Francisco basin of 34% and 47% by 2030 and 2050, respectively, and this could result in a reduction of approximately 60% and 80%, respectively, in the NE's annual average streamflow and resulting hydroelectric generation (de Jong et al. 2018). Similarly, a study by The World Bank (2017) indicated that for the period 2020–2040 the São Francisco's average streamflow could drop by 32% and 57% considering the MIROC5/Eta and HADGEM2/Eta models, respectively. Projections beyond 2040 where not published in the report. According to Neto et al. (2016), the São Francisco's streamflow—simulated with the MIROC5/Eta and HADGEM2/Eta models using the RCP8.5 scenario—is projected to decline by 41% and 63%, respectively, by 2041–2070. Considering the same models, streamflows in the Tocantins, Xingu, Parnaíba, Madeira, Tapajós and Maranhão basins are all projected to decline substantially by 2041–2070 (Neto et al. 2016).

It is worth noting that climate models are subject to cumulative uncertainties, and this is especially true for long-term regional scale hydrological projections. Some models can exhibit large biases when compared to observed data, and the projections from different models can vary significantly. Nevertheless, most models tend to agree in the overall trend direction of a climate variable (e.g. precipitation) in a particular region.

There are also regional impacts on rainfall and streamflow as a consequence of deforestation, removal of riparian vegetation and irrigation farming. As a result of climate feedbacks from land use changes, the continued deforestation of the Amazon and surrounding tropical forests are expected to cause average rainfall reductions and higher temperature extremes over the entire Amazon basin as well as the Brazilian southwest region (Lawrence and Vandecar 2015 and Oliveira et al. 2013). Such rainfall reductions could even reach as far south as Argentina's Rio de la Plata basin

[1] The study also found that a significant increase in wind speeds is projected for the North, Northeast, Southeast and South regions of Brazil, especially in summer and autumn (Ruffato-Ferreira et al. 2017)

and would negatively impact most Brazilian agricultural regions (Lawrence and Vandecar 2015), as well as affect the hydroelectric potential.

Methodology

Downscaled climate change projection data from 3 different CMIP5 global climate models was obtained from CPTEC-INPE (Centro de Previsão de Tempo e Estudos Climáticos/Weather Forecasting and Climate Studies Centre—Instituto Nacional de Pesquisas Espaciais/National Institute for Space Research) for the Brazilian territory. The 3 global climate models are the Hadley Centre Global Environment Model version 2—Earth System (HADGEM2-ES) developed in the UK, the Model for Interdisciplinary Research on Climate version 5 (MIROC5) developed in Japan, and the Second Generation Canadian Earth System Model (CANESM2). The downscaled projections at higher resolution were carried out by CPTEC-INPE using a South American regional climate model (RCM) known as the Eta Model (Chou et al. 2014a, b; MCTI 2016). The output data (generated by CPTEC-INPE) from the 3 downscaled models known as HADGEM2-ES/Eta, MIROC5/Eta and CANESM2/Eta is available on the PROJETA Platform (CPTEC-INPE 2019). For each of the 3 models there are projections from 2006 until 2100 considering the RCP8.5 (high emissions) scenario and the RCP4.5 (low emissions) scenario. Hindcast data from each model for the historical period from 1961 to 2005 is also available.

The downscaled projection data used in this study has a 20 km spatial resolution and monthly and 3 h temporal resolutions. Projections of precipitation (PREC) and average temperature (TP2M) data with the RCP8.5 (high emissions) scenario will be analyzed. Analysis will focus on the model projections for hydroelectric resources in Brazil considering the 2021–2050 and 2070–2099 climate periods in comparison to the 1961–1990 baseline period.

Rainfall and Streamflow Changes

Climate change impacts on rainfall and streamflow in the São Francisco River, Tocantins River, Parnaiba River, and Uruguay River basins will be estimated. The long-term projections of average rainfall over each of these entire basins from the downscaled HADGEM2-ES/Eta, MIROC5/Eta and CANESM2/Eta models considering the RCP8.5 scenario are calculated using R Core Team (2013) for the periods 2021–2050 and 2070–2099 and compared to the baseline period of 1961–1990. The results from the downscaled models will be compared to observed historical rainfall data from 1961 to 2018, which was provided by CPTEC-INPE.

The projected percentage changes in rainfall relative to the baseline are then used to estimate the projected changes in streamflow in each basin based on the precipitation elasticity factor of each basin. The precipitation elasticity is the amplification of streamflow changes in relation to precipitation changes in a particular basin. The precipitation elasticity of streamflow for each basin is calculated using the methodology of de Jong et al. (2018) and Sankarasubramanian et al (2001). Specifically, the "elasticity" factor is calculated using an equation that models streamflow (Q) as a function of precipitation (P) as follows:

$$Q = \alpha P^{\beta};$$

where α and β are constants and the precipitation elasticity $E_p(P, Q) = \beta$. Observed historical streamflow data from 1961 to 2018 from the Operador Nacional do Sistema Elétrico (ONS 2019) for the lower São Francisco River, Tocantins River, Parnaiba River and Uruguay River are used together with historical rainfall data to calculate the elasticity factor, β of each basin by plotting the 12 monthly rolling average of the streamflow and precipitation in a scatterplot and fitting a power curve to the data. The elasticity factor of the São Francisco, Tocantins, Parnaiba and Uruguay basins were estimated to be 1.8, 1.3, 1.2 and 1.6, respectively. It should be noted that these elasticity factors are only estimates and can be influenced by irrigation withdrawals, deforestation and other land use changes.

Results

The changes in average temperature under the RCP 8.5 scenario projected for 2070–2099 compared to the baseline period of 1961–1990 can be observed in Fig. 3.1.

It can be observed in Fig. 3.1 that temperature is expected to increase across all of Brazil. This can also be observed in Fig. 3.2, which shows temperature projections compared to historical observations from 1961 to 2018 at Imperatriz in the state of Maranhão and at Santa Vitoria do Palmar in the state of Rio Grande do Sul. (Imperatriz is located on the most westerly edge of the NE region and Santa Vitoria do Palmar is located in the extreme south of Brazil). The top graph in Fig. 3.2 shows that since 1961–1965, the average temperature measured at Imperatriz has increased by approximately 2 °C, and under the RCP8.5 high emission scenario it is projected to increase an additional 6 °C by 2100.

Rainfall and Streamflow

The percentage change in precipitation in Brazil and over various basins under the RCP 8.5 scenario projected for 2070–2099 compared to the baseline period of 1961–1990 using the MIROC5/Eta, HADGEM2-ES/Eta and CANESM2/Eta models can be observed in Fig. 3.3.

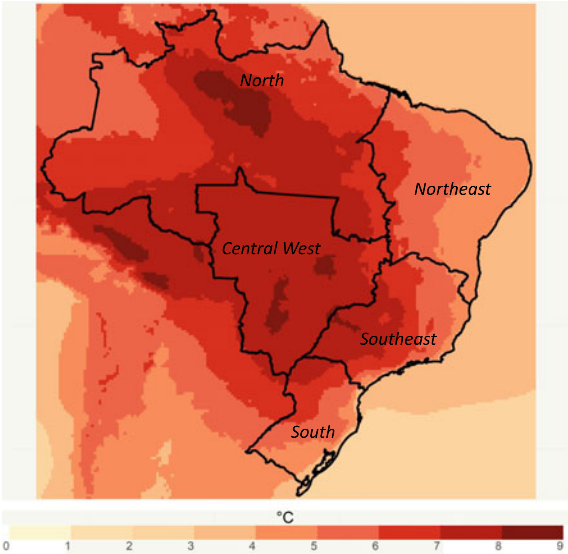

Fig. 3.1 Climate projections under the HADGEM2-ES/Eta RCP8.5 scenario. Changes in average temperature (°C) projected for 2070–2099 compared to the 1961–1990 baseline period in the different regions of Brazil (de Jong et al. 2019)

It can be observed that precipitation is projected to decline dramatically across most of the Brazilian North and semiarid NE regions, especially considering the CANESM2/Eta model. Considering the HADGEM2-ES/Eta model, the largest declines in the percentage of rainfall are mostly over the São Francisco and Tocantins basins as well as most of the semiarid NE region and parts of the east Amazon. The climate change impact on average annual rainfall over the São Francisco, Tocantins, Parnaiba and Uruguay basins are shown in Tables 3.1, 3.2, 3.3 and 3.4 for the 3 different downscaled models (HADGEM2-ES/Eta, MIROC5/Eta and CANESM2/Eta) and their ensemble considering the RCP8.5 emissions scenario. In addition to the hindcast of each model, the Table 3.1 also shows the observed average annual rainfall for 1961–1990.

The Simple Ensemble data shown in Tables 3.1, 3.2, 3.3 and 3.4 is the average of the 3 downscaled climate models (HADGEM2-ES/Eta, MIROC5/Eta and CANESM2/Eta). The ensemble is used in order to overcome idiosyncrasies of one specific climate model. The ensemble rainfall projections over the São Francisco, Tocantins, Parnaiba and Uruguay basins are shown in Figs. 3.4, 3.5, 3.6 and 3.7.

It can be observed from Figs. 3.4, 3.5, 3.6 and 3.7 that rainfall is projected to significantly decline over the São Francisco, Tocantins and Parnaiba basins. Furthermore, the 10-year rolling average and the linear trend-line of the observed annual rainfall of these 3 basins each appear to be declining more rapidly than the respective climate model ensemble data. However, the observed annual rainfall and projected rainfall for the Uruguay basin show a slightly increasing trend over the historical and projected periods.

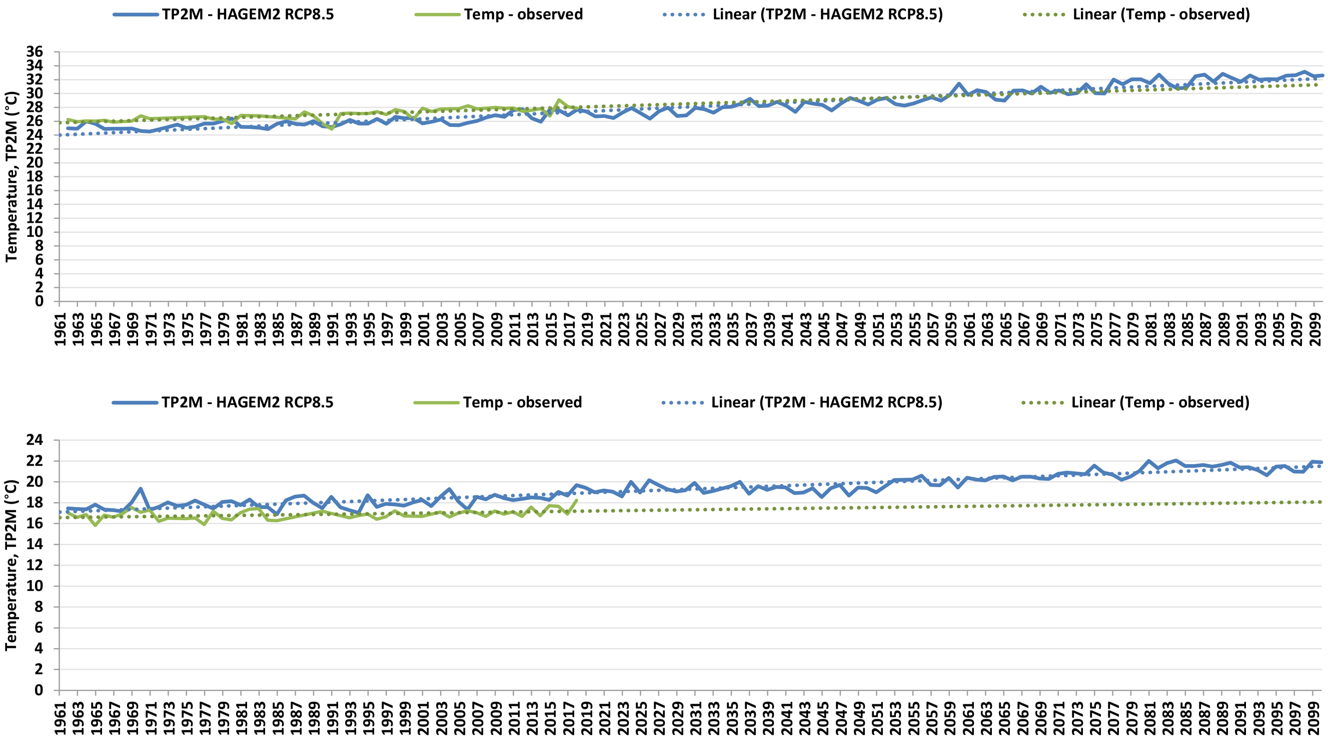

Fig. 3.2 Temperature–TP2M (°C) projections (using the HADGEM2-ES/Eta RCP8.5 scenario) compared to historical observations (BDMEP 2018) of temperature (°C) at Imperatriz in the state of Maranhão (top) and at Santa Vitoria do Palmar in the state of Rio Grande do Sul (bottom)

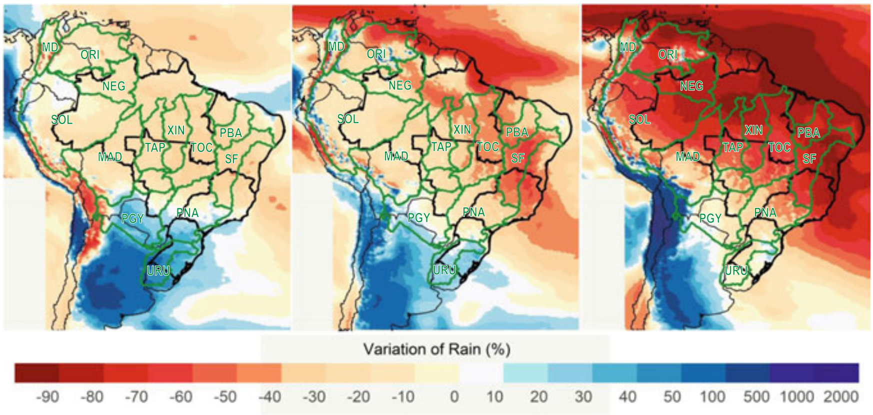

Fig. 3.3 Percentage change in precipitation projected for 2070–2099 compared to the baseline period of 1961–1990 under the RCP8.5 scenario (LHS: MIROC5/Eta; middle: HADGEM2-ES/Eta; RHS: CANESM2/Eta). Note, the boundary of various basins is shown with green lines. Key to basin names: **SF—São Francisco**; **TOC—Tocantins**; **PBA—Parnaiba**; XIN—Xingu; TAP—Tapajós; MAD—Madeira; PNA—Parana; PGY—Paraguay; **URU—Uruguay**; NEG—Negro; SOL—Solimões; ORI—Orinoco; MD—Magdalena

The Case of the São Francisco Basin

Applying the rainfall elasticity factor of 1.8 calculated for the São Francisco River signifies that, for a given decrease in rainfall, the decrease in streamflow would be amplified 1.8 times. Therefore, the projected decline in the São Francisco River's streamflow by the 2080s, considering the downscaled HADGEM2-ES and MIROC5 models, would be 91% and 54%, respectively. These results concur with the finding of Neto et al. (2016). However, considering the rainfall decline of 70% projected by the CANESM2 downscaled model it is possible that the São Francisco River could virtually dry up by 2070–2099. Moreover, it should be noted that of the 3 different models used in this study, it is the downscaled CANESM2 model that appears to most accurately model the decline in observed rainfall from 1961 to 2018, as can be seen in Fig. 3.8.

In comparison to observed average rainfall over the São Francisco basin, the HADGEM2-ES/Eta model simulation has a negative bias (that is, it underestimates rainfall). Furthermore, the simulation of annual rainfall (considering a 10-year rolling average) from 1961 to 2018 has a correlation of only 0.075 with the observed annual rainfall due to an anomaly in the simulated rainfall data from 1964 to 1980. However, the simulation does show a declining trend for the entire period from 1961 to 2099, although the gradient is less steep than the decline in observed annual rainfall from 1961 to 2018.

The MIROC5/Eta model simulation has a positive bias (that is, it overestimates rainfall) in comparison to observed average rainfall over the São Francisco, (as well as for the Tocantins and Parnaiba basins). Furthermore, the simulation of annual rainfall

Table 3.1 Changes in average annual rainfall over the São Francisco (SF) basin compared to the 1961–1990 baseline for 3 different climate models and their ensemble with the RCP8.5 emissions scenario. Observed average rainfall and streamflow changes are shown in bold

Basin	Climate model	Annual rainfall 1961–1990 (mm)	Avg rainfall 2011–2018 (mm)	Annual rainfall 2021–2050 (mm)	Rainfall % change	Streamflow % change	Annual rainfall 2070–2099 (mm)	Rainfall % change	Streamflow % change
SF	HADGEM2-ES RCP8.5/Eta	671	543	456	−32%	−57%	331	−51%	−91%
SF	MIROC5 RCP8.5/Eta	1283	1355.1	932	−27%	−49%	899	−30%	−54%
SF	CANESM2 RCP8.5/Eta	969	904	697	−28%	−51%	291	−70%	−126%
SF	*Simple ensemble*	*974*	*934*	*695*	*−29%*	*−52%*	*507*	*−48%*	*−86%*
SF	**Observed avg rainfall/flow**	**1083**	**720**	**% change: −33%**		**−60%**			

Table 3.2 Changes in average annual rainfall over the Tocantins (TOC) basin compared to the 1961–1990 baseline for 3 different climate models and their ensemble with the RCP8.5 emissions scenario. Observed average rainfall and streamflow changes are shown in bold

Basin	Climate model	Annual rainfall 1961–1990 (mm)	Avg rainfall 2011–2018 (mm)	Annual rainfall 2021–205 (mm)0	Rainfall % change	Streamflow % change	Annual rainfall 2070–2099 (mm)	Rainfall % change	Streamflow % change
TOC	HADGEM2-ES RCP8.5/Eta	1335	1166	1055	−21%	−27%	791	−41%	−53%
TOC	MIROC5 RCP8.5/Eta	1823	1826	1324	−27%	−36%	1259	−31%	−40%
TOC	CANESM2 RCP8.5/Eta	1346	1298	1057	−22%	−28%	494	−63%	−82%
TOC	*Simple ensemble*	*1502*	*1430*	*1145*	*−24%*	*−31%*	*848*	*−44%*	*−57%*
TOC	**Observed avg rainfall/flow**	**1609**	**1200**	**% change: −25%**		**−33%**			

Table 3.3 Changes in average annual rainfall over the Parnaiba (PBA) basin compared to the 1961–1990 baseline for 3 different climate models and their ensemble with the RCP8.5 emissions scenario. Observed average rainfall and streamflow changes are shown in bold

Basin	Climate model	Annual rainfall 1961–1990 (mm)	Avg rainfall 2011–2018 (mm)	Annual rainfall 2021–2050 (mm)	Rainfall % change	Streamflow % change	Annual rainfall 2070–2099 (mm)	Rainfall % change	Streamflow % change
PBA	HADGEM2-ES RCP8.5/Eta	841	689	665	−21%	−25%	507	−40%	−48%
PBA	MIROC5 RCP8.5/Eta	1174	1221	924	−21%	−26%	879	−25%	−30%
PBA	CANESM2 RCP8.5/Eta	788	767	614	−22%	−26%	167	−79%	−95%
PBA	*Simple ensemble*	*934*	*892*	*735*	*−21%*	*−26%*	*518*	*−45%*	*−54%*
PBA	**Observed avg rainfall/flow**	**1140**	**692**	**% change: −39%**		**−47%**			

Table 3.4 Changes in average annual rainfall over the Uruguay (URU) basin compared to the 1961–1990 baseline for 3 different climate models and their ensemble with the RCP8.5 emissions scenario. Observed average rainfall and streamflow changes are shown in bold

Basin	Climate model	Annual rainfall 1961–1990 (mm)	Avg rainfall 2011–2018 (mm)	Annual rainfall 2021–2050 (mm)	Rainfall % change	Streamflow % change	Annual rainfall 2070–2099 (mm)	Rainfall % change	Streamflow % change
URU	HADGEM2-ES RCP8.5/Eta	1466	1445	1530	4%	7%	1697	16%	25%
URU	MIROC5 RCP8.5/Eta	937	1024	1045	12%	18%	1244	33%	52%
URU	CANESM2 RCP8.5/Eta	1765	1898	2011	14%	22%	1652	−6%	−10%
URU	*Simple ensemble*	*1389*	*1456*	*1528*	*10%*	*16%*	*1531*	*10%*	*16%*
URU	**Observed avg rainfall/flow**	**1714**	**1664**	**% change: −3%**		**−5%**			

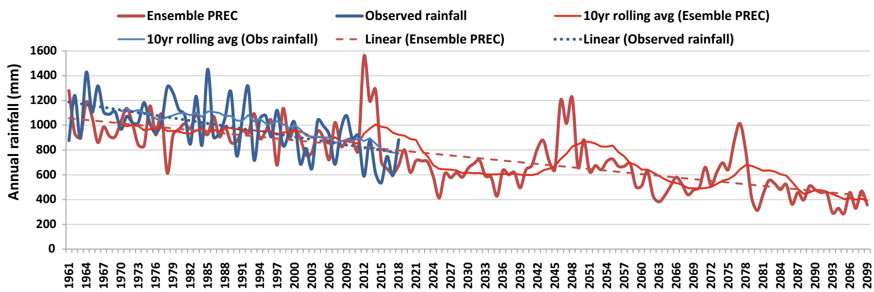

Fig. 3.4 Simple ensemble projection of annual precipitation with the RCP8.5 scenario and observed average annual rainfall over the São Francisco basin from 1961 to 2018

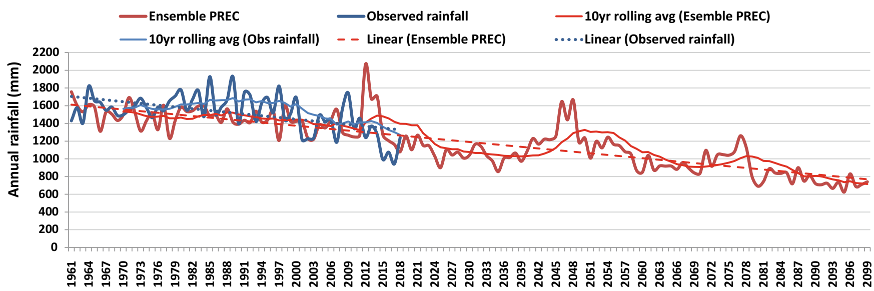

Fig. 3.5 Simple ensemble projection of annual precipitation with the RCP8.5 scenario and observed average annual rainfall over the Tocantins basin from 1961 to 2018

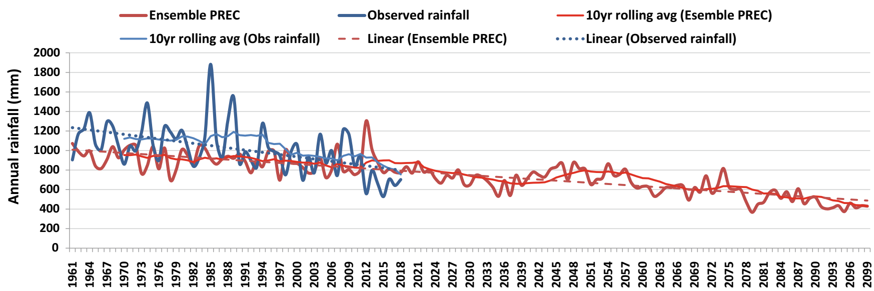

Fig. 3.6 Simple ensemble projection of annual precipitation with the RCP8.5 scenario and observed average annual rainfall over the Parnaiba basin from 1961 to 2018

(considering a 10-year rolling average) from 1961 to 2018 has a correlation of only 0.187 with the observed annual rainfall and also shows a declining trend for the entire period from 1961 to 2099. Again, the gradient is less steep than the decline in observed annual rainfall over the São Francisco basin from 1961 to 2018. Moreover, the projected average rainfall decline of 27% for 2021–2050 is only marginally lower than the projected decline for the 2070–2099 period. However, according to the linear

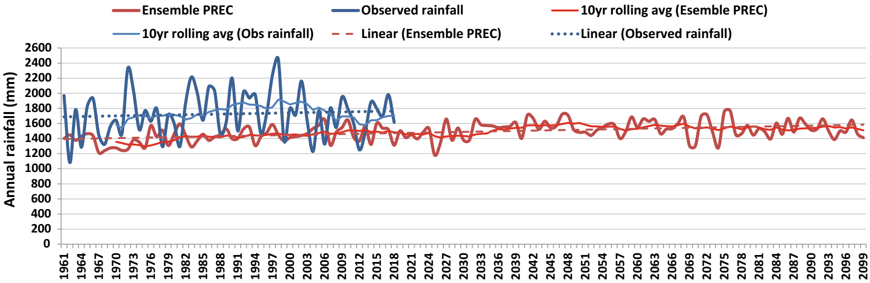

Fig. 3.7 Simple ensemble projection of annual precipitation with the RCP8.5 scenario and observed average annual rainfall over the Uruguay basin from 1961 to 2018

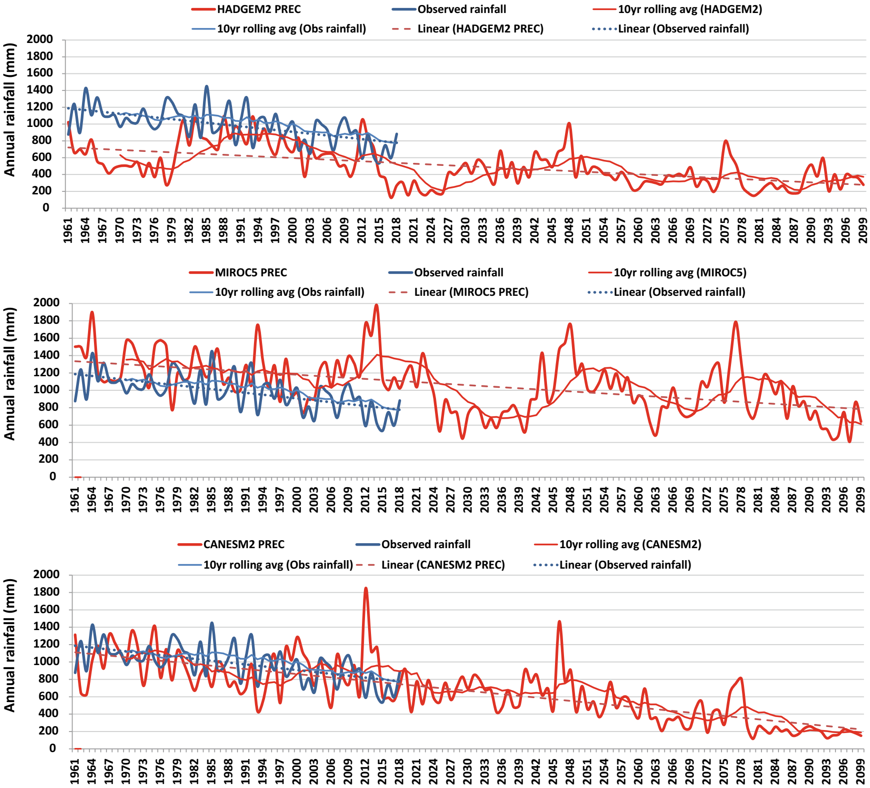

Fig. 3.8 Annual precipitation projections for 3 different downscaled climate models (from top to bottom: HADGEM2-ES/Eta, MIROC5/Eta and CANESM2/Eta) with the RCP8.5 scenario and observed average annual rainfall over the São Francisco basin from 1961 to 2018

observed rainfall trend-line (see Fig. 3.8), rainfall over the São Francisco basin has already declined by more than 25% from the 1961–1990 baseline average (de Jong et al. 2018) and the annual rainfall since 2011 has actually declined by an average of 33%. Furthermore, it was noted that the standard deviation of rainfall projected by the MIROC5/Eta model was substantially higher than the projections from the other models for both the 2021–2050 and 2070–2099 periods. Therefore, it appears that the MIROC5/Eta model does not satisfactorily simulate observed rainfall data in the region. It should be noted that some reanalysis data products of rainfall do not reproduce the decline in rainfall over the São Francisco basin that has occurred since 1995 (de Jong et al. 2018) and this might be one reason for the poor performance of some climate models on a regional scale.

The CANESM2/Eta model simulation appears to have almost no bias in comparison to observed average rainfall over the basin, although it slightly underestimated rainfall during the 1961–1990 baseline period. Furthermore, the simulation of annual rainfall (considering a 10-year rolling average) from 1961 to 2018 has a correlation of 0.221 with the observed annual rainfall. The simulation also shows a declining trend for the entire period from 1961 to 2099 with a gradient that matches the decline in observed annual rainfall from 1961 to 2017.

The Simple Ensemble model simulation (shown in Fig. 3.4) appears to have almost no bias in comparison to observed average rainfall over the basin, although it also slightly underestimated rainfall during the 1961–1990 baseline period. Furthermore, the Simple Ensemble simulation of annual rainfall (considering a 10-year rolling average) from 1961 to 2018 has the best correlation of 0.475 with the observed annual rainfall. The simulation also shows a declining trend for the entire period from 1961 to 2099 with a gradient that is a little less steep than the decline in observed annual rainfall from 1961 to 2017.

These results illustrate that projections from different models can vary significantly. Moreover, while the CANESM2/Eta model appears to have reasonably simulated the historical trend in annual rainfall, there is still uncertainty that rainfall over the basin will continue to follow the CANESM2/Eta model. Nevertheless, all 3 models projected very similar declines in annual rainfall of 27–32% over the semi arid São Francisco basin for the 2021–2050 period compared to the baseline period. Consequently, streamflow and hydroelectric potential in the São Francisco River could decline by 49–57% by the 2030s compared to the baseline period. Moreover, considering the projected rainfall reductions in combination with inter-annual rainfall variations, it could mean that the São Francisco basin and agriculture in the semi arid NE region will be increasingly vulnerable to severe droughts in the coming decades, which is consistent with the findings of Marengo and Bernasconi (2015), Neto et al. (2016), Marengo et al. (2016) and de Jong et al. (2018).

As a consequence, irrigation in the São Francisco basin and other basins in the region is likely to increase to compensate for lost rainfall. Therefore, in accordance with the findings of Neto et al. (2016), de Jong et al. (2018) and by The World Bank (2017), hydroelectric generation from the São Francisco River could continue to decline in the coming decades. On the other hand, wind power in the NE region is complementary to hydroelectric generation and will improve energy security by saving water in the São Francisco basin (de Jong et al. 2017).

Conclusions

Climate change is predicted to cause significantly reduced rainfall and higher temperatures in most regions of Brazil compared to the end of the twentieth century. Specifically, streamflow in the São Francisco River is projected to decline dramatically according to all 3 climate models used in this study. However, there were substantial differences between the model projections, particularly for the 3rd climate period from 2070–2099. The CANESM2/Eta model and the Simple Ensemble best approximated the historical decline in rainfall over the São Francisco basin. The projected reduction in streamflow, considering both the CANESM2/Eta and HADGEM2-ES/Eta models, together with inter-annual weather variations and an expected increase in irrigation could cause the São Francisco's hydroelectric production to virtually cease in the second half of the twenty-first century. This is consistent with the findings of de Jong et al. (2018) who concluded that streamflow in the semi arid São Francisco basin is particularly vulnerable to climate change.

In general, the CANESM2/Eta model projected the biggest decreases in rainfall across most of Brazil and the other tropical regions of South America. However, projected rainfall changes across Brazil's southern region demonstrated only marginal reductions, and in some areas of the southern region slight increases in rainfall were projected, while a large increase in rainfall is projected for northern Argentina and especially across northern Chile. In comparison, the HADGEM2-ES/Eta model typically showed intermediate decreases in rainfall, with the exception of Brazil's southern region and northern Chile and Argentina which showed increased rainfall, while the MIROC5/Eta model demonstrated smaller decreases in rainfall across the north and NE regions and a substantial increase in rainfall over Brazil's southern region and northern Argentina and most of northern Chile. However, the MIROC5/Eta model appeared to be the least reliable model of the three for simulating past climate data in Brazil (such as historical wind and rainfall data). This result is consistent with the findings of McSweeney et al. (2015) who showed that the MIROC global climate models exhibited significant shortcomings in reproducing historical observations.

However, given the differing results amongst the 3 climate models, this study also demonstrates the large uncertainties and variations between different downscaled climate models, particularly when estimating long-term rainfall. In order to more accurately estimate changes in hydrology, an ensemble of the 3 climate models together with basin elasticity factors were used to estimate basin rainfall and streamflow changes, respectively.

Future work could also compare historical rainfall and streamflow data to climate model projections for other vulnerable river basins in South America such as the

Xingu, Madeira, Tapajós and Parana basins in Brazil, as well as the Orinoco river basin in Venezuela and the Magdalena river basin in Colombia.

Acknowledgements We would like to thank CPTEC—Centro de Previsão de Tempo e Estudos Climáticos/INPE—Instituto Nacional de Pesquisas Espaciais for providing downscaled climate projection data for Brazil and historical rainfall data for the São Francisco basin. We would also like to thank the Brazilian National Council for Scientific and Technological Development/"Conselho Nacional de Desenvolvimento Científico e Tecnológico"—CNPq Brazil (process number 153144/2018-1) for their financial support for this research.

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Chapter 4
Urban Gardens: Possibilities of Integration with Smart Practices

Leila Dal Moro, Liane Dalla Gasperina, Rafaela Vicenzi Pagnussat, and Luciana Londero Brandli

Abstract One of the biggest global problems is the lack of food, with little nutritional diversity and poor distribution, compounded by the indices of the increasing population. In general, the urban population is increasing, which implies several factors besides the preoccupation with the production of food, which can be enlivened by the participation of society's individuals and public agencies. The objectives of this research are to create a context of possible relationships between urban agriculture and smart practices, creating alternatives for food safety and achieving the goals of the Sustainable Development Goals, created by the UN in 2015. This research was divided into three stages: the first stage aims to analyze the connection and possibilities of the application of smart practices in urban gardens, with the discussion of global initiatives and possible applications and benefits of these practices; the second stage aims for an analysis of success cases and failure factors of these techniques; and the last stage presents a case study to look for possible implementations in other regions. This research hopes to contribute to food safety, as well as to assist in achieving the goals of the Sustainable Development Goals, mainly actions and initiatives for SDG 2, 11 and 12.

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Introduction

With the increase of the population and the worldwide urbanization of the last decades, there have been numerous changes in the quality of life and the distribution of food, which are reflected in the food safety conditions and the health of the population (Ribeiro et al. 2015). Food production is constantly increasing, but some populations still suffer from poor distribution, thus leading to serious social and economic problems, raising great concerns about the world's food sovereignty. In this sense, urban agriculture (mainly vegetable gardens) has brought about changes in the landscape of cities. This practice is mainly carried out in backyards, terraces, communal spaces or undeveloped public spaces and residences (Pires 2016).

Urban gardens are also carried out on the roofs of buildings, vertical gardens in urban areas, and planting in squares and terrains. They are usually made in small areas for the family's consumption, or to generate income from small-scale sales in local markets. Urban gardens have emerged as a response to the need to meet the sustainable demands of today's world and the production of local foods. In addition to contributing aesthetically to cities and to food production, vertical and rooftop gardens help contain pollution and increase the humidity of the environment (Valent et al. 2017).

Nowadays, technology is fundamental in all areas, contributing to the development of various sectors; food production is no different. Smart practices bring innumerable benefits by leveraging the activity. Cities today possess technologies and tools which could also be used to enhance food cultivation. According to Bakici et al. (2012) and Albino et al. (2015), a city that uses information and communication technologies (ICTs), that connects people, makes spaces sustainable and green, and most importantly, increases the quality of people's life can be considered a smart city.

Smart practices, analogous to the practices used in smart cities, are possible in various places and activities, using technology or not. For Nam and Pardo (2011), Schuurman et al. (2012), Gabrys (2014) and Rizzon et al. (2017), the key to smart practices is the connection of people with technology; that is, there is no use having the tools unless the population gets involved. To this end, smart practices can combine with the urban garden culture through the implementation of technologies aimed at the efficiency of the process as a whole, from increasing productivity and reducing losses to providing a possible tracking system to improve chances of success.

The issues presented here thus far fit directly or indirectly into at least 3 of the 17 SDGs (Sustainable Development Goals) launched by the United Nations (UN) in 2015. In all, there are 169 specific goals covering all areas and scales of the world, based on and built on the SDGs to balance the three dimensions of sustainable development: environmental, social and economic. For the UN (2015), they must involve the whole world, be applicable to all, and always respect the limits and capabilities of each other.

For Hayles (2018), sustainable development must take into account the current impacts in a way that does not jeopardize future generations, while the UN (2015) states that the world is at a time of great challenge for achieving sustainable development. Research, actions, projects and initiatives are necessary to contribute globally towards the minimization of these challenges. This work will focus on SDGs 2, 11 and 12, dealing respectively with Sustainable Agriculture, Cities and Sustainable Communities and Sustainable Production and Consumption.

This research seeks to support sustainable production and consumption through the promotion of organic food, with family labor in urban and residential gardens that utilizes devices, some equipment, and applications. In this way, it is possible to verify the potential and the importance of technology in smart practices for food safety.

Methodology

The methodology was divided into phases to fulfill the proposed objective (Fig. 4.1):

a. **Description of smart practices**—A global survey was conducted of articles, websites, case studies, and national and international papers with the following topic keywords: technologies in food production, smart practices in urban gardens, technologies in the production of residential food, smart practices in residential gardens.
   The objective was to understand the systems, equipment and devices that are used as smart technology in food production. The similarities between the choices of the smart practices were taken into account. In a sense, the similarities presented a benefit to the user, as the smart practices had already been implanted and tested. Results were sought from applications in urban gardens, with the description and benefits both for the environment and for the population. This is a multi-case study that justifies itself from the number of cases, not allowing generalization, but for the possibility of predicting similar results (Yin 2005).

Fig. 4.1 Methodological steps *Source* Authors, 2019

b. **Analysis of practices**—In this stage, we tried to analyze cases of success and the failure factors of the smart practices (applications) in the urban gardens, focusing on the potentialities, challenges and their contribution to food production.
c. **Case detailing**—We sought to deepen the chances for possible contributions to sustainable development with the implementation of smart urban garden practices in other global regions. To do so, we began the search for a case study (applications) that contemplated urban gardens linked to smart practices and verified in detail the solutions and sustainable impacts. For the selection of the applications, an analysis was made of the ones that were used and presented in their sources, with comments from users, testimonials and criticism, thus providing an evaluation of the positive and negative points of the same applications.

Possible contributions have also been identified for the achievement of the Sustainable Development Goals, in particular the three addressed in this research (2, 11, 12).

Results

To present some practices used for the production of food around the world, Table 4.1 was prepared in such a way that the first two columns match the first phase, and the practices and descriptions thereof can be observed along with the benefits.

The third and fourth columns respond to the second phase; the cases of success and the failure factors of these practices can be analyzed. For Ramos et al. (2011), it is necessary to understand the factors of success and failure to obtain answers about what can influence the final result.

As the association of technology with small-scale food production is constantly growing, these smart practices support organic production where families are allowed to produce their own food. In this way, urban gardens can transform the growing number of consumers into producers. In addition, some people want to connect with nature, and this influences their eating habits, as well as the use of natural resources and manpower (Winkler et al. 2019).

The analyzed smart practices have similar characteristics, using systems, equipment and devices that stand out for automation and ease. They have light controllers as needed for each plant, water sprayers and other nutrients that plants need, connected through applications that often warn the user at the correct time of harvest. The inclusion of smart practices in residential and urban gardens provides opportunities for more and more people to produce their own food. For Winkler et al. (2019), the health aspect of nutrition and the social aspect of pleasure in producing are important motivators.

In relation to the benefits presented by smart practices in urban gardens, they bring various contributions to sustainable production, presenting modern and sustainable technological systems for organic food and easy access. Among many other positive aspects, this interaction between technology and cultivation enables alternative forms of cultivation, an ease provided by the automation from the planting of the food to the harvest phase, a practicality and mobility of the devices equipped with technology, and economy and food safety.

The implementation of smart practices in urban gardens and the creation of alternatives of food production involving technology have already been perceived in many countries. In the present study, the equipment produced and applied in the United States was highlighted, standing out for its diversity and popularity, due to the greater number of practices found there.

Concerning the potentialities or cases of success of these practices, it is possible to verify that they are portable, small, and need little labor; in addition, they can be used as a base for the planting of several species.

When we mention the challenges or failure factors, it is possible to understand that they cannot favor large-scale production, some require a high investment to obtain them, and although they are sustainable, they generally require electricity.

With the strong expansion of global environmental degradation, social inequality has increased, as has the concern over the exacerbated consumption of natural resources (Adams et al. 2015).

Also, we sought to detail a case study that brings contributions to achieving the goals of the Sustainable Development Goals. By compiling a list of applications and their descriptions, it was possible to analyze and highlight different aspects to expand in order to disseminate the importance of using the applications to promote sustainable development and food production. Table 4.2 illustrates this analysis.

Table 4.2 exemplifies some of the global applications that favor the management of food production, assisting in the preparation of gardens, species identification, and the need for light, water and fertilization. Many of these applications generate a database that people can access to exchange experiential activity in planting, growing and harvesting facilitated by the use of technology.

Aiming to contribute to the Sustainable Development Goals, this study addresses issues that focus on the themes of the SDGs, thereby assisting in relevant issues that can promote sustainable development. It is important to underline the great importance of theoretical and practical research that is added to public and private partnerships so that we can have positive results for humanity.

Regarding the contributions to the achievement of the Sustainable Development Goals, it can be noted that there are three SDG's addressed in this study, SDG 2, 11 and 12; more precisely, some of these goals can be observed in Fig. 4.2.

In a way, by using the applications identified in Table 4.2 in urban gardens, at least partial achievement of some SDG goals can be achieved.

All of the applications, primarily presented, aim for everyone having access to safe food and information on how to grow your own food with the help of technology, even on a small scale, and this is associated with the goals highlighted in SDG 2.

For Giordani et al. (2017), the social promotion in this food issue is based on the way people eat, the means by which they access the food, and what food they have access to. Thus, applications are alternative ways of seeking food assurance, such as quality information, origin and modes of consumption.

Table 4.1 Smart practices, benefits, potentials and difficulties

Smart Practices Implementation site	Description and benefits (Global initiatives)	Potentialities (Success stories)	Difficulties (Fault factors)	Source
Niwa device Spain	• Combination of lights, water sprays, fans and sensors. You only need to place the seeds in a hydroponic base and let the device do the rest	• Little space and manpower • Organic production	• Little production • High cost	Get Niwa [S.a.]
IO Sprouts Kit United States	• Automatic management of the amount and frequency of water, light and fertilizer through a camera-equipped smart vessel and application • Cultivation of plants suspended in the air, without land use, with spraying of water and nutrients at the root • Moisture, temperature and pH meter of plants for data creation	• Resource saving • Alternative form of cultivation • Data management and production • Organic production	• Little production	Nunes (2014)
Aspara system Hong Kong	• Portable mini garden with automatic irrigation, only need to fill the reservoir. Also, sensors and intelligent lighting with LED lamps, adapting the environment for each species	• • Little space • Organic production • Adaptation for various species	• Little production	Aspara [S.a.]

(continued)

Table 4.1 (continued)

Smart Practices Implementation site	Description and benefits (Global initiatives)	Potentialities (Success stories)	Difficulties (Fault factors)	Source
Small garden box 2 Denmark	• Mini box with various seed substrates. Wi-Fi connection and application where you can get information about: species, water, humidity and light, among other functions	• Organic production • Amount of information	• Little production	Edntech [S.a.]
Grove eco system equipment United States	• Device with artificial light and compost generated from fish waste in a coupled aquarium. Connection to own application for information and conditions of each component	• Organic production • Use of waste and no need for cleaning the aquarium	• High cost to obtain • Uses electricity • Occupies a large space	Garrett (2015)
Counter crop system United States	• Boxes with LED lamps imitating sunrise and sunset, as well as the natural changes of each season, can be controlled. It only needs planting, water and fertilizer	• Little space and manpower • Organic production	• Little production • High cost	Kickstarter [S.a.]
Veritable garden France	• Automatic plant growing equipment, adaptable with independent lighting, different plant sizes and growth rate, irrigation and nutrients	• Organic production • Recyclable and biodegradable packaging of plant refills • Portable	• Produces little amount • Uses electricity	Veritable [S.a.]

Source Authors, 2019

Table 4.2 Applications

Application	Description of the application	Source
Garden time planner	• Large database of informative instructional plans and videos, weather forecasting and if plants are evolving	Burpee (2019)
Gardroid	• Teaches you how to plant and ensures that plants receive exactly what they need	De kerrf (2019)
Garden compass	• Assists in the identification of pests and diseases. You can simply take a picture with the application that can identify it	Garden Compass (2019)
Vegetable tree	• Explain the important characteristics of different fruits and vegetables. Tips and tricks on how to create a variety of plants	Azam [S.a.]
Planting	• Information on the cultivation and varieties of vegetables, spreading the practices of urban agriculture, also, on sun exposure, soil type, the season of the year, what foods use the products, and simple methods for control of pests • Teach when, how and where to sow, plant at home, harvest and water about 28 varieties of crops	Plantit [S.a.]
Salad guide	• Tips for anyone who wants to start planting at home • The application has a connection to an urban garden that can be installed on the balcony of the apartment, in the yard or in small pots spread in sunny environments	Rosa (2015)
Garden at home	• Information on different types of vegetables and vegetables, watering and light reminders • Has a catalog where users can order seeds of various species and receive in their home, as well as a guide on how to grow all species as organic	Tech x play (2018)
Cultivating in Brazil	• Focused on food independence in Brazil. The application has information on better seasons for growing crops, planning, and pest and disease control. It can be also accessed offline	Rodrigues (2017)
Garden answers	• Easy recognition of plant species, vast database where it is necessary to take a photo of the plant and the recognition is done in seconds	Gardens Alive (2019)

Source Authors, 2019

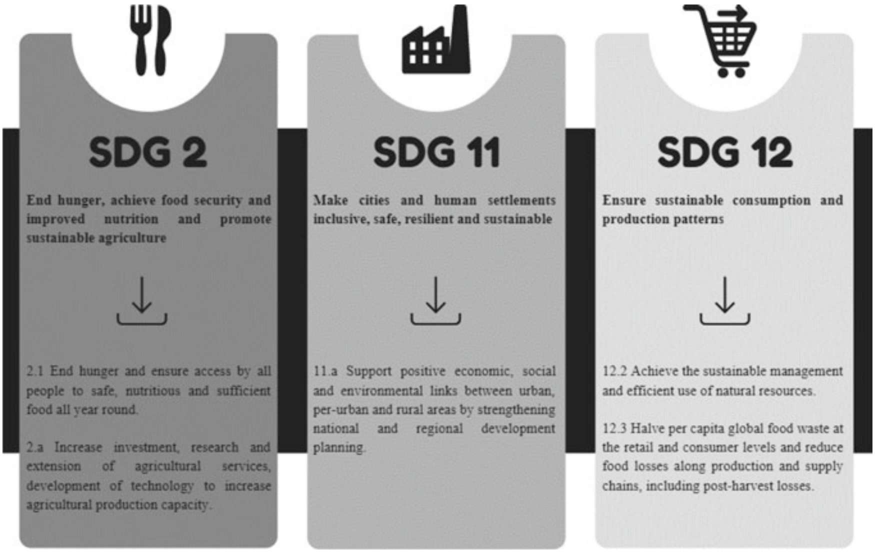

Fig. 4.2 SDG goals addressed in the study. *Source* Authors, 2019

Using applications gives producers the ability to have an extensive database, and they can even be registered in farming associations, thus obtaining economic relations and planning, thereby being closer to reaching the goal highlighted in SDG 11. In agreement, Costa et al. (2018) say that technology is not intended to replace the producer's experience or wisdom, but to provide information on various aspects, with greater efficiency and less waste.

By being able to drive growth, smart urban gardeners can acquire knowledge at all stages, from cultivation to the right time of planting, thereby improving the quality of food and also seeking to achieve the goals highlighted in SDG 12. For Minerva et al. (2015) it is a technology that aims to empower producers and increase productivity, promoting even the reduction of costs and improvement in the quality of the users' life.

Conclusion

Currently, cities have been growing, developing and resolving innumerable obstacles with planning, or lack of it, by public agencies and individuals in general. In relation to this growth, smart practices associated with food cultivation in urban gardens promote environmental, social and economic initiatives, because they are usually carried out by producers and consumers who are looking for a healthier diet, are economical and care about the environment.

Taking into consideration the numerous alternatives for the urban production of fresh and organic food, it was possible to detail and analyze the smart practices through the equipment, systems, devices and the numerous applications that are viable and assist in the activity. While all these technological practices have benefits and potentialities, some may contain some of the failure factors that can present both economic and environmental challenges for the population.

Based on the UN Sustainable Development Goals to reduce poverty through the guarantee of access to food, to make agriculture more sustainable and to promote more sustainable production and consumption, there is still need for further research, as well as an awareness of all types of waste involving food.

We need different ways of thinking and acting if we are to contribute globally to the food system. Smart practices play an important role, as technology is increasingly viable and accessible to the population, contributing to the attainment of these goals and favoring various sectors, going beyond consumer needs.

Overall, this article sought to present information inherent in the use of technology, food concern and consumption. This is a subject in constant growth, but currently has little popularity. As the final objective, this study hopes to instigate studies involving smart practices in urban gardens so that the topic is disseminated and discussed more frequently, taking into consideration the numerous possibilities of research, partnership and deployment.

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Chapter 5
Mass Exchange in Dead Water Zones: A Numerical Approach

Luiz E. D. de Oliveira and Johannes G. Janzen

Abstract Dead water zones (DWZs) in natural open channels, formed by consecutive groynes, are regions separated from the main channel, characterized by recirculating flows. These regions present lower velocities compared to the main channel, increasing the deposition of sediment and the temporary storage of polluted materials. Exchange processes between DWZs and the main channel influence the transport of pollutants in channels. This study adopts the k-omega shear stress transport (SST) turbulence model to examine the mass exchange between the main channel and the DWZ created by an infinite series of groynes. The computational results were compared to data collected in literature. A good agreement was achieved in the mass exchange coefficient, with a relative error of approximately 2%.

Introduction

In fluvial engineering, channels are generally shaped by complicated boundaries that can be composed by dead water zones (DWZ), which can be formed by consecutive groynes (Xiang et al. 2019). Groynes are transversal dykes placed in sequence along riverbanks to keep the flow away from the banks. The effects of this structure in rivers are an increase in mean velocity and water depth in the main channel, improved navigability, increased efficiency of sediment transport, protection against flooding and the mitigation of bank erosion (McCoy et al. 2008). Its placement also provides lateral heterogeneity that can favour the presence of aquatic organisms, improving

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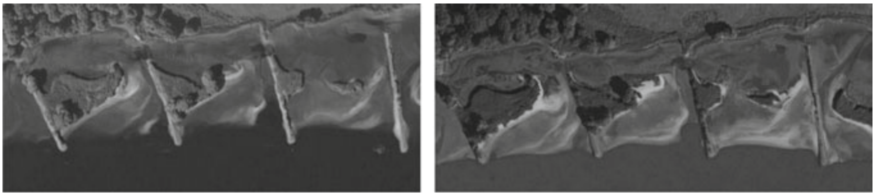

Fig. 5.1 Groyne fields bathymetry change (left) December 2008 (Google Earth Pro 2018) (right) December 2009 (Google Earth Pro 2018)

the biodiversity of river ecosystems (McCoy et al. 2008, 2015; Buczyński et al. 2017; Mignot et al. 2017; Buczyńska et al. 2018; Xiang et al. 2019).

Since the magnitude of mean flow velocities inside the DWZ is approximately 25% of the flow velocities in the main channel, not only the deposition of sediment is enhanced, but also that of nutrients and contaminants which are readily attached to fine particles (Sukhodolov 2014). For instance, the attachment of contaminants to particles was observed in the Middle Elbe River, in Germany, leading to a low standard classification from an ecological view (Schwartz and Kozerski 2003). The authors found, in the groyne fields, the deposition of fresh organic mud with high nutrient and pollution content (e.g. nitrogen). The deposition of pollution content attached to sediments creates a problem for river management (Uijttewaal 2005), especially in flood seasons, when the groyne field becomes submersed, being a source of contaminants to the main channel.

The exchange processes at the groyne field-channel interface can substantially modify the transport and dispersion of contaminants (Constantinescu et al. 2009). It is important to understand, then, how the pollutant cloud interacts with the groyne fields, the storage time and how the pollutants tends to settle. Quantitative knowledge of the exchange processes allows a better estimation of global pollutant spread, which can be used in forecasting models for water quality and river pollution (Weitbrecht et al. 2008). Furthermore, it can indicate a life cycle of groyne fields, as with time it becomes more and more shallow (Fig. 5.1 Left and Right).

Therefore, in order to estimate the transport of pollutants in a channel, it is important to be able to understand and predict the exchange processes between the main channel and the DWZ formed between groynes (Weitbrecht and Jirka 2001). These exchange processes were studied in detail in a series of laboratory experiments carried out by Weitbrecht (2004). Hinterberger et al. (2007) used large eddy simulation (LES) to model Weitbrecht's experimental results. Although it is a very precise model, the LES is also more time consuming when compared to simpler models. Therefore, this study aims to investigate the mass exchange between the main channel and the groyne field using a simpler two-equations turbulence model, k-omega SST. The computational results are compared to Weibrecht's results and a good agreement was obtained.

Methods

The geometry was chosen to match the groynes from the second series of experiments described in Weitbrecht (2004). The flow depth (h) was kept constant at 0.046 m and the experimental channel width (B) at 1.80 m. The emergent groynes were 0.50 m long (W) and spaced 1.25 m apart (L), producing an aspect ratio of $W/L = 0.40$. The groyne heads were in a semi-circle format with a diameter of 0.05 m. The Reynolds number was 7360, and thereby turbulent.

The flow past the most downstream-located groyne in the series had a periodic behaviour (Hinterberger et al. 2007). Consequently, the flow from only one complete groyne field and two halves (located upstream and downstream from the complete one) were computed and a translational periodic boundary condition was imposed (Fig. 5.2). The mean streamwise velocity in the computational domain was approximately $U = 11$ cm/s, which corresponds to a mass flux of 6.56 kg/m^2 of water in the periodic zones.

As the effects of the obstacles in the main channel extend up to one obstacle length in the transversal direction (y-axis) (Brevis et al. 2014) the domain was two-thirds of the experimental flume width (B), reducing the computational effort. A free-slip symmetry boundary condition was imposed on the surface (Fig. 5.2). This boundary condition was also used on the free surface plane, as it is an acceptable simplification for flows with Froude numbers smaller than 0.5 (our Froude number was 0.24) (Alfrink and van Rijn 1983). All walls, bed, lower side wall and groyne walls were considered hydraulically smooth.

The domain was calculated in a three-dimensional grid (Fig. 5.3a). The spatial discretization had a higher refinement in regions close to walls and at high velocity gradient regions. The meshing of the groyne's heads considered its curvature and the proximity to the wall. This region used an O-grid with an increasing element size (Fig. 5.3b). The mesh had 20 divisions in the z-axis, increasing gradually from the

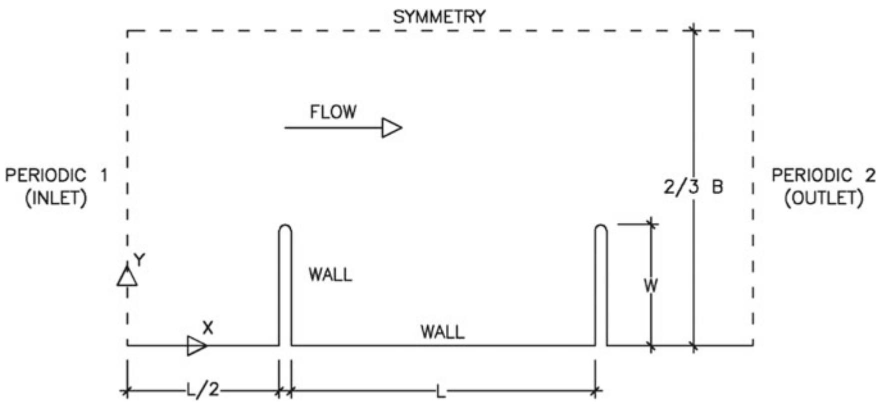

Fig. 5.2 Upper view of the computational domain, from the free surface, and its boundary conditions

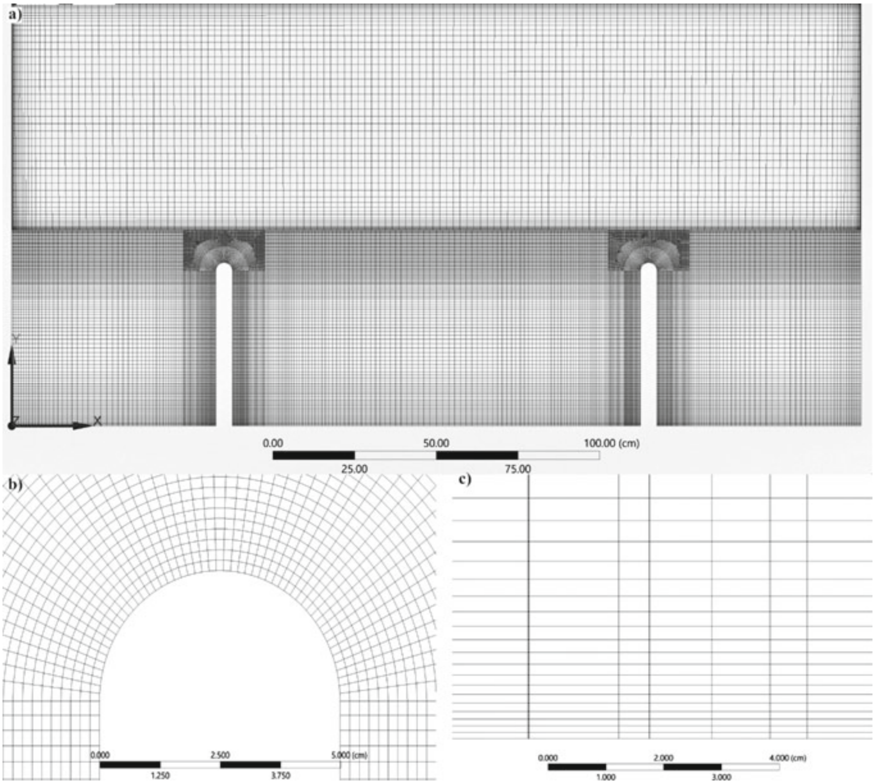

Fig. 5.3 Computational mesh: **a** mesh in the free-surface plane; **b** curvilinear grid around groyne tip; **c** mesh in a vertical plane near the middle of the groyne field

bottom of the channel to its free surface (Fig. 5.3c). In the y-axis, the groyne field had 70 divisions that gradually increased in size as they get closer to the middle of the field. The strip that contains the groyne's heads had finer elements due to the momentum transfer in the shear layer. The total grid presented approximately one million elements.

The commercial software called Ansys® FLUENT (version 14) was used to solve the grid, using the finite volume method to discretize the governing mass and momentum equations. The turbulent model chosen is based on the Reynolds-averaged Navier–Stokes equations (RANS) approach, that consists of time-averaged equations for fluid flow. The turbulent calculations were solved using the k-omega SST model proposed by Menter et al. (2005), due to its capability of solving fluid flow in low Reynolds numbers. The pressure–velocity coupling method was SIMPLE and the gradient spatial discretization was Least Squares Cell Based. The momentum was discretized in a third order MUSCL scheme. The turbulent kinect energy (k) and specific dissipation rate (omega) were discretized in a second order upwind scheme.

In addition to the velocity field, tracer concentration fields were also calculated by solving the following transport equation

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla.\left(\rho \vec{v} Y_i\right) = \nabla\left(\rho D_{i,m} + \frac{\mu_t}{Sc_t}\right)\nabla Y_i \tag{5.1}$$

$$Sc_t = \frac{\mu_t}{\rho D_t} \tag{5.2}$$

where ρ is the fluid mass density, Y_i is the local mass fraction of each species, $D_{i,m}$ is the mass diffusion coefficient for species in the mixture, ν is the velocity vector, $D_{i,m}$ the mass diffusion coefficient for species in the mixture, Sc_t is the turbulent Schmidt number (5.2) ($Sc_t = 0.7$), μ_t turbulent viscosity and D_t the turbulent diffusivity. In other terms, the transport equation means that the rate of change and the net rate of flow (convection) equals the rate of change due to diffusion.

Equation (5.1) does not consider any chemical reactions or addition of phases during the solution and was discretized in a second order upwind scheme. The tracer was conservative, pursuing the same properties as water.

The time step in the simulation was 0.024 h/U. The simulation was run for nearly 180 h/U until the fully developed state was achieved. Once the flow reached the fully developed state, the tracer mass fraction was set to 1 within the groyne field and 0 in the other parts of the channel. Then, statistics of the mean flow and tracer transport were calculated using the instantaneous flow fields and mean tracer concentration inside the groyne field over the next 548 h/U.

Results and Discussion

Two gyres could be observed in the groyne field: a large primary gyre (right vortex in the central groyne field) and a small secondary gyre in the upstream groyne (Fig. 5.4). The formation of this system occurred from the momentum transferred by the main channel through a mixing layer. As the main flow went downstream, the shear in between zones excited an anticlockwise gyre (primary gyre) that further excited a smaller clockwise circulation (secondary gyre) that had no contact with the main channel. The secondary gyre was smaller in size (approximately 21% of the groyne field area) and velocity magnitudes, when compared to the mean circulation (Fig. 5.4).

Figure 5.5 shows the mean streamwise velocity distributions for $x/L = 0.25$, 0.50 and 0.75 (x has origin in the right face of the first groyne and points to the right). Overall, the model had a good accordance in the main channel and in the central part of the groyne field. The computational model was able to capture the circulation pattern inside the groyne field. However, near the groyne heads (interface between the main channel and the groyne fields) the concordance was not so good. This is due to the high dissipation of momentum that occurred in the mixing layer. Despite the fine resolution of the grid, the model could not describe the flow inside this region.

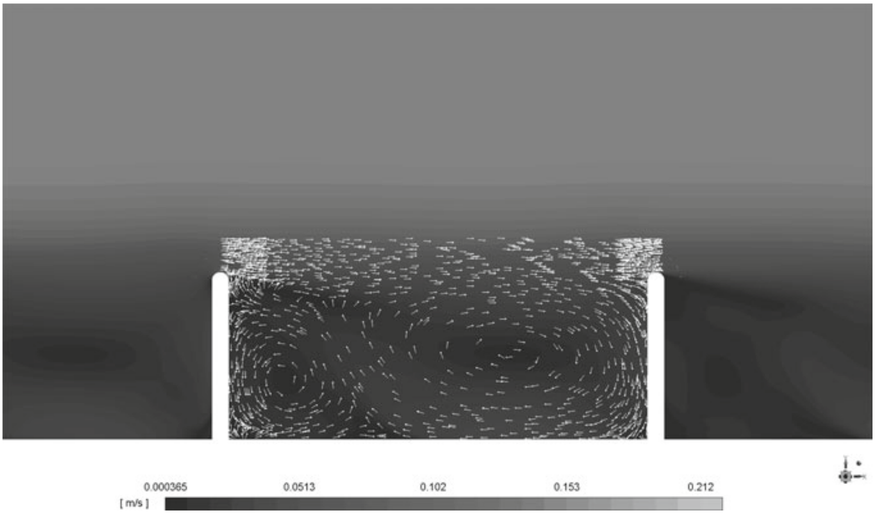

Fig. 5.4 Mean velocity contour

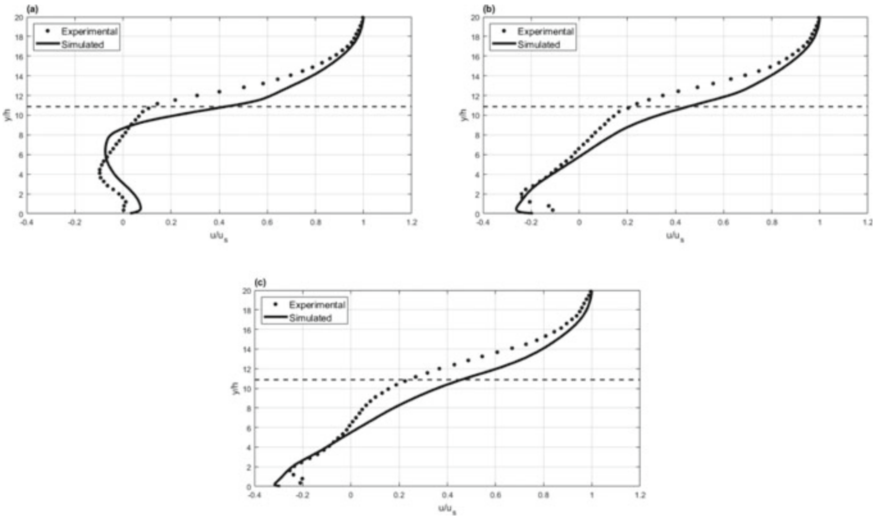

Fig. 5.5 Mean streamwise velocity distributions. **a** $x/L = 0.25$, **b** $x/L = 0.50$ and **c** $x/L = 0.75$. The dashed line represents the groyne head position ($y/h = 10.87$)

For the same reason, the secondary gyre did not have contact with the mixing layer, since this vortex was formed by the dissipation of momentum from the primary gyre. The mean error was approximately 102, 21 and 47% for Fig. 5.5a–c, respectively. However, the flow was in the same order of magnitude as the experimental, which indicates that Fig. 5.4 represents qualitatively, at least, the flow within the region.

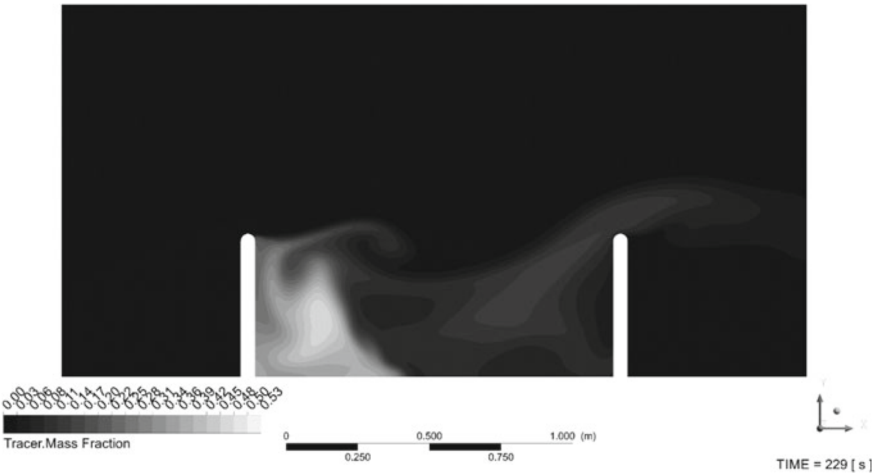

Fig. 5.6 Tracer mass fraction in the free-surface plane in time 229 s

The ejection of tracer from a groyne field to the mixing layer (region between the DWZ and the main channel) occurs in the upstream portion of the field (up to 40%), while the following 60% is a region where mass can re-enter the system (Weitbrecht, 2004). The tracer concentration stayed higher in the secondary gyre, while the primary gyre oscillated due to the injection of tracer from the mixing layer and its natural ejection (Fig. 5.6). This movement was captured by the model and can be seen completely in https://youtu.be/9b-4JZJdeA0.

The tracer concentration inside the field was fitted in a first order decay model (5.3) following the same procedure from the experimental study (Fig. 5.7).

$$C = C_0 \exp(-t/MRT) \tag{5.3}$$

where *MRT* is the mean retention time. Based on the *MRT*, the mass coefficient k (5.4) was calculated in order to estimate the intensity of mass exchange (Weitbrecht and Jirka, 2001).

$$k = \frac{W}{MRTU} \tag{5.4}$$

The fitted curve presented an $MRT = 117.7$ s that related to an exchange coefficient of $k = 0.026$. The relative error between the mean value of Weitbrecht's experiments and our model was 1.99% for the exchange coefficient and 1.69% for MRT (Table 5.1).

Although we could observe a good agreement between our computational model and the experimental results, it can be observed that the system presented two slopes, with a breakpoint near $C/C_0 = 0.2$ (Fig. 5.7). The first slope was influenced by the

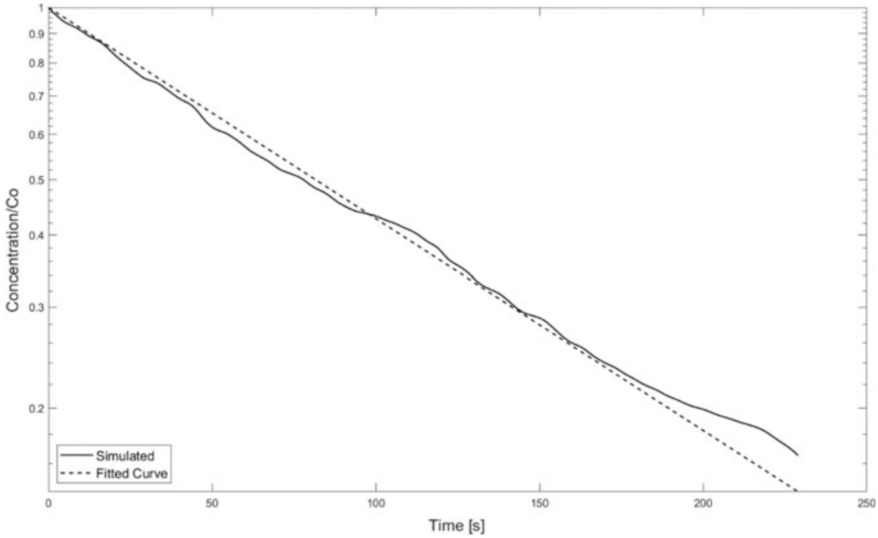

Fig. 5.7 Volumetric averaged mass concentration inside groyne field

Table 5.1 Comparison of mean residence time inside groyne field and exchange coefficient in between experimental and numerical studies

Experiment/Model	MRT [s]	k
Experiment 1	97	0.029
Experiment 2	114	0.028
Experiment 3	125	0.022
Mean value of experiments	118	0.027
3D LES (Hinterberger et al. 2007)	137	0.023
2D LES (Hinterberger et al. 2007)	75	0.042
3D k-omega SST (global fitted curve)	117.7	0.026
3D k-omega SST (first slope)	113.3	0.0274
3D k-omega SST (second slope)	121.62	0.0256

tracer concentration present in the primary gyre, that oscillates between ejecting mass and re-absorbing via the shear layer. The second one ejects mass slower, as the concentration in the field was mainly disposed in the secondary gyre. Figure 5.8 shows the tracer concentration fitted in two curves, the first curve presented an $MRT = 113.27$ s and a $k = 0.0274$ while the second $MRT = 121.43$ s and $k = 0.0256$. The summary of the model and comparisons with previous studies can be seen in Table 5.1.

Our results are consistent with field observations. Sukhodolov et al. (2004), for example, observed that the mass concentrated in the secondary gyre, since it presented the slowest velocities in the groyne field.

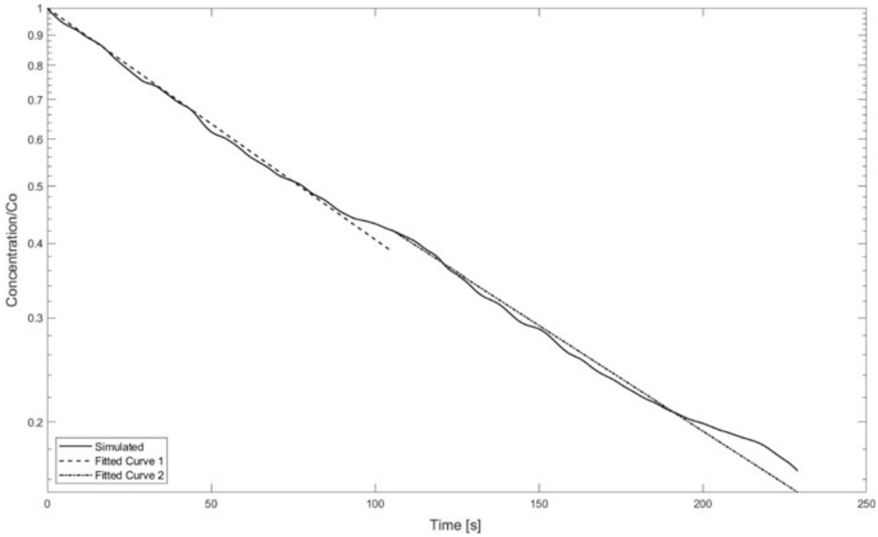

Fig. 5.8 Volumetric averaged mass concentration inside groyne field fitted with two curves

Conclusion

A 3D k-omega SST simulation was presented for a periodic shallow water flow in a groyne field. Our model was able to reproduce a similar structure and magnitude flow compared to experimental data. Furthermore, our model could predict the mass exchange coefficient between the main channel and the DWZ and the mean retention time of the DWZ, being in good concordance with experimental results. In agreement with experimental and field observations, the decay of mass inside the field is described in two phases, first when the primary gyre dominates the ejection and second when the mass is concentrated in the second gyre prolonging the MRT. Hence, a simpler model than LES can predict the main parameters related to the mass exchange process in groyne structures.

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Chapter 6
Potential for Application of the Biogas Produced from Manure of Dairy Cattle in a Cheese Factory

J. V. Paim, G. S. Pereira, K. C. R. Madruga, and E. Virmond

Abstract Biogas is a biofuel whose application requires observance of factors such as composition (CH_4, CO_2, NH_3, H_2S), purification needs, calorific value, Wobbe number and gas pressure, among others. The present work analyzed the biogas from a biodigester built under the first project of the Association Technology without Borders (TwB) Brazil in a rural property located in Araranguá, SC, Brazil. The project aimed to apply biogas in the biodigester as a partial substitution of the liquefied petroleum gas (LPG) used in the cheese factory. The biogas, besides containing low concentrations of H_2S (40 ppmV), presented a NH_3 concentration of 175 ppmV, estimated Lower Heating Value of 25.42 MJ m^{-3} and Wobbe index of 29.16 MJ m^{-3} (both at 25 °C and 1 atm). The preliminary combustion test indicated good quality of the produced biofuel. Therefore, the biogas produced in the system and under the evaluated conditions showed potential for partial replacement of LPG in the considered application.

Introduction

According to projections of the Ministry of Agriculture, Livestock and Food Supply, milk production is expected to grow from 35.3 billion liters in 2018–50.1 billion liters at the end of 2018, at an annual rate of 2.9% (Brasil 2018a). Along with the increase in milk production, there is also an increase in animal production, consequently increasing the production of manure (mixture of manure and urine), which has great pollution potential if not managed accordingly.

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Biodigestion represents an effective way of treating the effluents from confined bovine production and can contribute to reducing the emission of greenhouse gases (Brasil 2018b), since these residues release such gases during its natural degradation if dumped in the open air.

The National Agency of Petroleum, Natural Gas and Biofuels (ANP), in the ANP Resolution no. 8 of 30/01/2015 (Brasil 2015), defines biogas as the raw gas obtained from the biological decomposition of biodegradable organic products or residues of vegetal or animal origin, in the process known as biodigestion. The reactors applied to this process are to be properly designed and operated, aiming for the optimized production of biogas and other products such as organic fertilizer, which is widely applied in agriculture in substitution for chemical products.

The biogas production in Brazil increased from 15,000 tons of petroleum equivalent (tpe) in 2010 to 137,000 tpe in 2016 (Coelho 2017). According to Biasi et al. (2018), the south of Brazil presents great potential for biogas production due to the intensive and dense production of dairy cattle manure. The biogas production and energetic utilization in the Santa Catarina state has been regulated by resolution CONSEMA 98/2017 (Santa Catarina 2017), and more recently, law No. 17,542 presented the State Policy of Biogas (in Portuguese "Política Estadual do Biogás"), delineating directions, instruments and incentives for biogas production, exploration, management and commercialization (Santa Catarina 2018b).

The energy application of biogas in Brazil is divided into 49% for thermal energy generation and 44% for electricity generation; the remaining is either converted into mechanical energy or upgraded to biomethane (Gahb 2017). The most usual thermal conversion application is for partial or total substitution of fossil derived fuels (natural gas or Liquefied Petroleum Gas—LPG) in heating and cooking systems. In Brazil, the domestic cooking systems fueled by gas are regulated by the standard ABNT NBR 13,273 (ABNT 2003), in which the gaseous fuels are classified into three categories—manufactured gases, natural gas and LPG—according to the chemical composition, Higher Heating Value (PCS), Wobbe index (I_w) at 15 °C and 101.33 kPa and relative density. Gases with the same I_w may present the same energetic performance, with the same rate of heat transfer.

The biogas characterization is the first step when aiming for its energy application, and is given in terms of volumetric flow rate, pressure, temperature and chemical composition. From the chemical composition it is possible to estimate the heating value, which is taken into account for energetic equivalence purposes. However, it is not usually possible to convert the raw biogas, because some of its components—such as NH_3, H_2S, H_2O—may be harmful to the combustion systems depending on the concentrations, affecting the conversion efficiency or causing corrosion of components of the conversion system. Thus, from the chemical characterization, the need for purification for an intended application may be defined (FNR 2010).

The objective of the present work was to evaluate the potential for application of the biogas produced from dairy cattle waste in a biodigester installed in a rural property of the municipality of Araranguá, SC, Brazil, as an alternative source of energy in a cheese factory aiming at the partial substitution of LPG. In order to do so, the biogas was firstly characterized and a biogas combustion test was performed to evaluate basic aspects of the intended use by analyzing the exhaust gas composition.

Material and Methods

The selected rural property is located in Araranguá, Santa Catarina State, in southern Brazil. An Indian model biodigester was adopted for this family unit, as described in detail by Pereira (2018). Due to the routine already existing in the property, the hydraulic retention time (HRT) of the biodigester under study was 15 days, with the feed of the biodigester being a 1:1 diluted mixture (manure and water) in order to facilitate the loading and unloading operations (which are simultaneous).

Biogas was characterized in the following time intervals over an HRT (15 days) from day 0. Time interval 1 corresponded to day 0 through day 4, time interval 2 corresponded to day 4 to day 9, and time interval 3 from day 9 to day 15. The composition of the biogas was determined immediately upon the exit from the gasometer of the biodigester. At the end of each analysis, the remaining biogas in the gasometer was completely exhausted, returning to the lower level, and the valve closed again for filling in the subsequent time interval. For each day of analysis, the local temperature was checked and recorded, as well as the height of the gasometer (measured using a metric scale). Due to the stage of the biodigester installation (not yet completed), it was operated without the necessary gasometer overweight to pressurize the biogas in the pipeline up to the point of consumption. From the gasometer elevation records, the biodigester dimensions and the volume of waste fed, the volume of biogas produced was determined and, considering the time intervals mentioned, the daily biogas production rate was estimated, since it is required to evaluate the potential for LPG replacement.

For the determination of the biogas composition, a portable analytical set-up (Alfakit, Brazil) was used based on the colorimetric method to determine the concentrations of hydrogen sulfide (H_2S) and ammonia (NH_3), and the volumetric method was used to determine the concentration of carbon dioxide (CO_2); therefore the methane (CH_4) concentration was obtained by the difference. The Origin 6.1 software, with one-way ANOVA function, was used to analyze the results of the chemical characterization of biogas at a significance level of 0.05.

In addition, the biogas Lower Heating Value (LHV) was calculated considering the stoichiometric combustion reaction of CH_4 through Eq. 6.1 (adapted from Hilsdorf (2015)) considering the percentage of CH_4 determined in the biogas analysis.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

$$LHV = \frac{G * 1000}{22.4} * h_G \qquad (6.1)$$

In which G is the percentage of CH_4 in the biogas and h_G is the enthalpy of combustion of CH_4 (−802 kJ mol^{-1} at 25 °C and 1 atm). The Wobbe index was calculated through Eq. 6.2 and the relative density of the biogas at 0 °Cand 1 atm was obtained considering the relation established by Ryckebosch et al. (2011) between the Wobbe index and the relative density as a function of the percentage of methane in the gas. The resulting relative density was corrected to the same pressure condition of the LHV.

$$I_w = \frac{LHV}{\sqrt{relativedensity}} \quad (6.2)$$

In the cheese factory, the considered point of fuel consumption uses an aluminum cooker (CF), which consumes 850 g of LPG per hour, and it is used three days per week for a total of five hours per day, resulting in 12.75 kg of LPG per week.

A biogas combustion test was performed in order to evaluate basic aspects of the intended use (partial replacement of LPG), which lasted approximately 20 min. For this purpose, a multi-purpose burner 06 (Caulins) was used, which was coupled to the pipeline of the gasometer. The valve installed at the outlet of the gasometer was fully opened to release the biogas to the burner; it was necessary to overweight the top of the gasometer in order to increase the pressure of the biogas as the definitive overweight had not yet been installed. The composition and temperature of the flue gas originating from the biogas combustion were determined as described by Virmond (2007,2011) using a gas analyzer Greenline MK2 (Eurotron Italiana S.r.l.) for CO, O_2, SO_2, C_xH_y (measured as CH_4), NO and NO_2. CO_2 concentrations were calculated by the instrument based on the composition of the reference fuel (natural gas) and on the excess of oxygen.

Results and Discussion

The first biogas analysis took place on 5 November, 2018 (day 4), the second on 10 November, 2018 (day 9) and the third on 16 November, 2018 (day 15) at the temperatures of 21 °C, 21.9 °C and 30 °C, respectively.

Table 6.1 shows the values obtained in the biogas analyses. The discrepant results were disregarded in the calculations of the average concentrations.

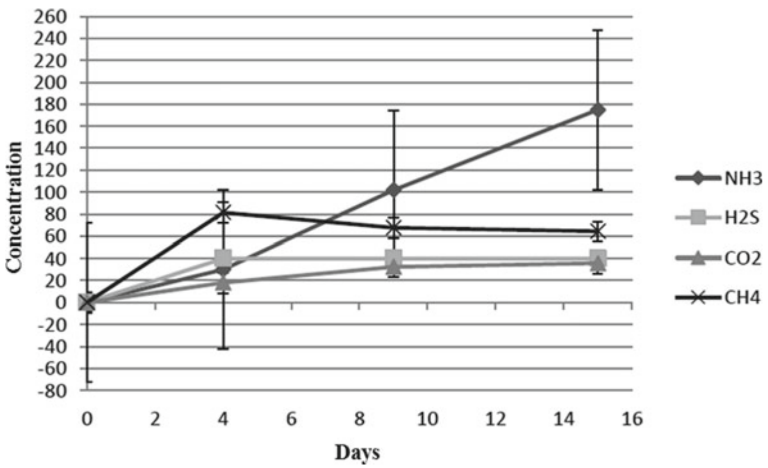
Each biogas sample was collected in a plastic bag and small volumes of it were taken for the determination of each parameter. In the analytical procedures on days 4 and 9, it was observed that the concentration of NH_3 decreased progressively from sample 1 to 3, such as presented in the data in Table 6.1 and Graph 6.1. This might be related to the fact that in these days the analysis of NH_3 was not prioritized, leading to the rapid escape of NH_3 from the solution due to the fact that at atmospheric pressure its boiling temperature is −33.34 °C (Linde 2015). Once the method of analysis of NH_3 was modified, (prioritizing the ammonia analysis) the stability of the concentrations of the three samples of day 15, in the range of 175 ppmV, was verified.

Table 6.1 Results of the biogas chemical characterization at days 4, 9 and 15

	Sample/repetition	1	2	3	4	Mean and standard deviation
Day 4	NH_3 (ppmV) at 25 °C	45.0	15.0	–	–	30 ± 21.2
	H_2S (ppmV) at 25 °C	40.0	40.0	–	–	40 ± 0.0
	CO_2 (%, v/v)	16.0	35.0	20.0	–	18 ± 2.8
	CH_4 (%, v/v)	82.5	65.0	80.0	–	81.3 ± 1.8
Day 9	NH_3 (ppmV) at 25 °C	175.0	85.0	45.0	–	101.7 ± 66.6
	H_2S (ppmV) at 25 °C	40.0	40.0	–	–	40 ± 0.0
	CO_2 (%, v/v)	32.5	15.0	32.5	–	32.5 ± 0.0
	CH_4 (%, v/v)	67.5	85.0	67.5	–	67.5 ± 0.0
Day 15	NH_3 (ppmV) at 25 °C	175.0	175.0	175.0	–	175 ± 0.0
	H_2S (ppmV) at 25 °C	40.0	40.0	–	–	40 ± 0.0
	CO_2 (%, v/v)	20.0	32.5	37.5	37.5	35.8 ± 2.9
	CH_4 (%, v/v)	80.0	67.5	62.5	62.5	64.2 ± 2.9

It was thus recognized that the method performed in the third biogas characterization (day 15) is the correct method for obtaining ammonia concentration values. The H_2S concentration was stable in the analyses performed on days 4, 9 and 15, which made the results satisfactory.

Graph 6.1 shows the stabilization of concentrations of H_2S, CO_2 and CH_4, and an increase of the NH_3 concentration of almost five times from day 4 to day 15. This increase in the NH_3 concentration, however, may be related to the method of analysis of this component, which had to be adjusted, incurring a significant



Graph 6.1 Results of the biogas chemical characterization at days 4, 9 and 15: NH_3 (ppmV at 25° C), H_2S (ppmV at 25 °C), CO_2 (%) and CH_4 (%)

difference in the concentration of NH_3 from day 4 to day 15 ($F = 6.88842$ and $p = 0.03659$) in statistical analyses of the results of the chemical characterization of biogas (Table 6.1). The concentrations of CO_2 ($F = 0.31845$ and $p = 0.73885$) and CH_4 ($F = 0.28244$ and $p = 0.76344$) were statistically equal between the days 4 and 15. This indicates that the biodigestion process was not completed in 15 days under the conditions applied. It is possible and even necessary to increase the hydraulic retention time in order to increase the degree of substrate conversion in biogas and, consequently, the volume of the produced biogas and the quality of organic fertilizer.

The estimated LHV was of 25.42 MJ m^{-3} at 25 °C and 1 atm. The Wobbe index calculated was 27.88 MJ Nm^{-3} (or 29.16 MJ m^{-3} at 25 °C and 1 atm), very close to that obtained from Ryckebosch et al. (2011), 30 MJ Nm^{-3}. However, these were about 40% lower than the values for natural gas reported by ABNT (2003) at 15 °C and 1 atm, disregarding the small difference of temperature: 50.98 MJ m^{-3} for natural gas with 90% of CH_4; 53.18 MJ m^{-3} for natural gas with 86% of CH_4; 51.23 MJ m^{-3} for natural gas with 82% of CH_4. Therefore, biogas has lower energy performance than natural gas. Compared to GLP (87.54 MJ m^{-3} for 100% C_4H_{10}; 76.84 MJ m^{-3} for 100% C_3H_8; 72.86 MJ m^{-3} for 100% C_3H_6), it was verified that the Wobbe index of biogas was approximately two to three times smaller than that of LPG. Thus, it is verified that the biogas presents energy performance inferior to LPG also, which implies greater volumetric consumption of biogas to supply the same energy demand.

The results of the characterization of the biogas combustion exhaust are presented in Table 6.2.

Flame stability was observed in the burning biogas during the evaluated time interval (approximately 20 min). CO was formed at a mean concentration of 2,642.2 ppm. Its presence indicates partial combustion, which is in agreement with the measured concentrations of CO_2, O_2 and C_xH_y (given as CH_4). In the complete combustion of the biogas, the concentration of O_2 would be lower than the reported one, the concentration of CO_2, in turn, higher, and C_xH_y concentration smaller and tending to zero along with the concentration of CO. However, the result of this combustion test was important to confirm the quality of the produced biofuel,

Table 6.2 Results of the characterization of the flue gas originating from the biogas combustion test

Sample	O_2 (%)	CO (ppm)	CO_2 (%)	C_xH_y (%)	T (°C)	NO (ppm)	NO_2 (ppm)	SO_2 (ppm)
1	12.7	4,157.0	4.6	1.34	573.0	16.0	1.0	165.0
2	13.5	2,179.0	4.1	–	587.0	20.0	0.0	48.0
3	14.2	2,347.0	3.7	–	681.0	20.0	0.0	40.0
4	12.7	2,177.0	4.6	–	687.0	29.0	1.0	47.0
5	11.4	2,351.0	5.3	–	700.0	28.0	1.0	43.0
Mean	12.9	2,642.2	4.5	1.34	646.6	22.6	0.6	68.6
Standard deviation	±1.1	±1.1	±0.6	±0.0	±60.5	±5.6	±0.6	±53.9

because even without any control of the variables of the combustion process given the simplicity of the system used, the concentration of CH_4 was reduced from 71 to 1.34%, thus, with reasonable efficiency.

The volumes of biogas measured on days 4, 9 and 15 (non-cumulative volume) were, respectively, 3 m^3, 2.84 m^3 and 2.77 m^3, totaling 8.61 m^3 in the HRT evaluated (15 days), when only 29% of the processing capacity of the biodigester was used, such as described by Pereira (2018). The average daily production calculated was 0.574 m^3 day^{-1}. Considering this rate of production, the consumption of 10.9 m^3 of LGP in the same time interval at the selected consumption point of the cheese factory and also the energy equivalence of 1 m^3 of biogas to 0.572 m^3 of LPG according to Pompermayer et al. (2003), the total biogas volume produced would be enough to replace only 45% of the LPG consumption at the reference spot in the cheese factory. However, such production can be increased, by increasing the amount of biomass processed in the biodigester, whose volume is 7 m^3.

When aiming to apply the biogas to an agroindustry, even though there is no specific technical standards for biogas, the following standards can be considered with some modifications: "IN 008—Instalação de gás combustível" (Portuguese for Installation of Fuel Gas) (Santa Catarina, 2018a), which establishes and standardizes criteria for design and sizing of the fuel gas installation (LPG and natural gas), and the normative instruction "Instrução Normativa no 16" (Portuguese for Normative Instruction) (Brasil 2015), which establishes the specific rules for inspection and sanitary supervision of products of animal origin.

Conclusions

The biogas produced from the dairy cattle waste in the biodigester of the present study was qualified as applicable to partial replacement of LPG in the cheese factory. The chemical characterization of biogas indicated a mean CH_4 concentration of 71% (v/v), which indicates that there is a high probability of a combustion system to operate with the same injectors, valves, inlet pressure and other accessories used for operation with conventional gas, LPG or natural gas. However, even with the concentration of methane resting above 70%, it is worth remembering that there may be a need for modification in the burner or in the connecting ducts to increase the biogas flow at the point of consumption. Given the presence of H_2S (40 ppmV) and NH_3 (175 ppmV) in the biogas, its treatment may be necessary in order to avoid negative effects in the burners, especially corrosion, whose study is suggested for future work.

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Chapter 7
The Importance of Green Area Maintenance for Greenhouse Gas Mitigation

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Abstract Greenhouse gases have been increasingly researched due to evidence of their relation to global climate change. Among these gases, carbon dioxide (CO_2) is one of the most relevant to changes in land use and land cover. The research estimated the CO_2 emissions in an urban park in the town Sorocaba due to the change in land use over two periods, 1995 to 2007 and from 2007 to 2017. In both periods, there was an increase in the issuance of CO_2, totaling approximately 13.8 $GgCO_2$. This is evident due to the urban expansion around the park in recent years. The first period had the largest emission due to a period of greater transformation of the landscape and incentive to local urban development.

Introduction

Green areas are linked to the population as well as to the environment where they are located, ensuring a better balance between urban and natural areas by reducing atmospheric pollution, increasing thermal comfort and photosynthetic processes, serving as a shelter for fauna, and protecting the streams and springs. The composition of this natural space also breaks the monotony of urbanized areas, creating a visual and ornamental appreciation of the environment (Londe and Mendes 2014).

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These green infrastructures have several important functions that guarantee a better quality of life for visitors: psychological, educational, ecological, aesthetic and social. The psychological functions are associated with relaxation activities, while educational functions present natural concepts present in these areas in an extraordinary way. The ecological function represents the natural interaction between biotic and abiotic factors to minimize the impacts in these areas. The aesthetic functions display the beauty of the natural areas in contrast to the monotonous urban landscape, and the social functions are related to the capacity of these areas to have events that integrate the visiting population (Bargos and Matias 2011).

The greenhouse effect is a natural phenomenon arising from the interaction between the reflected heat of the Earth's surface elements and the greenhouse gases (GHG) that guarantee the existence and survival of the planet's species by maintaining the earth's temperature. Changes in land use, through increasing consumption of natural resources in urbanized areas, intensify the emission of GHGs, mainly CO_2, which have negative consequences for the population (Sousa et al. 2020). The suppression of vegetation in land use transitions in urban spaces causes imbalances in nature, and is responsible for the second highest emission of CO_2 in the world and the main source of GHG emissions in Brazil (Sousa et al. 2020). These imbalances linked to urban expansion are directly related to changes in the local microclimate, causing environmental impacts through soil sealing, reduction of relative humidity, formation of heat islands, and in some urbanized areas, a variation of up to 10 °C in relation to rural areas (Feitosa et al. 2011).

In this context, the objective of this study was to calculate CO_2 emission in the years 1995, 2007 and 2017, based on the change of land use in this period, and to understand the importance of green areas to reduce possible environmental impacts.

Methodology

The city of Sorocaba is localized in the southwest region of the São Paulo state. The total population in 2010 was 586.625 inhabitants, and the estimated population by 2018 was 671.186 habitants, with a demographic density of 1.304,18 inhabitant/km^2 and a territorial area of 450,382 km^2. Sorocaba is considered a city with 82.2% of public roads within forested areas and 48.5% of urban public roads (IBGE 2010, 2019).

Predominantly situated in the Atlantic Forest biome, Sorocaba has a vegetation distributed in forest fragments, intercalating of urban and agricultural area, including those found in municipal green areas (Lourenço et al. 2014). Sorocaba has a total of 23 green areas of the type "municipals parks," including the "Chico Mendes" Natural Sports Park (Smith et al. 2014) (Fig. 7.1).

This park was inaugured in 1977. It has an area with 15.57 ha and boasts a high rate of visitation and public access, especially during the weekends. The vegetation is characteristic of the Atlantic Forest, where exotic eucalyptus species have been

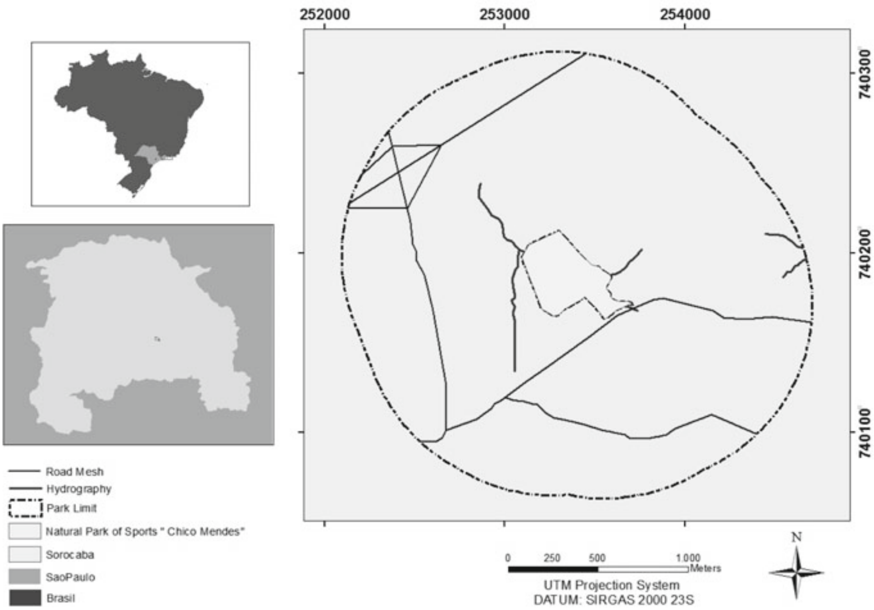

Fig. 7.1 Localization of the Chico Mendes Park, Sorocaba, Brazil

found. The educational activities that happen in the park are related to hiking trials, playground, spaces for barbecue, and an environmental educational center.

Carbon Dioxide Estimate

For carbon dioxide (CO_2) estimation, three variables are used: mapping of land cover and use, pedology and past vegetation.

Coverage and Land Use Mapping

Mapping of land use was carried out around the Park within a radius of 1000 m as defined in Rodrigues et al. (2017). These mappings refer to the years 1995, 2007 and 2017 and were performed using only ArcGIS 10.5 Software (ESRI 2016) using the visual interpretation of the features identified in the study area, based on several elements such as texture, color and tint (Fitz 2008).

The image used for the year 1995 was provided by the Sorocaba Environmental Secretariat. In 2007 it referenced the Spot satellite, with a spatial resolution of 2.5 m, provided by the São Paulo State Environmental Planning Coordination (CPLA) and

Table 7.1 Carbon stock values resulting from soil-vegetation association

Vegetation	Soils (Kgc/m^2)	
	High activity clay soils (S1)	Different soils of low activity clay oxisols (S2)
Atlantic forest	5.83	4.29

Source Adapted from CETESB (2012)

Table 7.2 Values of fc variables

Land use	fLu	FMg	fI	fc
Field	1	–	–	1
Forest	1	–	–	1
Urbanized area	0	–	–	0
Flooded area	0	–	–	0

Source Adapted from CETESB (2012)

for 2017, it used a 5-m spatial resolution RapidEye satellite image for 2015 that was provided by the Ministry of the Environment. For all mappings, there was rectification with the help of historical images by Google Earth Pro.

Obtaining Pedology and Past Vegetation

Pedology mapping was obtained from the DataGeo website available in shapefile format (Rossi 2017). The past vegetation archive was also obtained in vector format. This file is the result of a mapping done by RADAM/Brazil and made available by the Brazilian Institute of Geography and Statistics (IBGE 2004). For both data, an intersection with the study area buffer was performed to obtain the existing soil and vegetation classes in this area. The procedure was performed using ArcGIS 10.5 software (ESRI 2016).

Based on the vegetation groups of the Atlantic Forest biome and soils established for Brazil as defined by Bernuox et al. (2002), the stock values for soil-vegetation association were obtained, as established by the São Paulo State Environmental Company (CETESB 2012). As the vegetation of this study is characterized as Atlantic Forest and the soil found is Argisol type, the adopted value was 5.06 Kgc/m^2, which is an average between the two values presented in Tables 7.1 and 7.2.

CO_2 Estimation Calculation

Calculations of estimates of CO_2 emissions and removals for land cover and land use change, as well as for changes in soil carbon stock, are required. Estimates of CO_2

emissions and removals for land cover and land use change were calculated based on the adapted equations of CETESB (2012).

Equation 7.1 was used for calculated the transitions from Flooded Area to Urbanized Area, from Flooded Area to Field, from Urbanized Area to Flooded Area, from Urbanized Area to Field, from Urbanized Area to Forest, from Field to Urbanized Area, from Field to Forest, from Forest to Flooded Area, from Forest to Urbanized Area, and from Forest to Field. Equation 7.2 was used for calculated the transition from florest to flooded area.

$$\mathrm{E}i = \mathrm{A}i * (\mathrm{Class\ 1} - \mathrm{Class\ 2}) \tag{7.1}$$

In which:

E*i*: refers to the carbon emission of polygon *i* in period T (tC); A*i*: polygon area *i* (ha); Class 1: Average carbon stock for classes before transition ($tC.ha^{-1}$); S: Average carbon stock for class it has become ($tC.ha^{-1}$).

$$Ei = Ai * \left\{\mathrm{Classe\ 1} - \left[Rebf * \left(\frac{T}{2}\right)\right]\right\} \tag{7.2}$$

In which:

E*i*: refers to carbon emission of polygon i in period T (tC); A*i*: polygon area *i* (ha); Class 1: Average carbon stock for classes before transition ($tC.ha^{-1}$); Rebf: average annual forest carbon increment [tC.(ha year) $^{-1}$]; T: interval of the inventoried period (year).

The value of the average carbon stock for Urbanized Area and Flooded Area was 0 (zero) $tC.ha^{-1}$ (CETESB 2012; MCTI 2015). Average carbon stock for the Field and Forest was 6.55 $tC.ha^{-1}$ and 122.92 $tC.ha^{-1}$, respectively (MCTI 2015). The value of the average annual carbon increment in the Forest was 0.32 $tC.ha^{1}$ $year^{-1}$ (MCTI 2015).

For calculations of estimates of CO_2 emissions and removals for soil carbon stock changes, we used the Eq. 7.3:

$$ESi = Ai * Csolo * (fc(to) - fc(tf)) * \left(\frac{T/2}{20}\right) \tag{7.3}$$

In which:

Es*i*: refers to the net emission of polygon *i* in period T due to soil carbon change (tC); A*i*: polygon area *i* (ha); Soil: Soil carbon content resulting from the polygon solo vegetation association [$tC.ha^{-1}$]; fc (to): Soil carbon change factor at baseline (dimensionless); fc (tf): Soil carbon change factor at the final moment (dimensionless); T: time interval (year).

The fc was obtained from Eq. 7.4, and the values of its variables are shown in Table 7.2.

$$fc = fLu * fMg * fI \tag{7.4}$$

For the final calculation of net emissions, a sum of CO_2 emissions or removals from land use changes and those from carbon in the soil was summed. However, to obtain the results in CO_2 gigagram ($GgCO_2$), Eq. 7.5 is used (ELETROBRAS 2009; Aguiar et al. 2016). Positive values mean that CO_2 was emitted to the atmosphere and negative values meant that CO_2 remission occurred.

$$ECO_2 = Ec * 3.66 \tag{7.5}$$

In which:

ECO_2: refers to CO_2 emission ($GgCO_2$), Ec = carbon emission (Ggc) and 3.66 which is the constant of the ratio of molecular weight of CO_2 to carbon (C).

Results and Discussion

According to Hoornweg et al. (2011), cities are blamed for at least 80% of greenhouse gas emissions when considering the production and consumption resulting from lifestyle and buying habits. However, emissions can vary not only between more populous and wealthy countries, but also between neighborhoods and cities in the same country.

In Fig. 7.2a–c show the land cover and use mappings for the three years 1995, 2007, and 2017. Table 7.3 shows the quantitative mappings.

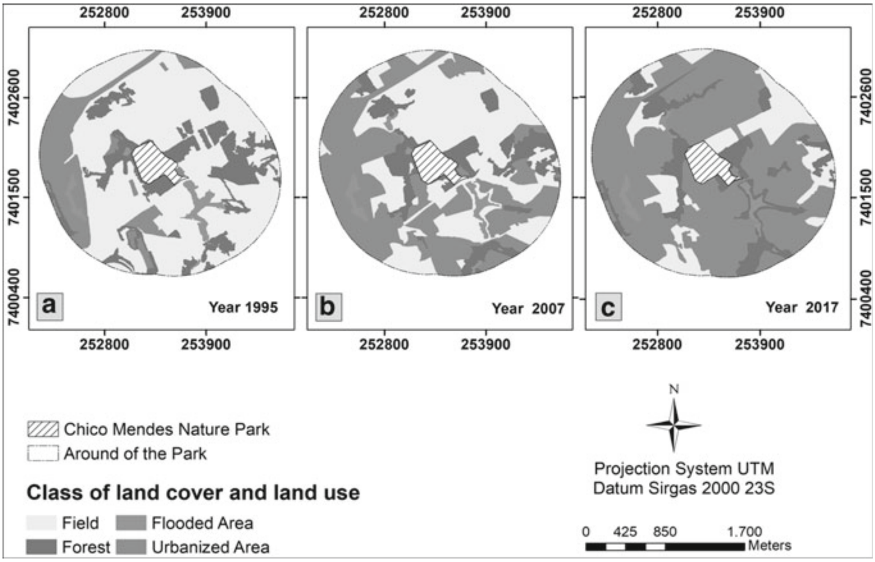

Fig. 7.2 Land cover and use mappings for 1995 (**a**), 2007 (**b**) and 2017 (**c**)

Table 7.3 Quantitative mapping of land cover and use for the years of 1995, 2007 and 2017

Class	1995	2007	2017
	Area (%)	Area (%)	Area (%)
Flooded area	2.867	2.746	2.167
Urbanized area	15.310	40.994	68.245
Field	65.348	43.036	16.923
Forest	16.475	13.224	12.666

In the last 22 years, there has been a marked growth in the urbanized area, which represents an increase of over 52%. In contrast, there are the field areas that showed a decrease of approximately 48%, forest (3.8%) and flooded area with only 0.7%. Both the increase of urbanized area and decrease of fields correspond to the conversion of natural to anthropic area that induces the emission of greenhouse gases. This conversion is associated with the expansion of the urbanized area around the park and is reflected in the construction of new residential subdivisions, roads and a larger flow of people, activities and vehicles. However, Detlef (2017) points out that the effects of climate change use transitions can only be observed in 2100 with a combination of resource efficiency, sustainable production methods and human development.

Figure 7.3 shows the transitions that occurred from 1995 to 2007 and from 2007 to 2017.

Tables 7.4 and 7.5 show the quantities of transitions between 1995–2007 and 2007–2017.

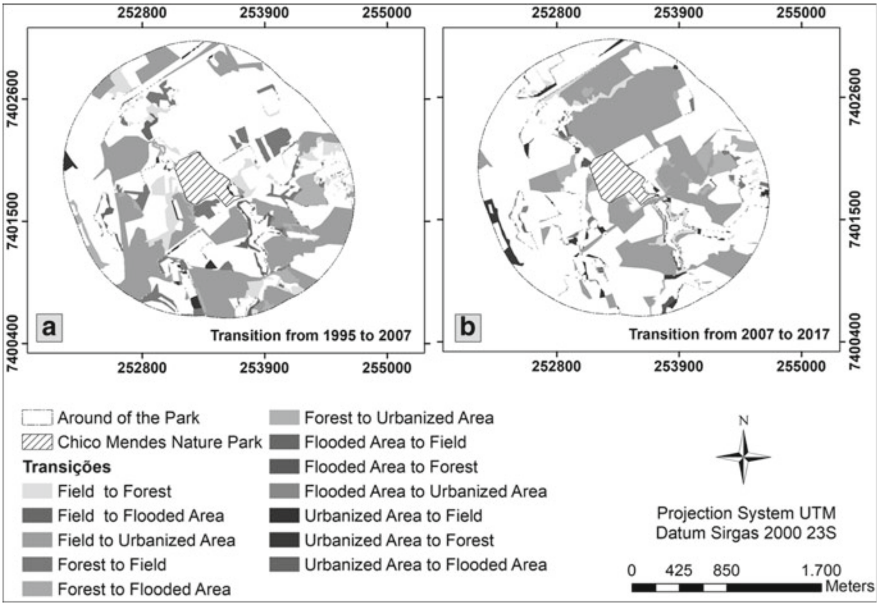

Fig. 7.3 Transitions from 1995 to 2007 (**a**) and from 2007 to 2017 (**b**)

Table 7.4 Quantitative transitions between 1995 and 2007

Previous class (1995) (ha)	Class that became (2007) (ha)				Total 1995	Transition
	Flooded area	Urbanized area	Field	Forest		
Flooded area	9.052	0.971	3.523	0.371	13.918	4.865
Urbanized area	1.375	68.455	3.690	0.776	74.296	5.841
Field	2.231	113.144	176.951	24.777	317.104	140.153
Forest	0.670	16.379	24.640	38.254	79.944	41.690
Total 2007	13.329	198.950	208.804	64.178	485.261	192.549

Table 7.5 Quantitative transitions between 2007 and 2017

Previous class (2007) (ha)	Class that became (2017) (ha)				Total 2007	Transition
	Flooded area	Urbanized area	Field	Forest		
Flooded area	9.256	1.253	0.441	2.379	13.329	4.073
Urbanized area	0.400	188.184	3.866	6.500	198.950	10.766
Field	0.658	123.916	74.212	10.018	208.804	134.592
Forest	0.200	17.819	3.585	42.574	64.178	21.603
Total 2017	10.514	331.172	82.104	61.471	485.261	171.034

It was found that the field class was the one that presented the largest transition for both periods, most of which was destined for the expansion of urbanized areas, 113.144 (ha) from 1995 to 2007 and 123.916 (ha) from 2007 to 2017. The second category with the largest transition was the forest area from 1995 to 2007; these areas were mainly converted to field (24.640 ha) and between 2007 and 2017 to urbanized area (17.819 ha). In both transitions, there is a conversion of vegetation cover for other uses, reducing the sequestration capacity of CO_2 for the photosynthetic process and less availability of this gas for the greenhouse effect. Vegetation plays a fundamental role in the sequestration of greenhouse gases in its photosynthetic process, and the reduction in residential areas favors the increase of several factors, including the emission of carbon dioxide into the atmosphere, temperature increase and air pollution.

The conversion of natural areas and vegetation cover for the real estate expansion around the park is confirmed, considering that the Chico Mendes Municipal Sports Park is the only green area with vegetation and tree cover. Its importance is maximized for what it offers in local ecosystem services, including the reduction of the availability of greenhouse gases. For Hoornweg et al. (2011), the increase in greenhouse gases is a byproduct of urbanization, and when these gases exceed the Earth's support limit, they must be analyzed for lifestyle changes, as the urban population has grown to the detriment of the rural population and the scenarios are even more linear.

Such conversions need to be assessed in line with municipal urban policy, city statutes, and the policy of promoting sustainable development for 2030 by preaching health and quality, beyond just combatting climate change. In relation to these objectives, it is emphasized that the Sustainable Development Goals seek to end poverty, create a path of sustainable economic growth, protect the planet from degradation and signals the interest of countries around the world to cooperate more with sustainable development issues (Detlef 2017).

It is also emphasized that the current conversion model will cause the park to be an inadequate environment for the survival of fauna and flora species, compromising the ecological functions performed. Darkwah et al. (2018) stresses that among the promising modern, inexpensive solutions to reduce GHG emissions in the Earth's atmosphere are an increase in tree planting, a reduction of fossil fuel burning, and the capture and sequestration of carbon dioxide. Of these, the park operates directly in all, with the availability of seedlings for planting by the population, environmental education activities and biodiversity conservation. Figure 7.4 shows the spatialization of CO_2 emissions and reductions that occurred, and Tables 7.6 and 7.7 show their quantities.

Based on the temporal mapping, the identified conversions and the municipal development model, the surroundings of the park presented more emissions than CO_2 reduction, which totaled 13,812 $GgCO_2$, but from 1995 to 2007 this emission was almost twice as high between 2007 and 2017 (Tables 7.6 and 7.7), reinforcing the conversion pattern of natural areas. Emissions in the first period (1995–2007) are evidenced due to the conversion of forest field to flooded area and urbanized area. However, it is noteworthy that emissions stood out mainly due to the suppression of

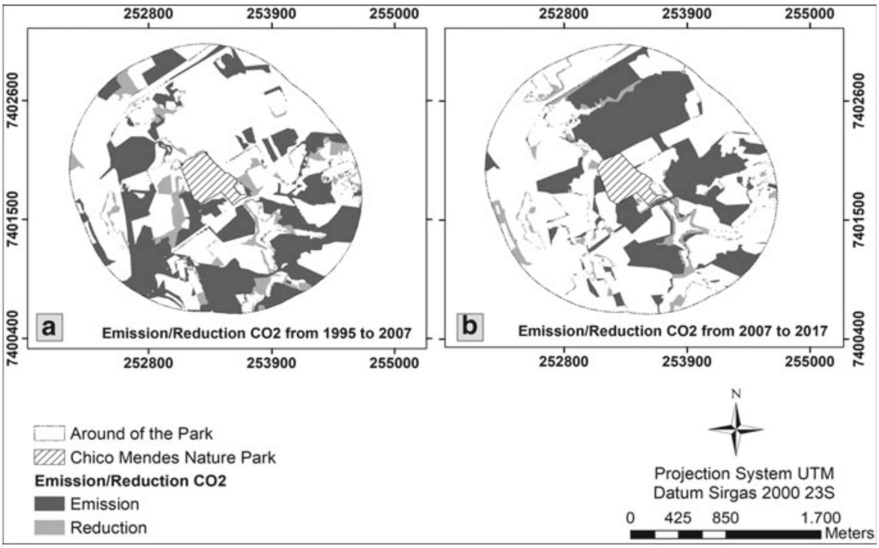

Fig. 7.4 CO_2 emissions and reductions from 1995 to 2007 and 2007 to 2017

Table 7.6 CO_2 emissions and reductions from 1995 to 2007

Class	CO_2 emissions/reduction from 1995 to 2007 ($GgCO_2$)			
	Flooded area	Urbanized area	Field	Forest
Flooded Area	–	–	−0.064	−0.002
Urbanized Area	–	–	−0.064	−0.344
Field	0.041	2.084		−10.410
Forest	0.279	7.189	10.319	
Net total	9.028			

Table 7.7 CO_2 emissions and reductions from 2007 to 2017

Class	CO_2 emissions/reduction from 2007 to 2017 ($GgCO_2$)($GgCO_2$)			
	Flooded area	Urbanized area	Field	Forest
Flooded area	–	–	−0.008	−0.003
Urbanized area	–	–	−0.070	−2.774
Field	0.013	2.398	–	−4.133
Forest	0.072	7.844	1.446	–
Net total	4.784			

forests to meet the expansion of urbanization, or its degradation, giving rise to rural areas, which also became urbanized areas in the second period, thus contributing to emissions. The study developed by Keywan et al. (2017), indicates even more conflicting scenarios worldwide, with agricultural boundaries expanding up to 700 million hectares of land and CO_2 emissions ranging from about 25 $GtCO_2$ to over 120 $GtCO_2$ per year, both of which are projected up to 2100. The authors also argue that emission reductions depend on government policies to reduce gases and the current socioeconomic profile.

Both periods show that the reductions that occurred were due to the emergence of forest areas, even though they did not have a significant increase, but enough to note their importance in terms of CO_2 sequestration. This highlights the importance of maintaining green areas for greenhouse gas mitigation, and reforestation and restoration projects for both rural and urban degraded areas. Even so, the municipalities of São Paulo are encouraged to adopt environmental actions through the Green Blue Municipality Program. For Hoornweg et al. (2011), cities need to be efficient in managing their resources, so that municipal administrations and their citizens can handle the task of achieving greenhouse gas emission reductions. Undoubtedly, the existence of green areas will be a way to reach this goal.

Conclusion

In 22 years, the surrounding area of the park has undergone a real estate growth that resulted in a 52% increase in its area and a 51.8% reduction in vegetation cover that helps reduce greenhouse gases. 42.459 ha of forest area was converted to vegetation cover from 1995 to 2017. The conversion of natural areas and vegetation cover was evidenced in the real estate expansion around the park, culminating in an emission of 13.812 $GgCO_2$. Governmental measures and municipal involvement should be reinforced, focusing on the conservation of green areas which have ensured the maintenance of the population's quality of life, efficiency in CO_2 sequestration and contribution to the reduction of greenhouse gas emissions.

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Chapter 8
The Treatment of Effluents in Promoting Sustainable Development: The Use of Led Lamps in the Process of Removal of Phosphorus in Effluents

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Abstract The present article aims to verify the promotion of Sustainable Development through the treatment of effluents in relation to the removal of excess phosphorus. Based on the 9th and 12th axes of the Sustainable Development Goals (SDG)—Responsible Consumption and Production; Industry, Innovation and Infrastructure—proposed by the United Nations (UN) in its 2015–2030 agenda, this article sheds light on an innovative phosphorus removal technology for effluents through the use of LED lamps combined with microalgae culture. Thus, it is intended to jointly evaluate the methanogenic potential of algal biomass produced after being subjected to different techniques of cell lysis. In this sense, the following specific objectives of this chapter are: to assess whether the processes of clean technology generation for the practical use of phosphorus adheres with the agenda of the post-2015 SDGs of the United Nations; to present an innovative phosphorus removal technology for effluents from the use of LED bulbs combined with microalgae culture; and to evaluate the potential of the use of phosphorus removal both for the health of the environment freed from its excess, as well as the reuse and/or use of this in other activities that demand it. The methodology, regarding the objectives, is considered descriptive and exploratory. The technical procedures are bibliographical research and experimental study, and the problem approach is qualitative. The methodological trajectory follows in three phases: the adherence to the SDG of the technological innovation presented; the proposition of a practical-theoretical experimental model for the removal of phosphorus from effluents; the assessment of the removal impact and potential use of the removed phosphorus for sustainable reuse. In the end, it is possible to show that, from the three experiments performed with different white LEDs, the photobioreactor 2.2 obtained the best removal at the end of the experiment (52 μE m^{-2} s^{-1}), with 71.42% total phosphorus removal.

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Introdução

Sustainable Development must be more than just a goal; it must become a reality available to all. Thus, this article seeks to verify how it is possible to develop clean technologies that can contribute to the economic, environmental and social balance in a combined manner, as indicated by the foundations of Sustainable Development (triple bottom line) (Fig. 8.1).

In this sense, this article proposes to evaluate whether the clean technology generation processes for the practical use of phosphorus adheres with the post-2015 agenda of the United Nations Sustainable Development Goals (SDGs). With special emphasis on the 9th and 12th axes of the SDGs—Responsible Consumption and Production; Industry, Innovation and Infrastructure—the present work aims to present an innovative technology for phosphorus removal from effluents through the use of LED lamps combined with the culture of microalgae, so that excess nutrient can find sustainable disposal.

In addition, the work will also seek to evaluate the potential use of phosphorus removed from the environment (effluents) for its reuse in other activities that demand it, in order to sustainably balance the amount of phosphorus available in nature.

Thus, the article will begin with an explanation of the SDGs, their creation, their intentions and their brief history in the post-2015 UN agenda. Subsequently, the paper addresses the theme of phosphorus equilibrium in the effluents, the harms of their excess in the environment and the benefits of removing this excess for the possible sustainable reuse of these quantities in other places than effluents.

Finally, the article indicates a technological innovation for the effluent phosphorus removal from the use of LED lamps combined with the microalgae culture, that together will allow an evaluation of the methanogenic potential of algal biomass produced after it is submitted to different cell lysis techniques.

Sustainable Development Goals of the United Nations Organization

The Sustainable Development Goals (SDGs) created by the post-2015 UN agenda were developed in the wake of events of global relevance. International conferences such as Stockholm 72, Eco 92 and Rio + 20 have helped to consolidate an inclusive and transparent intergovernmental process, open to all stakeholders and with a vision of creating global sustainable development goals to be endorsed by the UN General Assembly (Sustainable Development Knowledge Platform 2019).

In addition, the SDGs emerged as the consolidation of practices that culminate in the end of the Decade of Education for Sustainable Development (UN-DESD (2005–2014)), organized, among other entities, by UNESCO (United Nations Educational, Scientific and Cultural Organization). At the time, UN-DESD, designed to stimulate changes in attitude and behavior in populations, reflected the intellectual, moral and cultural capacities of modern man to meet his responsibilities to other living beings and to nature as a whole (UNESCO 2019).

In this regard, and with the support and broad discussion of organized civil society around the globe, international institutions and global permanent forums, the United Nations on its 70th anniversary, in September 2015, launched the Sustainable Development Goals. Structured on 17 axes, the SDGs make up a universal agenda that seeks, by 2030, 169 specific goals:

> The 17 Sustainable Development Goals and 169 goals we are announcing today demonstrate the scale and ambition of this new universal Agenda. They build on the legacy of the Millennium Development Goals and will conclude what they could not achieve. They seek to realize the human rights of all and achieve gender equality and the empowerment of women and girls. They are integrated and indivisible, and balance the three dimensions of sustainable development: economic, social and environmental (United Nations Brazil 2019a).

Among the 17 thematic axes of the SDGs, with special attention to the theme of this article, the 9th axis (*Industry, Innovation and Infrastructure*) and the 12th axis (*Responsible Consumption and Production*) can be highlighted (Fig. 8.2).

In this regard, it is evident that the United Nations is concerned with stimulating, in different ways, sustainable development in its entirety. In seeking to understand a universal agenda, the movement was made to contemplate all organized segments, in contrast to a policy of electing a specific area and devoting all possible efforts to it. Thus, while respecting the needs of each axis, the effectiveness of all axes is sought through goals that unfold in the measurement and materialization of practical and sustainable actions and products, extrapolating the simple theoretical exercise of the mere “objective”.

Specifically on these axes (9th and 12th), specific targets relevant to phosphorus removal through technological innovation can be considered, such as:

> Axis 9—Goal 9.5: “By 2030, modernize infrastructure and rehabilitate industries to make them sustainable, with increased resource efficiency and greater adoption of clean and environmentally sound industrial technologies and processes; with all countries acting in accordance with their respective capacities”.
>
> Axis 12—Goal 12.4: “By 2020, achieve environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international milestones, and significantly reduce their release into air, water and soil to minimize their negative impacts on human health and the environment” (United Nations Brazil 2019b, c).

Thus, considering the globally shared expectations of the SDGs, in addition to the needs for social, economic and environmental management of natural resources, the next sections will discuss the understanding of the need for phosphorus balance in the environment, in order to consider their harms when excessive in the environment, and in particular, how technology can facilitate its removal, with the aim for possible sustainable reuse in activities where phosphorus is required.

Phosphorus Balance in Effluents

Only 37.5% of the volume of sewage generated in Brazil receives any kind of treatment before its disposal in the environment (SNIS 2011). The most common situation in most Brazilian municipalities is the discharge of sewage directly into the water bodies. Of the places where there is treatment, only 57.1% have secondary treatment and 9% tertiary treatment (IBGE 2008). Even after secondary treatment, domestic sewage can present high concentrations of nutrients, which can cause eutrophication of water bodies, resulting in negative environmental impacts on the environment.

The disposal of nutrients wasted in effluents, especially domestic ones, is enormous. Phosphorus is present at substantial levels in effluents. This element is obtained from phosphate rocks, a limited resource in terms of both quantity and quality. Known reserves around the world have sufficient quantities to be exploited over the next 100–1000 years, depending on the efficiency of resource use during production and depending on fertilizer use in the coming decades (Smil 2000; Zhang 2008). In order to ensure the sustainability of industry and agriculture, phosphorus recycling should be widely encouraged around the world (Driver et al. 1999), and should be on the agenda of a country with strong agricultural production, such as Brazil. It is noteworthy that phosphate mining has a high negative environmental impact. Extraction of 1 kg of phosphorus produces 2 kg of tailings, contaminated with heavy metals and radioactive elements, which are not normally disposed of in an environmentally safe manner (Driver et al. 1999; Wilsenach et al. 2003). Sources of pollution from phosphorus use include agriculture, fertilizer application, industrial activities and domestic sewage waste.

Large amounts of phosphorus present in sewage are one of the main causes of eutrophication, which negatively affects many natural water bodies (Santos 2006). Phosphorus is found in the aquatic environment in the form of orthophosphates, polyphosphates and organic phosphorus, and its concentrations in urban sewage are quite varied and influenced by the presence of industrial discharges and non-point loads. In domestic sewage, (Sawyer et al. 1994) estimate a phosphorus concentration of 2–3 mg/L for inorganic forms and 0.5–1 mg/L for organic forms; the same author adopts a daily contribution of 1.5 g of phosphorus per inhabitant.

Thus, new technologies should aim not only to remove organic matter, but also to remove phosphorus. And these treatment technologies should move towards the concept of sustainable treatment plants, which aim to generate new value-added products at the end of the treatment process, minimizing negative environmental impacts. The use of microalgae for sewage treatment meets these conditions. The process can be simple to operate, low cost, have high removal efficiency of various pollutants, and produce biomass with ample use, especially for the production of bioenergy and biofertilizers for agricultural purposes.

Microalgae need water and nutrients to develop, both of which are present in sewage. As they grow, microalgae remove nutrients from the effluent and provide oxygen for aerobic degradation of organic matter. In fact, several studies state that microalgae can have a high growth rate when grown in sewage (Mutanda et al.

2011). Microalgae growth and nutrient absorption are not only affected by nutrient availability, they also depend on complex interactions between physical and chemical factors such as pH, light intensity and temperature (Tosseto 1995).

Recent research evaluates the use of LEDs (Light Emitting Diodes) to promote high growth rates of microalgae and achieve better pollutant removal results (Yan et al. 2013). Other studies show that the light intensity available to microalgae is closely linked to their phosphorus "luxury uptake" (Powell et al. 2008, 2009; Shilton et al. 2012). This luxury absorption is the accumulation of phosphorus in microalgae in the form of polyphosphate.

The light source of microalgae can be natural (sunlight) or artificial. Artificial light has advantages, such as the regulation of a certain wavelength, and does not affect the performance of microalgae by excess light. Sunlight, however, is a free feature while artificial light is energy-intensive, but this can be circumvented if low-energy light sources such as LEDs are used. When compared to fluorescent lights, LEDs have advantages such as: longer life (about 100,000 h), compact and robust design; free of toxic substances that may cause negative impacts on the environment; better energy efficiency with low heat production (Chevremont et al. 2012).

An Experimental Model of Effluent Phosphorus Removal

The work was carried out to evaluate different types of lighting (strips and LED lamps) for phosphorus removal and biomass growth, as well as to evaluate the use of synthetic effluent compared to the use of real effluent. 24-L photobioreactors were used and only white light was tested.

The photobioreactors were constructed in black polyethylene containers, with a 0.41 m wide, a 0.33 m high rectangular geometric configuration and a 24 L working volume. A slow-stirring system was installed using submerged aquarium pumps (Sarlo Better SB 1000A) in order to standardize biomass contact with the artificial light available above the surface of the liquid. In order for the illumination to be under the photobioreactor, a wooden structure was built to hold the artificial light. LEDs with luminous fluxes and distinct characteristics were tested.

Three experiments were performed at different times, with three different LED configurations. Two types of effluent were used, which will be described later. Figure 8.3 shows the configuration of each photobioreactor, as well as its nomenclature and luminous flux. It is noteworthy that the photobioreactors were assembled with 15% inoculum and 85% effluent, and operated in batch mode for 15 days. The photobioreactors had constant illumination (24 h/day) and were isolated from other external light sources.

In experiment 1, the domestic synthetic effluent elaborated according to the Organization for Economic Cooperation and Development (OEDC 1996) was used, with an increase in the amount of meat extract powder (Himedia 2003), so that the experiment presented values similar to a real domestic effluent, which is in the range of

400–800 mg L^{-1}, according to Von Sperling (2005). In the second and third experiments, the effluent of the Manta de Lodo Anaerobic Reactor (UASB) from the Sewage Treatment Station (ETE) of the city of Itabirito, Minas Gerais, was used.

The microalgae inoculum was produced from three liters of sample (which contained a consortium of microalgae species, but the genus *Chlorella Beyerinck 1890* was predominant) from a tilapia breeding tank located in the Institute's Botanical Garden of Exact and Biological Sciences (ICEB) of UFOP (Federal University of Ouro Preto). The choice of this environment for the sample was because it is an environment with nutrient accumulation, which favors the growth of microalgae.

Results and Discussions

Three experiments were performed with different white LEDs. Experiment 1 was performed using synthetic effluent, and two light streams were tested (photobioreactor 1.1 with 390 $\mu E\ m^{-2}\ s^{-1}$, and photobioreactor 1.2 with a luminous flux of 160 $\mu E\ m^{-2}\ s^{-1}$). In experiments 2 and 3, the effluent from the UASB reactor of the WWTP from Itabirito/MG was used. In these two experiments three light fluxes were tested (photobioreactor 2.1 and 3.1 with a light flux of 390 $\mu E\ m^{-2}\ s^{-1}$, 2.2 and 3.2 with a flux of 52 $\mu E\ m^{-2}\ s^{-1}$, and 2.3 and 3.3 with a flux of 160 $\mu E\ m^{-2}\ s^{-1}$).

Phosphorus behavior in the different photobioreactors is shown in Fig. 8.4 and Table 8.1. In experiment 1, in which synthetic effluent was used, it was possible to observe phosphorus removal between the beginning of the experiment and the third day (21.37%), then note an increase in values. The photobioreactor that obtained the best phosphorus removal at the end of the experiment was photobioreactor 2.2 (52 $\mu E\ m^{-2}\ s^{-1}$) with 71.42%. This value was close to those found by Yan et al. (2012, 2013), who obtained 85% and 70% removal at the light intensities of 1800 $\mu E\ m^{-2}\ s^{-1}$ and 2000 $\mu E\ m^{-2}\ s^{-1}$, respectively, with white light. Xu et al. (2013) achieved 71% removal at 2000 $\mu E\ m^{-2}\ s^{-1}$ intensity when using *C. vulgaris* in white light.

The photobioreactor that obtained the worst result for phosphorus removal was 1.2 (160 $\mu E\ m^{-2}\ s^{-1}$); there was a phosphorus increase in the middle of approximately 12%. Phosphorus removal may have been low in experiment 1 (synthetic effluent) due to the N:P ratio, which according to Yan et al. (2013) and Choi and Lee (2015) affects the removal of this nutrient. In experiment 1 (synthetic effluent) the N:P ratio was 10:1, while in experiments 2 and 3 (UASB effluent) it was 7:1. (As previously mentioned, Choi and Lee (2015) report that each species has an optimal relationship between these nutrients, and that removal is directly affected by it.)

The worst values in terms of phosphorus removal occurred in photobioreactors that presented homogeneously distributed light flux (1.2; 2.3 and 3.3), which may be related to some type of stress suffered by microalgae in photobioreactors with irregularly distributed light. It is known that phosphorus removal can be affected by microalgae stress, but more experiments are needed to better understand the system and be able to gauge it.

Phosphorus removal was not effective in the photobioreactors of experiment 1 (synthetic effluent), and this may have been due to the type of phosphorus used in the effluent and the concentration relationship between nitrogen and phosphorus. The best removal rate was 71.42% in photobioreactor 2.2 (UASB effluent, 52 μE m^{-2} s^{-1} flow). This value was similar to that of the studies by Yan et al. (2013), Wang et al. (2007) and Xu et al. (2013), in terms of removal, but with a lower luminous flux.

Phosphorus fractions in algal biomass found in photobioreactors were determined by the methods proposed by Aitchison and Butt (1973) and Kanai et al. (1965), which quantifies the fractions of soluble acid polyphosphate, insoluble acid polyphosphate and other forms of phosphorus in biomass. It can be seen from the graphs that when there are the lowest phosphorus concentrations in the photobioreactors, it is suggested that the phosphorus was assimilated by all microorganisms present in the photobioreactor, such as bacteria and microalgae.

Due to this reduction in phosphorus concentration, this may have become a limiting factor, which led microalgae to perform the luxury absorption process, stocking the phosphorus in the form of insoluble acid polyphosphate. This form according to Powell (2009) is that stored by microalgae when the phosphorus in the medium becomes limiting.

Final Considerations

This article sought to verify ways in which it is possible to develop clean technologies that can contribute to the economic, environmental and social balance in a combined way, adhering to the post-2015 agenda. Sustainable Development Goals (SDGs), in particular the clean technology generation processes for the practical use of phosphorus. With a special emphasis on the 9th and 12th axes of the SDGs—*Responsible Consumption and Production; Industry, Innovation and Infrastructure*—the present work aimed to present an innovative phosphorus removal technology which uses LED lamps combined with the culture of microalgae so that excess nutrient can find sustainable disposal.

In addition, the work also sought to evaluate the phosphorus removed from the environment (effluents) for possible reuse in other activities that demand it, so as to sustainably balance the amount of phosphorus available in nature.

Thus, this article began with the presentation of the SDGs' creation, aims and brief history in the post-2015 UN agenda, and then presented the theme of phosphorus balance in effluents, the harms of their excess in the environment and the benefits of phosphorus removal from effluents, highlighting the possible sustainable reuse of these quantities in other places than effluents.

The article also warned that only 37.5% of the volume of sewage generated in Brazil receives any kind of treatment before its disposal in the environment, and this critical situation of sewage release in most Brazilian municipalities is directly destined to the rivers and oceans.

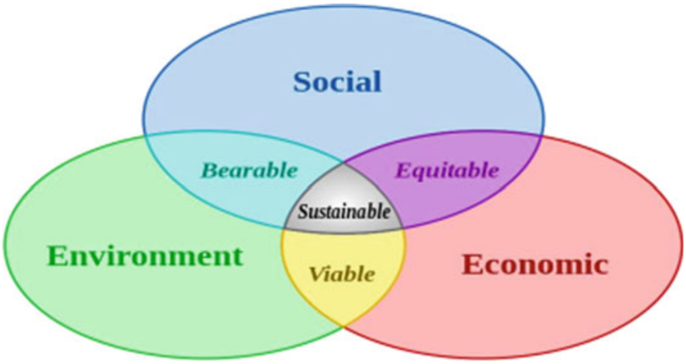

Fig. 8.1 Dimensions of sustainable development/sustainability. *Source: ADAMS (2006)

In this regard, as shown in the results, this article indicated a technological innovation for the phosphorus removal from effluents through the use of LED lamps combined with microalgae culture, that together allowed for an evaluation of the methanogenic potential of algal biomass produced after being subjected to different techniques of cell lysis. The work was carried out to evaluate different types of lighting (strips and LED lamps) for phosphorus removal and biomass growth, as well as to evaluate the use of synthetic effluent compared to the use of real effluent.

Three experiments were performed with different white LEDs. Experiment 1 was performed using synthetic effluent, and two light streams were tested, with the photobioreactor 2.2 showing the best phosphorus removal at the end of the experiment (52 μE m^{-2} s^{-1}), with 71.42% total removal.

Fig. 8.2 Sustainable development goals, UN, 2015–2030 Agenda

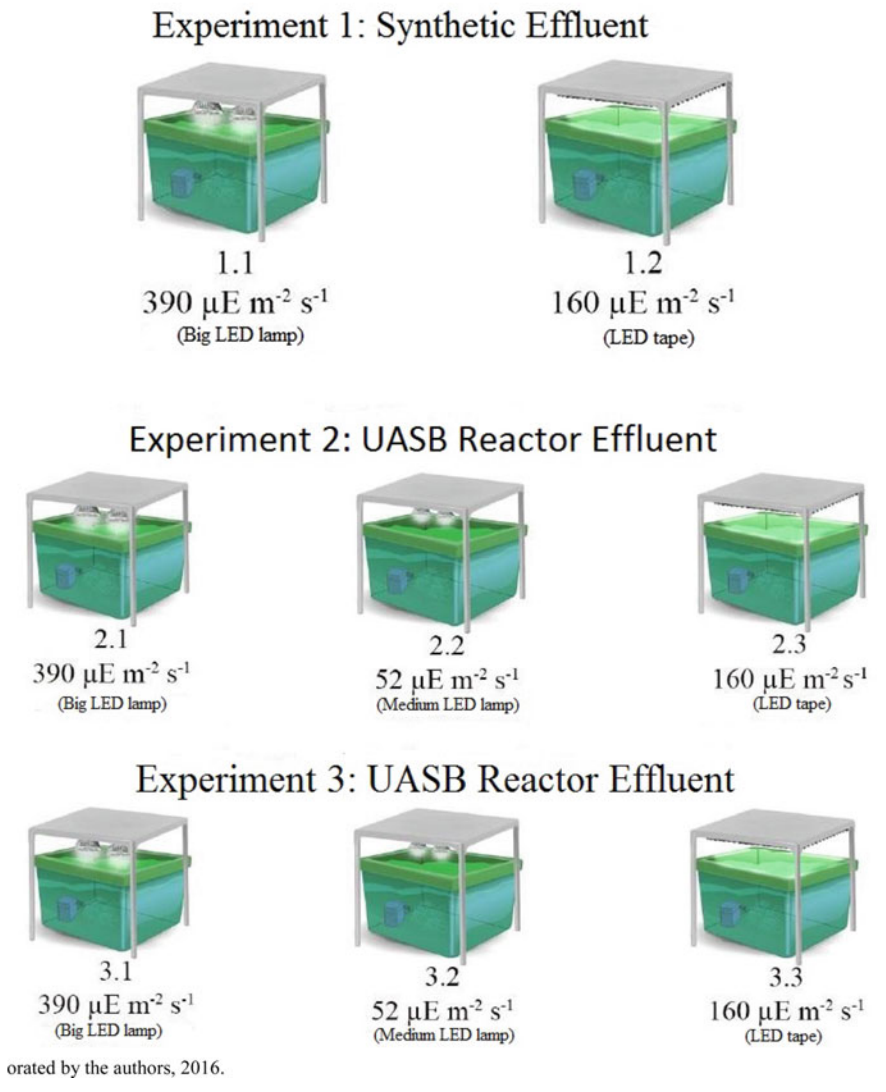

Fig. 8.3 Experiment setup. *Source* Elaborated by the authors, 2016

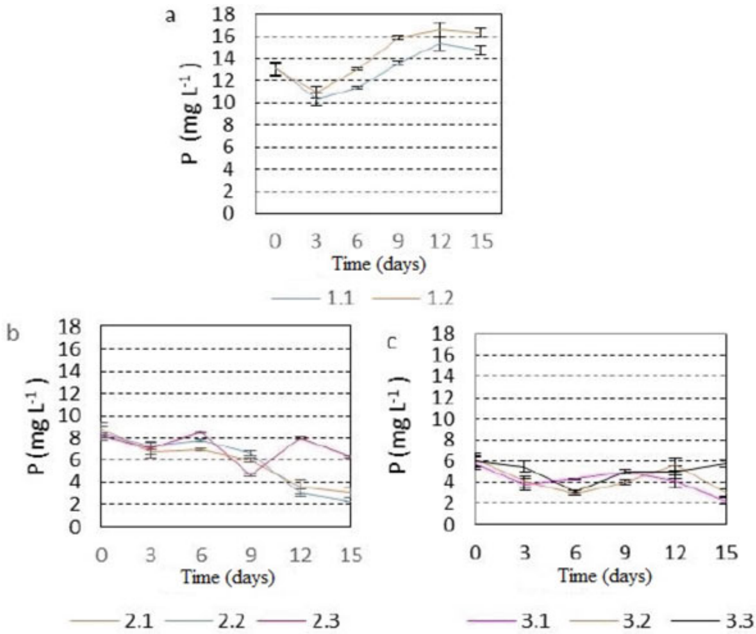

Fig. 8.4 Phosphorus removal. **a** Experiment 1 (synthetic effluent); **b** experiment 2 (UASB effluent); **c** experiment 3 (UASB effluent). *Source*: Elaborated by the authors, 2016

Table 8.1 Phosphorus removal in photobioreactors

Photobioreactor	% Phosphorus removal
1.1	− 11.21
1.2	− 25.38
2.1	64.77
2.2	71.42
2.3	23.17
3.1	60.34
3.2	51.61
3.3	3.33

Source Elaborated by the authors, 2016

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Chapter 9
The Contributions of Urban Agriculture to the Promotion of Food Security in the Context of Climate Change: A Literature-Based Review

Emanuelle Parenti, André Borchardt Deggau, Samara da Silva Neiva, Manoela de Oliveira Veras, Luíza Luchi de Paulo Gewehr, and José Baltazar Salgueirinho Osório de Andrade Guerra

Abstract After an intensification of climate change following industrial revolutions with impacts on the social, economic and environmental spheres of human development, issues related to food security have emerged mainly in urban centers. There is a progressive population growth in cities; transporting food from rural areas to urban centers presents difficulties, and there is insufficient space to continue using current production systems in agricultural areas. In this context, this article proposes a literature review aiming to expose the contributions of urban agriculture for the promotion of food security in the context of climate change. Since the increase of pests and diseases motivated by climate changes decreases the nutritional quality of agriculture production, urban agriculture is a more sustainable method that uses city gardens to ensure the access to food in sufficient quantity and quality for the development of a certain urban population, mainly in under-developed countries, thereby cooperating for food security.

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Introduction

There are two simultaneous and intertwined processes underway in the 21st Century: the world population is growing, and it is becoming increasingly urban. It took humanity 5000 years to get to 1 billion people, in 1960; 26 years later, we were 2 billion people (Seto et al. 2010). Today, the world population is 7.7 billion, and it is estimated to be 9.7 billion by 2050 (UN DESA 2019). Simultaneously, the population is concentrating in urban areas: in 2008, the urban population was larger than the rural population for the first time in history (Nevens et al. 2012); in North America, for instance, 80% of the population lives in cities (United Nations 2017).

In this scenario, several challenges for humanity must be faced in urban contexts. Food insecurity, for instance, is a larger problem in urban areas, since this population consumes much more food than it produces. Despite several efforts to address this problem, at least 793,000 people suffered from this problem in 2018 (Filippini et al. 2019). Poor populations living in cities are especially vulnerable to food insecurity risks (Poulsen et al. 2015; Berger and van Helvoirt 2017). These numbers demand an increase in food production and distribution (Carvalho 2006), especially since increases in world population will create demand for more food in the next thirty years (Popp et al. 2013).

All these problems happen in a context where the climate is changing: the concentration of greenhouse gases (GHGs) is currently the highest on the Earth in 800,000 years, contributing to an increase in temperatures that be as much as 4.8 °C warmer than pre-industrial levels (Karimi et al. 2018). Human actions are very relevant to this process, especially in cities (Choudhary et al. 2018), where 75% of GHG emissions and energy consumption take place (Amorim et al. 2019). Cities find themselves in the center of climate change, both in creating its causes and suffering the consequences: several vulnerabilities and threats relate to cities, and urban areas can become traps in case of environmental disasters (Jabareen 2015).

In the context of a growing world population, a high demand for food and problems caused by climate change, urban agriculture emerges as an option, since it is composed of small farming areas within cities to provide urban populations with a stable food source (Poulsen et al. 2015). Urban agriculture is part of a larger effort to create urban food policies that consider economic, social and environmental aspects of each area (Filippini et al. 2019). It could provide an answer to phenomena like "food deserts," where a significant share of the population lives away from supermarkets and other food providers, and has little physical or financial access to transportation to get any food (Berger and van Helvoirt 2017).

Sustainable Cities

Cities can be defined as centers of culture, science, commerce, productivity and social, industrial, environmental and economic development, where people are able to provide complex social and technological advances that are self-organizing, highly adaptative and are constantly evolving. At the same time, cities are extremely sensitive to human actions that ensure their growth without harm to the environment using sustainability practices (Baklanov et al. 2018). Several cities around the world have implemented many sustainability practices due to the growing concerns about the valorization of human capital interconnected with environmental concerns (Sodiq et al. 2019).

In this sense, Martos et al. (2016) states that urban centers must not only seek to limit its effects on the environment, but to become spaces that promote a better quality of life for citizens by actively participating in the development of means to meet their need sustainably. Andrade et al. (2017) adds that the development of sustainable cities is not only related to environmental issues; however, there is a complex arrangement of policies and indicators to allow for a better quality of life for its population.

This highlights the importance of the triple bottom line of sustainable development, since urban centers need to find a dynamic balance between targets of economic, social and environmental development. Competition for land use, a finite resource, is increasing in the last years due to fast urbanization, since the population of rural areas is diminishing. These areas are connected by the flows of goods, people and money (Un Habitat 2019).

Changes in land use could influence several services, such as providing food and mitigating and adapting to climate change, so policy-making related to land use must be stimulated (Lambin et al. 2001). Based on these premises, a research question was developed: how can urban agriculture contribute to solving the problem of food insecurity in urban centers, considering the context of climate change?

Methodology

This article was developed in the context of a literature review, as proposed by Arksey and O'Malley (2005) and corroborated by Levac et al. (2010). This method was chosen since this article seeks to evaluate the problem of food insecurity in urban centers, considering the context of climate change, using an analysis of literature. Considering that the topic of urban sustainability is broad, this topic of research was considered as adequate.

The process of literature review presented by (Arksey and O'Malley 2005) is composed of five steps. The first step refers to identifying the research question; in our article, it was defined as: how can urban agriculture contribute to solving the problem of food insecurity in urban centers, considering the context of climate change? The second step corresponds to identifying relevant literature to help answer the research question. In order to do that, research was conducted for articles in three databases, chosen for their level of international relevance and for being indexes in the CAPES system: Scopus, Science Direct and Web of Science.

Table 9.1 Selection of articles

Keywords	Science direct	Scopus	Web of science
urban agriculture/urban farm + food security	3445	385	301
urban agriculture/urban farm + climate changes	3491	104	96
food security + climate changes	12,057	4547	4.449
urban agriculture/urban farm + food security + climate changes	3459	26	31
Total of selected articles		56	

For the literature review, the following keywords were chosen: "urban agriculture" with its variations: "urban farm," "sustainable agriculture," "climate change," "food security," and "sustainable cities," with its variations "sustainable city" and "urban sustainability." In each database, a search was conducted using each individual keyword and their combinations.

The third step corresponds with the selection of articles for reading; due to a great number of articles in the Boolean equation, only the 20 most relevant and 20 most cited for pre-analysis of material were selected. After pre-selecting the articles in databases and reading titles and abstracts, 35 articles were selected for analysis according to their relevance to the research question. The results of this research are summarized in Table 9.1.

The fourth step corresponds to data mapping. In this step, the Excel software was used to organize the data in the following columns: year of publication, title of publication, author's names, journal of publication and concepts and definitions attributed to urban sustainability. The fifth and last step was to group, resume and report results to subsidize the construction of the following topics, using elements to identify and categorize the data by theme, as suggested by Arksey and O'Malley (2005) and Levac et al. (2010).

Climate Change

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as changes in the state of climate that can be identified by changes in variabilities and averages of its properties in an extended period, typically of decades or longer (IPCC 2007a).

Climate change is made worse by the emissions of Green House Gases (GHGs)—gaseous constituents in the atmosphere, both natural and man-made, that absorb and resend infrared radiation (UNFCCC 1992). GHGs act as a barrier for radiation on the Earth's surface, increasing temperatures on Earth (IPCC 2007b). Among these gases that stop heatwaves from leaving the surface, it is possible to cite carbon dioxide (CO_2), water vapor and methane. The carbon dioxide is released in natural processes and human activities, such as deforestation and use of fossil fuels (NASA 2019).

NASA (2019) adds that the concentration of carbon dioxide in the atmosphere has grown by more than a third since the Industrial Revolution and the emission of GHGs has increased by 70% from 1970 to 2014 (IPCC 2007a).

Changes in climate have been observed since the 1950s. Part of these changes have been linked to human action, including a rise in sea levels and extreme temperatures (IPCC 2014a). In recent decades, climate change has caused impacts on natural and human systems in all continents and oceans, indicating the sensitivity of these systems regarding impacts of climate change and its consequences (IPCC 2014a). According to (IPCC 2014a), human influences on climate systems is clear, and the emissions of GHGs of anthropogenic origin are higher than in any other period in history.

According to IPCC (2014b), climate change mitigation is the human intervention to reduce GHGs emissions, and a large part of it can be done in cities and urban areas (Mi et al. 2019), since these respond to more than 70% of GHGs emissions (McCarney 2019). Cities occupy only 3% of the Earth's surface; however, they are responsible for 60–80% of energy consumption and 75% of carbon emissions. Thus, it is evident that urbanization processes have great influence over the climate and the environment all over the world (Yang et al. 2017).

Mi et al. (2019) state that the effects of climate change affect urban sectors in different ways, while urban activities affect the environment in other ways. According to McCarney (2019), the vulnerability of cities to climate change is highly underestimated. This vulnerability associated with higher temperatures includes warmer days and nights, extreme climate events (such as heatwaves), an increase in water demand and reduction of water quality. Several cities are vulnerable to climate change and natural disasters due to their concentration of people and their location. This data helps to reinforce the importance of the development of urban resilience, which is crucial to avoid losses and disasters (UN 2018).

Food Security

Food security is defined as the condition in which all people have access to food that is sufficient, safe and meets their preferences and nutritional needs for a healthy and active life (FAO 2002) in social, physical and economic contexts (Peng and Berry 2018). The Food and Agriculture Organization of the United Nations (FAO) has estimated that, in 2017, 821 million people suffered from hunger (FAO 2018). To add to the problem, it is understood that the total world population might reach 9.7 billion by 2050, meaning 26% higher than today's 7.7 billion and creating a need for an increase of 70% of food production in the same period in order to meet current and future demands (Bayley et al. 2011).

There are four dimensions to the concept of food security: *food availability*, referring to its physical existence and offer, from cultivation to commercialization; *food access*, considering the resources needed to get the food, including economic, cultural and social aspects; *food utilization*, that considers conditions of health, nutrition and sanitation; and *food stability*, where the access to food needs to be stable over time, not depending on changing factors such as income, economy or politics (FAO 2006). Food insecurity, then, can be caused by several factors that may disrupt food availability, production and stability (Fyles and Madramootoo 2016). The problem of food insecurity affects especially urban centers, in developed and developing countries (Amorim et al. 2019) and affects one out of eight people in the planet. Around 75% of the food insecure population lives in China, India or sub-Saharan Africa (Fyles and Madramootoo 2016). As the world faces climate change, some of its problems affect agricultural production, causing soil erosion and changing the planet's temperature (Bhattacharya 2019).

Urban Agriculture

Urban agriculture emerges as a collaborator to increase food production in cities, since it is an agriculture system within an urban area that processes and distributes food using space and resources that are available in that environment (Mougeot 2000). This model is generally composed of a small or communitarian garden, vertical agriculture models or rooftop gardens (Zezza and Tasciotti 2010), contributing to an effort towards sustainable agriculture practices such as permaculture (Ikerd 1993) The urban agriculture model seeks to find a balance of environmental, economic and social aspects, making global consumption more sustainable, using less pesticides, and producing healthier food (Dixon et al. 2009).

Urban agriculture is also beneficial to economic development, reducing the production of GHGs (Lee et al. 2015). It promotes environmental development by creating green spaces and improving air quality (Kazemi et al. 2018), and it and encourages social development by engaging several social classes around a common goal and increasing environmental awareness in urban areas (Bujis et al. 2016).

The practice of urban agriculture is more common in developing countries, possibly since it contributes to spreading food more equally (Zezza and Tasciotti 2010). Cahya (2016) shows an example in the city of Jakarta, where fast population growth has contributed to an increase in pollution and in hunger, but urban agriculture has helped to improve the distribution of food for the population and reduce environmental problems, such as GHG emissions. Angotti (2015) adds that, in developed countries, urban agriculture has helped to offer fresh foodstuffs to the population, as seen in the cases of Portland and Detroit, in the United States.

Urban agriculture is understood to produce a silent revolution in the agricultural world production system, since it is a model that fits in countries with different social, environmental and economic realities to promote urban sustainability (Ferreira et al. 2018). Thus, urban agriculture demonstrates its importance for global sustainable development, highlighting the need to ensure access to varied sufficient food for all, since producers are also customers, contributing to consumption stability and diminishing the impact of seasonality (Zezza and Tasciotti 2010).

Discussion

Global food production in its current form can be understood as a threat to the environment (European Comission 2006). This current food production system occupies more than a third of the world's surface and is responsible for roughly 30% of anthropogenic GHG emission (Garnett 2011). According to a report by the Public Health Association Australia (2018), the food system (meaning production, processing, packaging, distribution, consumption and waste management after those processes) is linked to the environment on several levels; all those phases contribute to the emission of GHGs, thus aggravating climate change (Friel 2010). Beyond GHG emissions, the food production system contributes to the waste of water and food, as well as the loss of biodiversity (Public Health Association Australia 2018). At the same time, the expansion of the urban agriculture model can contribute to reducing transportation costs by producing food where it is consumed, reducing GHG emissions (Lee et al. 2015).

There used to be little discussion in the literature about food security in the context of cities. However, as the intersection between these subjects becomes more apparent, the integrated analysis of these situations becomes indispensable (Amorim et al. 2019). Food security has always been an essential issue for city dwellers (Barthel and Isendahl 2013), so urban food systems are as important as any "traditional" urban service, such as electric energy, basic sanitation, transportation and leisure (Born and Purcell 2006). This increases the demand for food systems to be productive locally, stimulating activities and individuals that can offer food in these areas (Dubbeling et al. 2016). The development of urban agriculture plays a key role in increasing the amount and diversity of food, while also offering another economic opportunity for the agricultural sector, one of the main sources of income all over the world (Sunderland and Rowland 2019).

In this context, the benefits of urban agriculture contribute towards food security, improving survival means and generating income for cities. It offers a source for more nutritive food, while allowing urban families to reduce the amount of money spent in buying food, as well as increasing their income by selling food, giving them an opportunity to spend more on other needs, such as health and education (Satterthwaite et al. 2010). Other benefits are a better use of available land, the greening of cities and the social benefits from building communities (Badami and Ramankutty 2015).

Regarding food security, urban agriculture plays a key role in ensuring food availability, access, utilization and stability: it improves economic issues, such as transportation, social issues, such as promoting social integration in communitarian gardens; and environmental issues, by greening cities and reducing urban heat islands (Deggau et al. 2019). Nadal et al. (2017) adds that using urban agriculture to create communitarian gardens and green roofs can help implement sustainability in urban areas by using water and natural fertilizers already available in those buildings.

Conclusions

The challenges of today's world are complex, and several circumstances are interconnected; therefore, complex and holistic solutions are needed to make an impact. This is the case with urban agriculture, which creates a framework to address a major world problem (in achieving food security) while considering the context and the environment where this problem happens (with people living mostly in cities and with important changes happening in the climate). This applicability of urban agriculture to several of the world's challenges is a fine example of its alignment with the Sustainable Development Goals (SDGs), proposed by the United Nations in 2015.

The SDGs were created as a blueprint for a sustainable future, considering the common challenges faced by humanity, building on the success of the Millennium Development Goals, proposed in 2000. The concept of sustainability proposed in these goals relates to a triple bottom line: economic, social and environmental spheres must be observed, respected and protected. Many of the 17 SDGs are related, and the agenda was created to be achieved as a whole. In this sense, the contribution of urban agriculture is to help achieve some of these goals—especially SDG 2 (Zero Hunger) and SDG 11 (Sustainable Cities and Communities)—while observing and contributing to others.

The main purpose of urban agriculture is to help achieve food security for urban populations, helping to bring an end to hunger and malnutrition (SDG 2) and making cities more sustainable (SDG 11) by providing a safer (SDG 3) and cleaner production (SDG 15). Urban agriculture also considers climate change mitigation (SDG 13), since it offers an alternative to a current model; thus, polluting less water (SDG 6) and using clean and efficient energy (SDG 7). Urban agriculture can also provide new opportunities for decent work for urban populations (SDG 5), creating opportunities to reduce inequalities (SDG 10) and poverty (SDG 1). Thus, it is evident that urban agriculture provides an efficient approach for addressing simultaneous problems. Combined with other plans, frameworks and ideas, urban agriculture can provide a pathway to a more sustainable future. Further research could focus on the limitations of the urban agriculture framework in providing food security in cities, or limitations on its response to the climate change problem.

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Chapter 10
Structural Litigation in Environmental Protection Systemic Failures: A Perspective of the Brazilian Dam Collapses

Micaela Linke and Marco Félix Jobim

Abstract The present article addresses structural litigation as an alternative for promoting solutions to systemic failures in environmental protection. Specifically, it aims to analyze the concept of this procedure in the Brazilian legal system and its application in the cases of the dam breaks in Barra do Fundão, Rio Doce, 2015, and in Córrego do Feijão, 2019, both in Minas Gerais, Brazil. Based on the doctrinal premises, the violation of fundamental rights, the state's omission, the urgency and need for judicial intervention and the complexity of the dispute, structural remedies were essential. These characteristics transformed the first disaster's class action into a structural procedure, even though it was not the initial intention, and due to the second episode, Public Civil Action 1,005,310-84.2019.4.01.3800 was filed with the purpose of reforming the mining control and inspection policies. Therefore, in its different forms, structural litigation—supported by the legal provision that atypical measures are permitted in Brazil's civil procedure—is an alternative for dealing with cases that need party constructed solutions.

Introduction

The present work discusses structural litigation as an alternative judicial option for dealing with cases that need party constructed solutions. It intends to revise the concepts surrounding these kinds of lawsuits in the Brazilian Civil Procedure Laws as an option when facing complex problems. The paper therefore aims to analyze the cases involving the dam collapses in the state of Minas Gerais: the one in 2015 in Barra do Fundão in Rio Doce and the most recent one in 2019 in Córrego do

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Feijão, focusing on the ends of Public Civil Action 1,005,310-84.2019.4.01.3800 and especially its claim.

Initially, the doctrine on structural actions was examined, reviewing the concepts of this technique in Brazil and the requisites that were considered essential, taking into account its foreign origin and international development. Subsequently, based on previous findings, the cases of the dam collapses were analyzed, focusing on the application of this type of lawsuit when facing environmental protection systemic failures in mining inspection policy, in the case of Córrego do Feijão.

Therefore, this paper used the deductive method, studying Brazilian law regarding the theme of structural litigation and its application in the country for the protection of social and environmental rights. In addition, the comparative method was used to enrich the study, as well as to help conclude it with critical analyses of the cases based on the general ideas obtained in the beginning. Thus, the work was exploratory and used primarily bibliographical research in consideration of the topic's recent emergence in Brazil and Brazil's constant evolution as a nation.

The relevance of this type of study, especially when linked to complex problems involving social and environmental law, is made clear by the advancement of structural litigation in Brazil, following global trends and a significant growth in this subject. Therefore, understanding the evolution of the study on structural litigation is necessary for the qualification of its use, in order to boost the protection of social and environmental rights in a sustainable way, as it is already being explicitly used.

Structural Litigation

Structural suits or injunctions—or as referred to in Brazil as structuring measures or techniques, structural decisions, structural litigation or complex litigation of structural rite—are gradually becoming important alternatives for solving organizational problems within the public systems, guided by the establishment of dialogue between the executive, legislative, civic and judiciary sectors involved. These lawsuits are characterized by the implementation of structural reform in an organization or an institution, aiming to achieve or protect fundamental rights through particular public policies or measures or to resolve complex disputes—in which multiple social interests worthy of authority collide, according to Fredie Didier and Zaneti (2019, p. 455).

As Brazil has a civil law-based system and uses its legislative texts to define rules, these claims and decisions are based on the authorization or power to promote the execution of decisions through atypical measures (Jobim 2016), as defined in general executive clauses—article 139, IV,[1] with article 536, § 1º[2] of the Civil Procedure Code of Brazil (Brazil 2015) (Didier and Zaneti 2019, p. 464). In other words, Brazilian law permits judges to use methods not previously mentioned in the law, as long as they are in accordance with the Federal Constitution of Brazil of 1988 (Brazil 1988) and the principles of the legislation of the country and its states in order to promote the effective execution of decisions. This is valuable, because, as Marco Félix Jobim explains (2013, pp. 82–83), a judicial decision alone does not alter social relationships, economic dynamics nor collective policies, even more so on the level of structural reform; it needs multifaceted concrete conditions for the public embodiment of such transformation.

In this regard, complex cases develop when fundamental interests oppose each other, and the community requires judiciary solutions capable of mitigating negative impacts, adjusting the resolution of the case according to its effects of macro justice, with an expected logic (Arenhart and Osna 2019, p. 132). These complex lawsuits that have the potential to impact an entire society can require structural reforms. The origin of structural injunctions goes way back to Brown v. Board of Education of Topeka, a landmark case in the United States of America in 1954 (Brown I, 347 U.S. 483) and again in 1955 (Brown II, 349 U.S. 294).

The original case in the 1950s was part of an international human rights movement (Goldstone and Ray 2004, p. 105), and it was responsible for effectively putting an end to the acceptance of the concept of *separate but equal*, enshrined in the nineteenth century in Plessy v. Ferguson (163 U. S. 537, 1896). It transformed the social reality, helping the country to achieve racial desegregation in the public education system (Pinho and Côrtes 2014, pp. 232–233). The international influence of this decision boosted the emergence and the development of structural actions as a trend in various legal systems, such as those in India, Colombia, Argentina, and South Africa throughout the years.

When analyzing this set of cases, whose common goal is to bring about change in failing systems, it is possible to identify some common characteristics. The most important of these is the constitutional violation of a fundamental right in a collective scope that the courts seek to eradicate. Therefore, they serve as a formal mechanism in which the judiciary can act towards the accomplishment of constitutional goals unattained up until that point. This concept is aligned with the ideas of Fiss (1979),

[1] Art. 139. O juiz dirigirá o processo conforme as disposições deste Código, incumbindo-lhe: (…). IV—determinar todas as medidas indutivas, coercitivas, mandamentais ou sub-rogatórias necessárias para assegurar o cumprimento de ordem judicial, inclusive nas ações que tenham por objeto prestação pecuniária; (…) (Brazil 2015).

[2] Art. 536. No cumprimento de sentença que reconheça a exigibilidade de obrigação de fazer ou de não fazer, o juiz poderá, de ofício ou a requerimento, para a efetivação da tutela específica ou a obtenção de tutela pelo resultado prático equivalente, determinar as medidas necessárias à satisfação do exequente.

§ 1º Para atender ao disposto no caput, o juiz poderá determinar, entre outras medidas, a imposição de multa, a busca e apreensão, a remoção de pessoas e coisas, o desfazimento de obras e o impedimento de atividade nociva, podendo, caso necessário, requisitar o auxílio de força policial. (…) (Brazil 2015).

who came up with the notion of structural injunctions and reforms in the American legal system from the case of Brown v. Board of Education of Topeka.

Another common characteristic which can be observed in structural litigation is that of recognizing an omission or inertia of the public power or of responsible institutions, as a way of guaranteeing the legitimacy of such procedure. As these significant decisions in the majority of cases interfere with the separation of powers and with the checks and balances system between the executive, the legislative and the judiciary branches—sometimes being seen as judicial activism—, the evaluation of the state's omission gained importance.

Also, understanding the reasons that brought the issue to this point is of uttermost relevance, as it gives insight into how they can correctly approach (Rouleau and Sherman) each case. Therefore, despite the state's disregard, incompetence, and intransigence, the causes of these omissions require distinct treatments (Roach and Budlender) in order to reach the intended purpose of the claim.

Moreover, the urgency and necessity of judicial intervention (closely related to the previous characteristics mentioned) and the complexity of the demand (by definition, due to the structural failures of the government that involve and require complex solutions) are also considered essential to the consolidation of a structural litigation, according to Eduardo Dantas (2019, pp. 94–101). To summarize, there are four reappearing aspects in the subject of structural litigation: the violation of fundamental rights, the state omission—in any of its forms, the urgency and necessity of judicial intervention, and the need for a complex solution, being intricate cases.

The acceptance and implementation of these kinds of procedures is a consequence of the attempt of the legal system to adapt itself to the constant transformation of humanity. As the law is a reflection of society, it accompanies its community through social, economic, political and legal changes. In particular, it can also be considered a product of the fundamental claims that arise with the establishment of the democratic rule of law in a scenario impacted by technological evolution, the chronic state of belligerence, and the process of decolonization of the second post-war period and its overwhelming consequences, according to Ingo Sarlet's lesson (Sarlet et al. 2017, p. 316). The fundamental rights of the third dimension—rights of brotherhood and solidarity—which are distinguished for being detached in their core from the figure of an individual man as their holder, are intended for the protection of human groups; consequently, they can be called transindividual (collective or diffuse) ownership rights.

In Brazil, these rights are defined in Article 81, sole paragraph, of Law no 8.078/90,[3] which is the Brazilian Consumer Protection Code (Brazil 1990). It explains that diffused rights comprehend indivisible ones, of an undivided nature,

[3] Art. 81. A defesa dos interesses e direitos dos consumidores e das vítimas poderá ser exercida em juízo individualmente, ou a título coletivo.

Parágrafo único. A defesa coletiva será exercida quando se tratar de:

I—interesses ou direitos difusos, assim entendidos, para efeitos deste código, os transindividuais, de natureza indivisível, de que sejam titulares pessoas indeterminadas e ligadas por circunstâncias de fato;

held by an indeterminate group of people bound by a fact or a circumstance; transindividual rights are also of an indivisible nature held by a group, category or class of people linked to each other or to the opposite party by a basic legal relationship; and the homogeneous individual rights are those arising from common origin. Among these, we highlight the so-called social and environmental rights, which are the meeting grounds of both perspectives, aiming to protect the biotic and abiotic worlds for current and future generations, with the integrity of ecosystems, economic growth, and social equity. That is, they are the product of the intention to build a permanent dialogue between their needs and demands (Molinaro 2015, p. 993).

As environmental protection systems or policies have a strong impact on fundamental rights, the conflicts involved tend to inherit the complexity of such rights. As such, the theoretical capability of these cases to match the aspects that characterize structural litigations becomes clear. In the Brazilian scenario of multiple systemic failures and severe political and institutional blockades (Porfiro 2018, pp. 1, 22–23), it was only a question of time until structural litigations were applied in its legal system and in environmental cases.

Application in the Brazilian Dam Collapses

Brazil's history with structural litigation began with a few decisions from its Federal Supreme Court (analogous to the American Supreme Court), such as in the case of Raposa Serra do Sol, which involved indigenous territory. However, even with the academic sparks generated in the early 2010s, it was only after the dam collapsed that structural litigation became a studied topic.

In recent years, the country has suffered two human-caused natural disasters—if they may be worded this way—in the breakage of dams. Dams are barriers constructed to hold back water and raise its level, forming a reservoir used to generate electricity, a water supply or to contain mining tailings, also called barrage, barrier, wall, embankment, levee, barricade, obstruction, hindrance or blockage.

The first disaster occurred on November 5th, 2015, and was called the Barra do Fundão or Rio Doce dam disaster, also known as the Mariana, Bento Rodrigues or the Samarco dam disaster.

An iron ore tailings dam in the city of Mariana, Minas Gerais started leaking and could not be repaired, resulting in a catastrophic rupture. According to the United Nations, it resulted in a mud flooding that killed 19 people and destroyed around 200 homes in the village of Bento Rodrigues. Around 60 million cubic meters of iron waste flowed from Barra do Fundão into the Rio Doce, contaminating the water with heavy metal and polluting substances reaching as far as the Atlantic Ocean. Entire

II—interesses ou direitos coletivos, assim entendidos, para efeitos deste código, os transindividuais, de natureza indivisível de que seja titular grupo, categoria ou classe de pessoas ligadas entre si ou com a parte contrária por uma relação jurídica base;

III—interesses ou direitos individuais homogêneos, assim entendidos os decorrentes de origem comum. (Brazil 1990).

aquatic animal populations were killed immediately by the contaminated sludge and the force of the mudflow ripped apart a nearby forest. Considered the worst natural disaster in Brazil's history, it created a humanitarian crisis and put the health of millions of people in danger, making it nearly impossible, even to this day, to measure the full extent of the damage.

The investigation uncovered reports that were delivered to Samarco prior to the incident, which indicated the risk of dam failure. The case put into question all those involved in mining dams throughout the country. Despite government sanctions, a R$20 billion fine (which did not include compensation for the people directly affected) and public outrage, on January 25th, 2019 a second dam disaster occurred.

The Córrego do Feijão or Brumadinho dam ruptured catastrophically. It was also a tailings dam, this time at the Córrego do Feijão iron ore mine near the city of Brumadinho, Minas Gerais, and was owned by Vale, a company involved in the former collapse at Mariana. This time the released mudflow advanced through the mine's offices, including a cafeteria during lunchtime along with the areas around it, destroying everything in its path and killing at least 248 people, mainly workers of the barrage. The rupture released around 12 million cubic meters of tailings containing metals that, incorporated into the river's soil, will affect the entire region's ecosystem.

Comparing both situations, it can be said that environmentally speaking, the Barra do Fundão/Rio Doce disaster has had more severe consequences, as the damage is still being felt and measured. On the other hand, the human loss in the Córrego do Feijão disaster is insurmountable. The former class action of the victims—with countless victims, immeasurable damage to lives, homes, communities, social relationships, and the environment, all caught in the polluted mudflow—has, in a way, became a structural litigation, as it is unconstitutional to try fitting this case in the ordinary Brazilian Civil Procedure. Common civil procedure rules, such as deadlines, steps, and measurements used in typical cases, cannot be applied in this case; flexibility is necessary in order to find some kind of answer for the victims and develop adequate reform to prevent these situations from repeating themselves.

It is true the latter was a smaller dam, but it was a repeat of what happened less than four years earlier, and, because of that fact alone, it raised major concerns about the weaknesses and gaps in regulatory structures. The department responsible for the inspection of mining operations, which includes tailing dams, is the National Mining Agency (ANM), previously called the National Department of Mineral Production (DNPM). As other regulatory institutions suffered—in the present decade—personnel shortages due to the retirement of a large percentage of its public employees without an adequate number of replacements, this raises questions about the licenses granted and the classification of the dam as a low risk of high potential damage. As the loss was mostly suffered by the employees, the harshest criticism came from the local mining union, as there were long-standing concerns and warnings about the structural integrity of the dam, thus building the hypothesis of a violation of workers' rights.

In the face of this scenario, motivated by the failure of the Córrego do Feijão dam and the damages caused, in April, 2019 the Federal Prosecutors Office (MPF) filed the Public Civil Action 1,005,310-84.2019.4.01.3800 with the purpose of provoking the necessary structural reform in the inspection policies of mining companies. The complaint (Ministério Público Federal 2019) against Brazil and the National Mining Agency (ANM) aims to bring an end to the constitutional violations caused by the systemic failure to inspect Brazilian dams and, made evident by their high rate of accidents. Explicitly, it proposes to institute a structural procedure based on the legislation mentioned earlier.

In other words, considering the damage to fundamental rights caused by the state´s omission in effectively enforcing the proper safety precautions policies with the mining companies responsible for the tailing dams, it was necessary for the judiciary to take action, putting an end to the wait since the Rio Doce's dam disaster and implementing complex reform that is urgently needed. Therefore, it is perceived that both suits—the latter intentionally, the former accidentally—are coherently structural, possessing the shared characteristics mentioned to ensure legitimacy and to enable their success, despite the arguments revolving around structural litigation in Brazil, of this kind of effective judicial implementation of institutional reforms (Jobim 2013, p. 91). The intervention of structural litigation is embraced by the current configured possibilities of alternative responses based on the dynamism of the contemporary civil procedure (Osna 2017, p. 144).

Considerations

Considering the concepts previously explained, structural litigation in Brazil has become an option when dealing with complex cases presented to the judiciary in which usual civil procedure norms cannot be applied, as they are unfit to adequately and efficiently resolve these cases. Furthermore, it follows the trend of flexibility in procedural formalities in order to achieve the recognition of fundamental rights violated or threatened in such scenarios, following in the footsteps of other countries like Argentina, Colombia and South Africa. Brazil started implementing the ideas of structural injunctions in lawsuits as a result of the national dam collapses.

Therefore, given the severe situation in which Brazil has found itself due to the losses derived from mining dam bursts, especially the loss of life, destruction and irreversible environmental consequences, it became painfully clear that it was necessary to find an alternative way to effectively solve the problem, avoiding reoccurrences and providing the minimum repairs to the damage caused. However, providing such a solution is not an easy task, and the truth is that this issue has reached the judiciary as the *ultima ratio*—last resort—to obtain a decision for the cases and to ensure the concretization of the constitutional values established in 1988.

As the class actions are filed, when looking at the full extent of the disasters, it becomes clear that common procedural rules are unable to grasp the magnitude of the problem. The overall damages are still being measured, and new damages are being continuously discovered years after the first collapse. With that in mind, the only option in face of these complex situations where civil rights have been violated is to adopt procedures which are flexible and can adapt to complex situations in order to give some kind of proper and efficient solution. However, the transformation of these class actions, directly affected by the disasters, into structural suits is the best solution, considering the difficulties in solving this litigation. The case of the Barra do Fundão in Rio Doce does not significantly touch upon systemic failure as in the case of Córrego do Feijão, which was when the cases became considered repeated incidents.

Public Civil Action 1,005,310-84.2019.4.01.3800 carries the potential to transform the failing mining inspection institution, policies and structure through an agreement made, signed and executed by the parties involved with the assisted supervision of the judiciary. Thus, the filing of the structural reform suits is an alternative with high potential for success. Because of that, this was the course of action taken by the Federal Prosecutors Office (MPF) to establish dialogue with the parties involved in order to correct the problem and completely change the system through reform, with a much greater likelihood of achieving its goals in the long run. Therefore, structural litigation poses itself as an alternative for reaching sustainable solutions in complex cases, such as the environmental protection systemic failures which are witnessed by the Brazilian population and furthermore, to promote sustainability along the way.

To summarize, although the Brazilian cases of the dam collapses have not completely ended and their results cannot be evaluated at the present moment, structural litigation, in theory, is an alternative for the prospective protection of social and environmental rights in cases where there are violations of fundamental rights and state omissions, requiring immediate judicial intervention through the construction of complex solutions. Considering this, once the questions about the legitimacy and plausibility of the use of such procedure are answered, structural litigation might be an instrument, if correctly used, capable of boosting national development because of its central relationship with systemic reforms, which are greatly needed in countless institutions in a country of social and environmental collapse like Brazil. After all, the Brazilian civil procedure is fundamentally an instrument for effective jurisdictional protection of rights (Marinoni 2004, pp. 145–146).

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Chapter 11
Access to Food and Availability in Areas of Social and Environmental Vulnerability: Threats to Sustainable Development

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Abstract Throughout the extensive journey until it appears on a plate, food goes through complex interactions with (un)sustainability. The discussion on food and sustainability has existed for many years, yet it is considered a current theme among studies. When it comes to food, the contextualization of food insecurity is of paramount importance, characterized as when people do not have access to food in sufficient and adequate quality and quantity. In the context of social inequality, we can state that social vulnerability is correlated with nutritional food insecurity, demonstrating that vulnerability hinders access to food. The objective is to discuss the relationship between social and environmental vulnerability and sustainable development, food and communities at risk in the municipality of Novo Hamburgo, in the south of Brazil. Thus, a short questionnaire of the Brazilian Scale for Food Insecurity

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(BSFI) of food consumption in areas of socio-environmental risk was used to verify the presence of nutritional food insecurity. The research demonstrates how social and environmental vulnerability increases the food insecurity of families of schoolchildren in at-risk areas and discusses the existence of public policies for the sustainable development of the municipality, considering the UN sustainable development goals.

Introduction

Social vulnerability has been the object of study by researchers in several areas, as Cutter (2003, 2010) has already stated. For Cutter (2003, 2010), the vulnerability of communities is not only the result of the dangers to which they are exposed, but also the conditions of life and marginality which they are subject to in their daily lives. The income component is one of the variables that increases or decreases social vulnerability. However, besides this relationship, it is an indicator of social inequality of populations, and thus it interferes with the ability to access food. When we talk about social inequality, it is generally considered a particular dimension of insufficient income, but there are several other situations that reflect social inequality, among those we can mention the food and nutrition security of individuals.

Food and nutrition security (FNS) in Brazil is characterized by Decree n. 7272 of 2010 as the right of all subjects to regular and permanent access to sufficient quality food without compromising access to other essential needs. This is based on promoting healthy eating practices that respect cultural diversity and that are environmentally, culturally, economically and socially sustainable (DOU 2010). On the other hand, food insecurity affects different types of populations in an unequal way, whether by political, economic, environmental, or educational factors, among others (Castro 2019).

The right to food encompasses two inseparable dimensions: the right to be free from hunger and the right to adequate food, as provided for in Article XXV of the Universal Declaration of Human Rights 2009 (ONU 2009). It is also a right guaranteed by the Brazilian Federal Constitution, so the government is responsible for adopting the necessary policies and actions to promote and ensure adequate nutrition (DOU 1988).

It is of utmost importance that current studies correlate the themes of food and sustainability in the context of food and nutritional insecurity. Beyond the understanding of food security, a reflection on the quality and quantity of the food consumed is necessary, which often evidences unhealthy food consumption. When these issues are linked to the context of a specific reality, it is possible to link two sectors that are the basis for the evolution of the FNS approach: the socioeconomic and health/nutrition sectors (Maluf 2007).

Furthermore, we can highlight the different interactions of food and nutritional insecurity manifestations in Brazil, since they occur through the immediate confrontation with hunger and undernourishment. Undernourishment is characterized by the condition in which daily food does not supply the energy necessary for the survival of the organism and the daily activities of a person. According to the WHO, undernourishment is multifactorial and has its root in poverty (Brasil 2005). This manifestation is understood as recurrent in populations that present deficiency or quantitative or qualitative inadequacy of the diet, or for poor hygienic conditions of the food ingested. It is common for people exposed to situations of social vulnerability to present clinical signs due to either the low daily energy intake (calories) or the lower quality of nutrients present in the food consumed (Maluf 2007).

Throughout the wide and complex journey of the food until it arrives on the table, there are a number of issues that must be addressed, as this food should promote health and nutrition for the individual who eats it. However, care still needs to be taken to generate sustainable food consumption models which favor family-based agriculture and proximity to local production with consumption of these foods and which promote environmental sustainability and the diversity of eating habits (Ruschel 2016).

When food, nutrition and sustainability are related, a new element of analysis emerges in the context of behavior, the eating habits. Non-communicable chronic diseases are currently considered urban epidemics. In this sense, some factors are directly related to the food consumed, the nutrition available through these foods and also the sustainability regarding the entire production process until actual consumption (Ribeiro et al. 2017).

Thus, this research aims to discuss the relationship between sustainable development, food and communities and social and environmental risk and vulnerability in the municipality of Novo Hamburgo, in the south of Brazil. We intend to contextualize the presence of nutritional food insecurity and discuss the existence of public policies for sustainable development of the municipality considering the UN Sustainable Development Goals (SDG).

Food and Nutritional Safety in Brazil

The fight against hunger and poverty in Brazil began in the 1930s, with the first policy to fight hunger, the publication of Act n. 185 of 1936 and Decree n. 399 of 1938, which set the national minimum wage (DOU 1936, 1938). In 1940, the minimum wage was constitutionally defined, with the objective of guaranteeing access to food, housing, health, education and leisure to individuals. In addition, in 1940 the Social Security Food Service (SSFS) was instituted, which was the first strategy to fight hunger more effectively, by establishing popular restaurants and offering modestly priced staple food, thus meeting the nutritional needs of workers. Later on, the program was expanded to assume educational functions among workers and their families (Vasconcelos 2005).

In 1945, the National Food Commission (NFC) was created, which aimed to propose the rules of the national food policy. The NFC sought to study nutrition status and eating habits, stimulate research on dietary issues and problems, verify corrections for defects and deficiencies in the Brazilian diet, encourage educational campaigns and support the development of the food dehydration industry (Pinto 2014).

In the following years, the NFC developed the National Food Plan, also known as the Food Conjuncture and Nutrition Problems in Brazil. This food and nutrition security policy aimed at the most vulnerable groups in society was based on the recommendations of the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO). Subsequently, a national school lunch program was structured (Pinto 2014).

The National Institute of Food and Nutrition (Inan) and the National Food and Nutrition Program (Pronan) emerged during the Military Regime, implemented in two stages between 1973–1974 and 1976–1979. Inan was directed towards the formulation of a national food policy, while Pronan primarily addressed nutritional supplementation and the promotion of training and research related to overcoming hunger. During this same period, the Workers' Food Program (WFP) was created, designed to focus on low-income workers, which was effectively initiated with the publication of Decree n. 5 of 1991 (Silva et al. 2010).

Other programs were created in the 1980s and 1990s, but in 2001, there was a more significant change in the structuring of social programs in Brazil, with the creation of the Federal Government's Single Registry for Social Programs (*CadÚnico*). This register has been used for the application of public programs aimed at overcoming misery and hunger in Brazil, such as the *Bolsa Escola*, the *Bolsa Alimentação* and the Food and Gas Assistance Card (Pinto 2014). The project *Fome zero*—A Proposal of Food Security Policy for Brazil, launched in 2001, has been operational since 2003 and was restructured in 2004, with the aim of broadening the fight against poverty and becoming the main strategy to guide economic and social policies (Silva et al. 2010). In 2006, *Fome Zero* migrated to the *Bolsa Familia* Program, created by Act n. 10836 of 2004, which unified and expanded these social programs into one single social program (DOU 2004a).

It is worth mentioning that Yasbek (2004) stated that food security should not be seen only in food supply expansion, lowered prices and emergency programs, but should rather be a model which goes beyond overcoming poverty and hunger. The objective of the food security policy should be associated with economic and social development strategies that guarantee equity and social inclusion.

Other programs have been set up to fight maternal and child undernourishment, improve school health standards, strengthen family farming and increase access to food. It is important to highlight the National Food Security System created by Act n. 11346 of 2006, with the objective of ensuring the human right to adequate food, with the participation of organized civil society (DOU 2006). Through this law, the Nutritional Food and Nutrition Council (CONSEA) emerges as an advisory body to the President of the Republic, being an instrument of articulation between citizens and the government in proposing guidelines for actions in the area of FNS, in the formulation of policies and definition of guidelines for the country to guarantee the human right to food for its population. However, CONSEA was extinguished by Provisional Measure n. 870 of 2019, leaving a gap in the fight against hunger (DOU 2019). Nevertheless, the permanence of the organization is still under discussion in the National Senate, as it is of great importance since it involves issues such as the fight against hunger, family farming, pesticide control, and school meals, among others (IPEA 2019).

With all these programs, Brazil was removed from the World Hunger Map in 2014, according to a global report produced by the UN Food and Agriculture Organization (FAO). The United Nations' first Millennium Development Goal was achieved, which was to halve extreme poverty between 1990 and 2015. However, according to the FAO (2019), Brazil is predicted to be reinstated in the Hunger Map, with approximately 5 million people currently malnourished in the country.

International Context of FNS

Some attempts to build food and nutrition policies were guided by two distinct paths within the international context. Initially, food policies were created with a focus on ensuring sufficient food production, and subsequently, nutritional policies were created to focus on the association between food and the health status of populations (Maluf 2007).

Over the years, the concept of food and nutrition policy has undergone some changes to improve its evolutionary process. Currently, a food and nutrition policy represents a concerted and crosscutting set of actions designed to ensure and encourage the availability and access to certain types of food, with the aim of improving the nutritional status of the population and promoting their health (Vieira et al. 2013).

In Portugal, for example, food and nutrition security is presented through the Second European Action Plan for Food and Nutrition Policy, from the WHO (World Health Organization), as well as the periodically updated National Health Plan. Related by intersectoral approaches, the countries of the European Union, as well as Brazil, present actions related to the FNS. However, in Portugal there are still those actions related to industry and the production of safe food (Vieira et al. 2013).

The current Portuguese diet departs from the Mediterranean model, and is now characterized by an increase in the consumption of food sources of sodium and fat. In addition, there was a decrease in the consumption of vegetables and fruits, especially in the younger age group (Vieira et al. 2013).

Regarding FNS in Portugal, the consumption of some foods considered essential is decreasing, due to economic difficulties in 8.1% of households. Data from the 4th National Health Survey of 2005/2006 indicate that in that period, in more than 1/3 of the population, food insecurity and overweight were present (Vieira et al. 2013). Despite the limited data on food insecurity in Portugal, it is estimated that 18% of the population lives at risk of poverty (Vieira et al. 2013).

As well as in Brazil, FNS in other countries has been intensively discussed, as it seeks to promote physical, social and economic access to sufficient, safe and nutritious food, meeting the nutritional needs and dietary preferences of individuals so as to provide them with a healthy and active life (Maluf 2007).

The Food and Agriculture Organization (FAO 2019) has an indicator to monitor progress in the eradication of hunger in the world, which measures the prevalence of undernourishment, or PoU. Prevalence of undernourishment (PoU) aims to measure approximately the restrictions on food access and consumption which are required for a healthy life. Data are expressed in percentages. Figure 1 shows the prevalence of undernourishment in different areas and, as noted, there is a reduction in this prevalence over the years, especially in central, southern, eastern south-eastern Asia, Latin America and the Caribbean. However, it should be noted that from 2015 onwards the data indicate a slight increase in undernourishment in the world.

In Brazil, FAO (2019) estimates indicate that from 1999 to 2001 there was a prevalence of undernourishment in 11.9% of the population. In the period from 2008 to 2017, 2.5% of the population was in this category.

In this context, the 17 UN objectives raise important points to be worked on over the next decade. Among them, we can highlight Objective n. 2, which is about ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture.

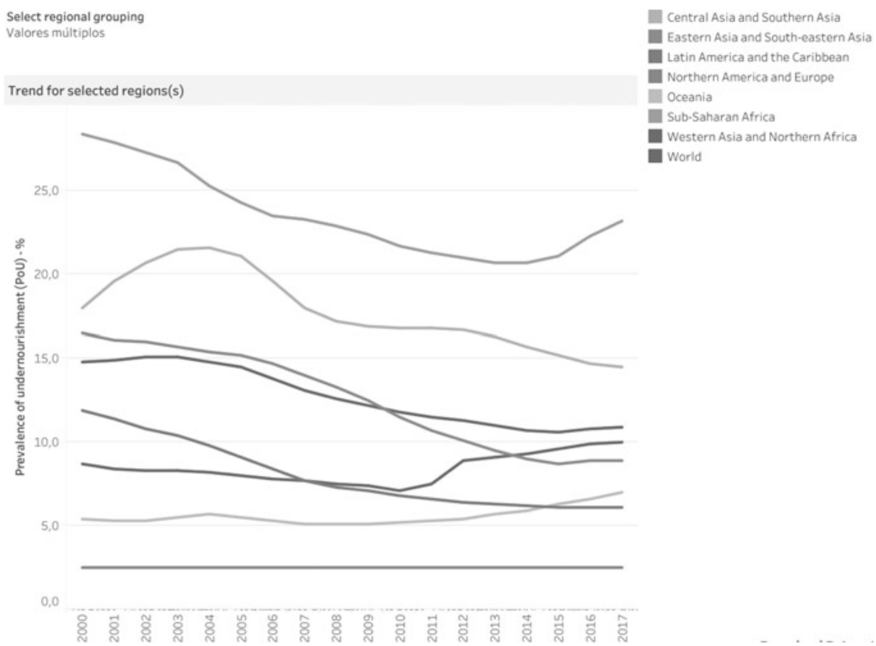

Fig. 1 Prevalence of undernourishment in the World, from 2000 to 2017. *Source* FAO, FAOSTAT (2019)

Methodology

The ongoing research is a case study in which a pilot study was conducted with the non-conventional application of a short questionnaire of the Brazilian Scale for Food Insecurity (BSFI). The BSFI is a scale duly validated and widely used, applied for the first time by IBGE, in 2004. The scale is able to directly measure the food and nutritional security in a population through the interviewees' perception and experience with hunger. This scale has fourteen questions that estimate the prevalence of food insecurity and classifies households into four categories with three levels of intensity: food security, food insecurity - mild, moderate or severe (MDS 2014).

In Brazil, the BSFI is applied by field researchers who directly interview the persons responsible for purchasing food in households. However, this procedure requires high financial resources and makes the completion of the field work more difficult.

The application was carried out with the parents of 30 students from a municipal school in Novo Hamburgo/RS, Brazil, located in an area with social and environmental risk and vulnerability. This municipality has subnormal clusters, mainly near environmentally fragile areas. In 2010, 19 subnormal urban agglomerates were registered with characteristics that, according to IBGE (2010), are a set consisting of 51 or more housing units characterized by lack of title deed and at least one characteristic such as irregularity of roads and lots or lack of public services (collection of waste, sewage, energy, among others).

In addition to the subnormal clusters, Novo Hamburgo has 11 sectors under risk of mass movements (mostly landslides) and floods (CEPED 2014). From the economic point of view, these locations are all in low-income neighborhoods. Thus, socially vulnerable areas are complex spaces.

Information on food safety was collected by sending questionnaires to the children's homes, along with a survey on food consumption and family income in order to better understand the socioeconomic status and nutritional quality of the studied population. Thus, the choice was to perform an unconventional application by sending the questionnaires home with the students of the selected school and using a short composite BSFI with five questions (Table 1).

Table 1 BSFI version applied in the case study

Short version of the Brazilian scale for food insecurity
(1) Did you worry that the food in your home would run out before you could afford to buy, receive or produce more food?
(2) Did the **food run out** before you had money to buy more?
(3) Did you **run out of money** to have a **healthy and varied diet**?
(4) Have you or an adult in your household ever **decreased the amount of food** at mealtimes, or **skipped meals, because there was not** enough **money** to **buy food**?
(5) Have you ever **eaten less** than you thought you should **because there was not enough money** to buy food?

The short version of the BSFI was proposed in 2013 by the Federal University of Pelotas, and concluded that the five-question model can be used as a short version of the Brazilian Scale for Food Insecurity, as it presented results similar to the original scale with fewer questions (Santos et al. 2014).

The proposed five-question scale aims to classify households into two categories: Food Security and Food Insecurity. The variable on the food security situation was obtained from the score from 0 to 5, obtained by the sum of affirmative answers to the BSFI questions. Each family was classified in the following degree of food insecurity: (a) Food security: Zero points; (b) Food insecurity: 1 to 5 points.

Only the respondents who returned the questionnaire signed by the parents and/or guardians were counted. The process took place in May, 2019.

In addition to the literature review that was conducted on the context of the FNS in Brazil and around the world, using data from official bodies and academic research, we aimed to comprehend the functioning of public policies on the subject at the local level. To this end, meetings of the Municipal Council for Sustainable Food and Nutrition Security were attended.

Results and Discussion

Out of the thirty questionnaires sent to the families of the students of the municipal school in Novo Hamburgo/RS, seventeen returned completed and signed, and were then considered for the analysis of the pilot application on the situation of food and nutritional security.

From the analyzed data, a prevalence of 82% of respondents indicated food insecurity, versus 18% of respondents indicating food security. Due to the type of questionnaire adopted, it was not possible to analyze the degree of food insecurity, only to verify if the family experiences food insecurity in any degree of intensity.

In addition, possible associations between the presence of food insecurity and family income were tested. Of the respondents, 65% reported income sources from 1 and 2 minimum wages, 18% from 3 or more minimum wages, 12% from income below 1 minimum wage and 5% did not respond. Thus, it is not possible to affirm a relationship between food insecurity and family income without associating other factors, because families who claim to have income from 3 or more wages expressed food insecurity, as well as those who declared income below 1 minimum wage. We believe that other factors need to be related to this variable, such as the number of people in the family.

Regarding food consumption, the low consumption of fruits and vegetables within families classified as experiencing food insecurity, compared to families who experience food security is highlighted. The data show that only 50% of families in the situation of food insecurity eat fruits and vegetables daily, while 100% of families identified as being in the category of food security consume this group of foods daily.

This result shows that the Food and Nutrition Security should verify the quality of food, in addition to the presence of sufficient food.. Inadequate diet can contribute to both low weight and undernourishment resulting from significant nutritional deficiencies, as well as excess weight and obesity with the consequent onset of chronic non-communicable diseases associated with excess body fat (Vieira et al. 2005; Veiga and Sichieri 2007).

In this sense, it is important to emphasize the importance of public policies, programs and actions focused on food and nutrition in the fight against hunger and adequate food. According to Ban Ki-moon (Scaling Up 2016), continuing as the eighth UN secretary general in 2017, nutrition is both a creator and a marker of sustainable development, as better health, education and employment rates, among other benefits, are possible by improving nutrition.

The organization Scaling Up Nutrition (2019) indicates that the 17 goals of sustainable development cannot be achieved without proper attention and action to combat undernourishment. At least 12 goals are correlated with nutrition and, if not prioritized, undernourishment can become an invisible impediment to achieving the goals of sustainable development.

The results obtained through this study demonstrate a high index of food insecurity in an area with social and environmental risk and vulnerability. In the municipality of Novo Hamburgo, the Municipal Council for Sustainable Food and Nutrition Security (COMSEA), created and instituted by Municipal Law 1189/2004, focuses on some specific activities, such as actions on the World Food Day (DOU 2004). These activities sponsored by the Council seek to promote healthy eating and overall health within the school community. However, there are some shortcomings relating to legal requirements and enforcement which must be faced so that the practices necessary for a significant decrease in the number of food insecure families in the Municipality are effective.

Considerations

The data presented in this study endorse the nationally released research on the reality of food insecurity and seek to demonstrate the importance of studying and publicizing aspects involved in the context of hunger in developing countries.

The challenges linked to achieving the United Nation Goals, in cases such as Brazil, go beyond the implementation of clean technologies, green industry and coping with climate change, for example. Hunger and food availability is one of the biggest challenges in this case, as there are still 17 deaths per day related to food insecurity in the country (Garcia 2019).

In Brazil as well as in other countries, it is essential to address the FNS topics in food and nutrition actions, as they can involve different areas of government and civil society. There is also the need for studies that seek to explore in more detail which aspects of food insecurity (that today affects a large part of the population) reach different social classes, as mentioned above.

A radical change in our food system is necessary to rethink the availability of highly processed and super-processed foods from the global model adopted. Moreover, in order to make this change truly permanent, the cultural, social and economic aspects of the population must be considered.

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Chapter 12
CAPEX and OPEX Evaluation of a Membrane Bioreactor Aiming at Water Reuse

Leonardo Dalri-Cecato, André Aguiar Battistelli, and Flávio Rubens Lapolli

Abstract The main discussion regarding the large-scale application of membrane bioreactors in effluent treatment is related not to their efficiency, but to the expenditures involved both in their implementation and operation. However, information on the costs of this technology is reported inconsistently, unevenly, and without periodicity, negatively affecting its credibility and the quantification of its economic impacts. Given that, this study consisted of the application of the life cycle cost evaluation methodology to evaluate the capital and operational expenditures of a membrane bioreactor designed to be implemented in Santa Catarina/Brazil, with a capacity to treat 6060 m^3 d^{-1} (50,000 inhabitants), and aimed at the production of reclaimed water. The estimated implementation costs considered the expenditures regarding the acquisition of membranes, area purchase, and construction. The operational costs survey considered membrane replacement, energy consumption, sludge disposal, and the payment of employees. Values equivalent to R$3363.08 m^{-3} d or R$407.61/inhabitant were estimated regarding the capital expenditure, and R$0.63 m^{-3} or R$2.10 per kg of BOD removed were estimated regarding the operational expenditures of the proposed wastewater treatment plant, which agree with other studies addressing the costs of membrane bioreactors. In addition, the proposed system tends to be competitive in producing reclaimed water, since the cost of its treatment is considerably below the amount charged for the drinking water in the region concerned.

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Introduction

Membrane bioreactor (MBR) technology consists of the combination of the classic wastewater treatment process of conventional activated sludge and the physical process of membrane separation (Judd and Judd 2011). MBR operation delivers advantages related to the high quality of the generated effluent and the consequent opportunity to perform water reuse. Also, the technology allows for operation with higher sludge ages and effluents with elevated suspended solid concentrations, resulting in reduced sludge production and its required disposal and necessary building areas (Metcalf and Eddy 2003; Le-Clech 2010; Kootenaei and Aminirad 2014).

However, despite the reported advantages, Judd (2017) points out that the main discussion regarding the application of MBR in wastewater treatment is not related to its efficiency, but in fact to the costs inherent in the process. The author also observes that, among the numerous possible approaches for raising and categorizing the expenses linked to an enterprise, the distinction between implementation (CAPEX—Capital Expenditure) and operation (OPEX—Operational Expenditure) costs is often employed. The information yielded by this methodology is often confronted with economic data regarding activated sludge technology, facilitating comparative analysis (Young et al. 2012; Iglesias et al. 2017; Judd 2017).

The number of scientific studies related to MBR cost estimation matches the lack of economic data about the technology. Judd (2017) conducted a bibliometric study on the main topics addressed in researches related to MBR and found that only 0.5% of the documents published between 2001 and 2016 addressed marketing and cost issues. Also, existing information on membrane bioreactor costs is reported inconsistently, unevenly, and without periodicity (Pirani et al. 2012; Judd 2017). Thus, the lack of credibility and availability of such data is harmful in ascertaining the economic viability of this technology (Verrecht et al. 2010).

Given the lack of information about this subject, it is necessary and relevant to expand knowledge about MBR, combining studies regarding their efficiency and operation with research that considers the economic viability of real-scale deployment for different situations and locations. In the Brazilian scenario, research of this nature is scarce. Thus, a greater emphasis in this field of knowledge would help, for instance, in the decision-making process regarding the type of sewage treatment applied in a given situation, as well as in the increase of Reclaimed Water Producing Plants (RWPP), which represent a promising alternative to current water crises (Dalri-Cecato et al. 2019).

In this regard, Life Cycle Cost Analysis (LCCA) emerges as a relevant tool to assist in accounting for the costs of environmental technologies. Rebitzer et al. (2003) highlight LCCA as an essential tool to introduce an economic point of view in decision-making processes concerning projects of environmental interest, such as choosing which type of treatment to apply in a Wastewater Treatment Plant (WWTP). Also, it is relevant to mention the studies of Dhillon (2010), who applies LCCA to a waste treatment plant, in addition to the works conducted by Koul and John (2015) and Bhoye et al. (2016), both of which address applications of LCCA in WWTP.

In this context, this study aimed to apply LCCA methodology as an aid to the survey and discussion of CAPEX and OPEX data from an MBR designed to be implemented in Santa Catarina/Brazil, addressing the production of reclaimed water.

Methodology

This research follows the methodology and principles presented by Dalri-Cecato et al. (2019). The following topics feature the criteria considered during the design and cost assessment of the evaluated membrane bioreactor.

Membrane Bioreactor

Cost simulation was performed considering an aerobic MBR designed to operate in a continuous flow regime, located in the state of Santa Catarina/Brazil, serving a population of 50,000 people. The arrangement chosen consisted of membrane modules submerged in a filtration tank separated from the biological system, as indicated by Metcalf and Eddy (2014). The implementation of a pre-denitrification step was considered in the project to reduce the effects of eutrophication and clogging during reuse practice (Von Sperling 2005; Marecos and Albuquerque 2010). Furthermore, an equalization tank was designed, enabling stabilization of incoming flow, reducing costs concerning the acquisition of membrane modules necessary to meet peak flow rates (Metcalf and Eddy 2014; Judd and Judd 2011).

LCCA of the MBR

Survey and cost assessment of the proposed MBR followed the principles of the LCCA methodology. The models proposed by Dhillon (2010), Koul and John (2015), and Bhoye et al. (2016) were adapted to address the situation of this study adequately.

CAPEX

The proposed MBR CAPEX survey considered the main contributors to the cost of installing membrane bioreactors, characterized by land acquisition (Judd 2017; Young et al. 2012), membrane acquisition (Judd 2017), and construction-related expenditures (Young et al. 2013), as presented in Eq. 1:

$$CAPEX = M + L + CC \quad (1)$$

In which:
M—membrane acquisition costs;
L—land acquisition costs;
CC—construction costs.

OPEX

The contributors to MBR operation cost considered in the OPEX calculation were energy consumption, periodic membrane replacement (Young et al. 2013; Iglesias et al. 2017; Judd 2017), employee's payroll (Young et al. 2012, 2013), and waste sludge management (Lo et al. 2015), as presented in Eq. 2. Data was compiled to represent the annual cost of operation.

$$OPEX = E + MR + P + SD \quad (2)$$

In which:
E—energy costs;
MR—periodic membrane replacement costs;
P—employee's payroll costs;
SD—sludge disposal costs.

Results and Discussion

Membrane Module

The membrane module chosen to compose the proposed MBR was Zeeweed 500D-370 from Suez Water Technologies & Solutions, with hollow-fiber and inward-flow characteristics, specially designed for use in MBR. Table 1 presents the module's main characteristics.

The application of Cassette 48M was predicted in order to organize the modules in the filtration tank. Produced by the same company, the chosen cassettes include the components necessary for membrane aeration distribution. Table 2 presents relevant information concerning 48M Cassette.

Table 1 Zeeweed 500D-370 membrane module characteristics

Parameter	Value
Material	PVDF
Nominal pore size (μm)	0.04
Length (m)	0.049
Height (m)	2.198
Width (m)	0.844
Volume (m^3)	0.091
Filtering area (m^2)	34.4

Source SUEZ (2016)

Table 2 48M cassette characteristics

Parameter	Value
Length (m)	2116
Height (m)	2561
Width (m)	1745
Volume (m^3)	9456

Source SUEZ (2017)

Membrane Bioreactor

The proposed MBR sizing followed the procedures presented by Dalri-Cecato et al. (2019).

Table 3 presents the main design parameters used to size the evaluated MBR.

Table 3 Project parameters for the proposed MBR

Input parameter	Value
Contributing population	50.000 inh.
Per capita water consumption	150 L/inh d
Sewage return rate	0.8
Average sewage flow (Q_{avg})	6.060 m^3 d^{-1}
Infiltration flow	1% Q_{avg}
Average BOD_5 concentration affluent to the biological tank	300 mg/L
Average COD concentration affluent to the biological tank	600 mg/L
Average TNK concentration affluent to the biological tank	45 mg/L
Affluent BOD load	1.818 kg/d
Sludge age	40 d
VSS concentrations in the biological tank	10 g/L

Table 4 Treatment units and respective dimensions

Treatment unit	Effective volume (m^3)	Height (m)	Surface area (m^2)
Biological tank	1.530	4.5	340
Equalization tank	945	4.5	210
Anoxic tank	387	4.5	86
Membrane tank	189	3.0	63

Table 5 Dimensions and operations of the filtration tank

Parameter	Value
Number of modules	375
Number of cassettes	8 + 1
Operation/Relaxation (min/min)	9/1
Critical flux (L/m^2 h^{-1})	25
Operation flux (L/m^2 h^{-1})	21
Volume (m^3)	189
Surface area (m^2)	63
Width (m)	3
Length (m)	21
Height (m)	3

Table 4 presents the main treatment units and their respective dimensions.

Table 5 synthesizes essential information about the dimensions and operation of the filtration tank.

CAPEX

Membrane Acquisition

Given the membrane module chosen, its supplier was contacted in order to collect data concerning the technology's cost. It was possible to obtain information regarding the market value of its square meter of filtering area (7 \$ ft^{-2} or 75.35 \$ m^{-2}, in July 2018), as well as the proportion between the purchase cost of the membrane modules and cassettes (70% and 30%, respectively, in August 2018), considering a fully populated 48M module.

Table 6 presents cost data per square meter of filtering area, proportions of values between modules and cassettes, as well as additional relevant information regarding the purchase of membranes required for the proposed MBR. Since the chosen product

Table 6 Summary of costs related to membrane acquisition

Parameter	Value
ZW 500D	75.35 $.m^{-2}[a]
Membrane cost/total cost	70%[b]
Cassettes cost/total cost	30%[b]
Number of MBR modules	375
MBR total membrane area	12.900 m^2
Membranes customs value	$971980.17
Cassettes customs value	$469882.99
Exchange rate	4.0687[c]
Converted membranes' customs value	R$3954695.72
Converted cassettes' customs value	R$1.911.812,90
Total converted customs value	R$5866508.62

Source [a]Contact with supplier in July 2018
[b]Contact with supplier in August 2018
[c]USD to BRL exchange rate (PTAX) in 08/27/2018 (BCB 2018)

Table 7 Taxes charged over membranes acquisition

Tax	Rate (%)	Value (R$)
II	14	821311.21
IPI	8	535025.59
PIS	2	123196.68
COFINS	10.65	624783.17
ICMS SC	17	1632578.67
Total taxes		3736895.31

must be imported, it is necessary to consider the taxes levied on NCM 84219999 (Brazil 2018b), considering the destination of the purchase in the state of Santa Catarina (1996), as presented in Table 7.

Furthermore, membrane installation costs were set as 10% of the total converted customs value, as indicated by Young et al. (2013), totaling R$586650.86. The final membranes acquisition cost, considering acquisition of modules and cassettes, taxes, and installation, was R$10190054.79 or 203.80 R$.inh^{-1}.

Land Acquisition and Civil Construction

The survey of land acquisition and construction costs considered data from historical and statistical series obtained from the Brazilian Institute of Geography and Statistics (IBGE).

Table 8 presents data related to the average cost of one square meter for Santa Catarina in 2018.

Table 8 Average land acquisition cost in Santa Catarina (SC)

Month (2018)	Average land cost in SC (R$.m^{-2})
January	1200.63
February	1207.52
March	1212.15
April	1211.98
May	1210.22
June	1228.70
Average	1211.87

Source IBGE (2018a)

Table 9 Building materials cost in SC

Month (2018)	Building materials cost in SC (R$.m^{-2})
January	562,92
February	569,81
March	571,22
April	571,05
May	571,23
June	576,06
Average	570,38

Source IBGE (2018b)

The purchase of an area equivalent to 0.15 m^2 inh^{-1} was considered in the calculation (Iglesias et al. 2017), resulting in 7.500 m^2 of land necessary for the installation of the proposed MBR. This yields a cost of R$9089.000, equivalent to 181.79 R$.inh^{-1}.

The construction cost, characterized by the sum of expenditures on building materials and labor, was estimated in the station's constructed area. Compiled historical data on average building materials and labor costs are presented in Tables 9 and 10, respectively.

Table 10 Average labor cost in SC

Month (2018)	Average labor cost in SC (R$.m^{-2})
January	637.71
February	637.71
March	640.93
April	640.93
May	638.99
June	652.64
Average	641.49

Source IBGE (2018c)

A constructed area of 2.036 m^2 was estimated, taking into consideration the sum of the surface areas of the treatment units presented in Table 4, in addition to a 30% margin for the construction of supplementary WWTP facilities. In this context, the costs related to the acquisition of construction materials and labor were calculated to be R$1161430.16 or 23.23 R$.inh^{-1} and R$1306213.14 or R$26.12 inh^{-1}, respectively. Therefore, the total cost of construction estimated was R$2467643.30 or 49.35 R$.inh^{-1}.

CAPEX Summary

Table 11 presents the summary of costs related to the proposed MBR CAPEX, including absolute and relative costs.

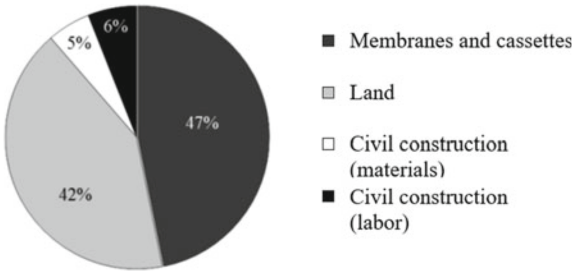
The estimated CAPEX of R$3588.56 m^{-3}d or 434.93 R$ inh^{-1} is consistent with surveys conducted by Iglesias et al. (2017) at MBR stations in Spain, that analyzed the costs of MBR compared to extended aeration activated sludge and other reuse water production technologies. According to the authors, the CAPEX of stations with a capacity between 5000 and 10,000 m^3 d^{-1} operating with (a) extended aeration activated sludge; (b) activated sludge with subsequent coagulation, sand filters, and disinfection; (c) activated sludge followed by membrane filtration; and (d) MBR is equivalent to 600, 715, 1030, and 960 € m^{-3}d, respectively. Moreover, the authors point out the influence of WWTP capacity on deployment costs, highlighting CAPEX values for flows between 1000 and 2000 m^3 d^{-1} to be around 420–650 € inh^{-1}, while for installations above 10,000 m^3 d^{-1} the cost is reduced to 94 € inh^{-1} due to the economy of scale.

The most significant individual contribution to the proposed MBR CAPEX was related to the acquisition of membranes and cassettes (47%), similar to the result found by Verrecht et al. (2010) (46.9%). The second most significant portion of CAPEX was related to land acquisition, representing 42% of the total value. Construction costs were relatively low, equivalent to 6% for hiring labor and 5% for acquiring construction materials, totaling 11%, while other surveys estimated contributions between 33 and 35% (Verrecht et al. 2010; Young et al. 2013). However, a better representation of this parameter can be achieved by increasing the cost of civil

Table 11 CAPEX summary for the proposed MBR

Parameter	Absolute cost	Relative cost	
CAPEX	(R$)	(R$.$inh^{-1}$)	(R$.$m^{-3}$d)
Membranes and Cassettes	10190054.79	203.80	1681.53
Land	9089000.00	181.78	1499.83
Construction materials	1161430.16	23.23	191.66
Labor	1306213.14	26.12	215.55
Total CAPEX	21746698.09	434.93	3588.56

Fig. 1 Individual contribution of CAPEX parameters



construction to consider the transportation of materials and soil, earthmoving, foundations, projects, and hiring of other employees required for the construction of the WWTP.

Figure 1 displays the distribution of the contributions of each evaluated CAPEX parameter.

OPEX

Energy Consumption

Studies show that for optimized MBR systems it is possible to achieve energy consumption values between 0.4 and 0.6 kWh m^{-3}, with perspectives of consumption reduction due to new research findings (Itokawa et al. 2014; Xiao et al. 2014; Iglesias et al. 2017; Judd 2017; Krzeminski et al. 2017). In this context, the total energy consumption of 0.5 kWh m^{-3} was adopted for the proposed MBR.

The determination of the adopted kWh cost took into consideration the rates charged by CELESC (Santa Catarina's energy enterprise) for projects related to sanitation. Thus, Group A, subgroup A4—Water, Sewage, and Sanitation's blue hourly peak hour rates were considered, characterizing the most unfavorable scenario for this type of consumer. Under these circumstances, the charges amount to R$0.45593485/kWh, in addition to the incidence of 25% ICMS (CELESC 2018), which is the tax applied to the movement of goods and services.

Hence, it was possible to estimate an annual electricity cost equal to R$635020.59 or R$0.29 m^{-3}. However, it should be noted that the rates charged by energy companies vary according to availability and demand, and for this reason, more advantageous electricity costs can be achieved.

Periodic Membrane Replacement

Total membrane replacement was considered to take place after ten years of operation (Cote et al. 2012), to be conducted with the same cost as the purchase and installation

Table 12 Salary for WWTP operators in SC

	Value (R$)	
Company		Source
SAMAE Orleans	2979.07	SAMAE ORLEARNS (2018)
VISAN Videira	2306.55	VISAN (2018)
SAMAE Blumenau	1180.32	SAMAE BLUMENAU (2018)
SAMAE São Bento do Sul	2912.58	SAMAE SÃO BENTO DO SUL (2018)
SAMAE Urussanga	2822.83	SAMAE URUSSANGA (2018)
Results		
Average Gross Salary	2440.27	
Taxes	1708.59	
Total per month per employee	4148.46	
Total per year for 4 employees	199126.03	

of original membrane modules considered in this project. It should be noted that this is a one-off operating expense, that for comparison purposes it was diluted over the lifetime of the station (considered to be 20 years), resulting in an annual cost of R$392317.11 or R$0.18 m^{-3}.

Cost of Employees

Table 12 presents the results obtained from the salary survey conducted to estimate the cost of employees, characterized by the payment of the WWTP operators. The surveyed payments refer to the year 2018. 70% of taxes were considered in addition to the actual salary, which must be paid by the employer.

A team of four operators was considered for the proposed WWTP (Young et al. 2012). Thus, the estimated annual cost with employees was R$199126.03 or R$0.09 m^{-3}.

Sludge Disposal

The cost of sludge disposal in landfills was calculated by collecting data regarding the unit costs for sludge management, annual generation of sludge (in tons), and total yearly sludge disposal cost of ten WWTPs operated by the Santa Catarina Water and Sanitation Company (CASAN), as shown in Table 13.

Table 13 WWTP sludge disposition costs in SC

WWTP	Unit cost (R$/ton)	Tons (ton/year)	Annual cost (R$)
Insular	218.64[a]	10.020	2190772.80
Canasvieiras		3.854	842638.56
Lagoa da Conceição		360	78710.40
Araquari Centro	281.00	158	44398.00
Canoinhas	329.00	150	49350.00
Indaial	267.00	100	26700.00
Braço do Norte	298.00	180	53640.00
Criciúma	247.00	2.700	666900.00
Laguna	350.00	220	77000.00
Chapecó	340.00	840	285600.00
Weighted average	232.25		

Source CASAN (2018a, b)
[a]Transportation costs not included

Given the adopted sludge age (40 days), a sludge disposal of approximately 43 m^3 d^{-1} or 430 kgTSS d^{-1} was estimated. Considering centrifugal dewatering, with 95% solids captured and 20% solids concentration in the sludge disposed (Andreoli et al. 2007), a sludge production of approximately 727 tons/year was stipulated, equivalent to R$168847.33/year or R$0.08/m^3.

OPEX Summary

Table 14 presents the summary of costs related to the proposed MBR OPEX.

The estimated OPEX of R$0.63/$m^3$ or R$2.10/kg of removed BOD is in line with studies carried out by Iglesias et al. (2017). According to the authors, the OPEX of stations with a capacity of 5000–10,000 m3d^{-1} operating with (a) extended aeration activated sludge; (b) activated sludge with subsequent coagulation, sand filters, and

Table 14 OPEX summary for the proposed MBR

Parameter	Absolute cost	Relative cost
OPEX	(R$/year)	(R$/$m^3$)
Energy consumption	635020.59	0.29
Periodic membrane exchange	392317.11	0.18
Employees	199126.03	0.09
Sludge disposition	168847.33	0.08
Total OPEX	1395371.64	0.63

disinfection; (c) activated sludge followed by membrane filtration; and (d) MBR amounts to 0.22, 0.31, 0.40, and 0.32 €/m^3, respectively, including the expenditure on sludge disposal. The authors also indicate values between 0.5 and 18 €/kg BOD when evaluating the OPEX of the studied MBR.

The WWTP energy consumption represented 46% of the operating costs, while other studies indicate contributions around 27–34% (Lo et al. 2015), 41% (Iglesias et al. 2017) and 79.6% (Verrecht et al. 2010). The cost relative to periodic exchange of membranes agrees with studies performed by Lo et al. (2015), representing 28% of the contribution.

The proposed MBR operators' payment represented 14% of OPEX, similarly to that estimated by Young et al. (2013) (15%). Lo et al. (2015) mention participation percentages equal to 14; 5.6 and 2.8% for stations of different dimensions. Brepols et al. (2010) show values of 24%, considering a capacity related to 10,000 people.

Finally, sludge disposal represented 12% of OPEX, being lower than the data presented by Iglesias et al. (2017) (16%), Verrecht et al. (2010) (17.9%), and Brepols et al. (2010) (21%). It is noteworthy that the cost assessment performed in this study included the classic form of sludge disposal (landfill). However, alternative options to dispose this waste may be considered, such as agricultural use, composting or anaerobic digestion.

Figure 2 displays the distribution of the contributions of each evaluated OPEX parameter.

The OPEX cost of R\$0.63/m^3 of treated effluent is considerably below the rates applied in Santa Catarina for drinking water, where for uses with consumption greater than 10 m^3/month in industrial, public, and micro and small commerce categories, one must pay R\$10.7866/m^3 (CASAN 2018a, b). This result is in line with the research conducted by Young et al. (2013) which highlights the competitiveness of MBR with activated sludge technology for situations where high nutrient removal rates are required, or reuse is desired.

It is important to emphasize that the costs of transport and chlorination should be considered when performing water reuse, which would increase OPEX. However, the transport of reused water to the desired location increases the overall OPEX by 0.02 to 0.04 €/m^3 (Iglesias et al. 2017), and chlorine disinfection represents less than 3% of total costs of operation (Verrecht et al. 2012). Therefore, the application of

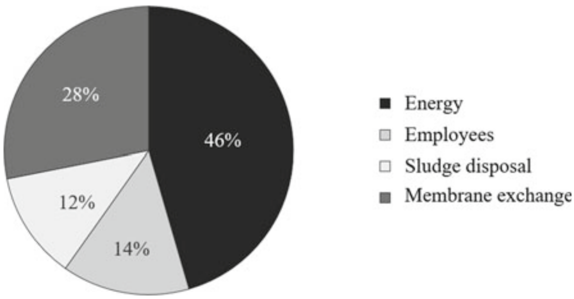


Fig. 2 Individual contribution of OPEX parameters

MBR in reclaimed water production in Santa Catarina presents itself as an attractive choice, both from an economic and environmental point of view, since the state has industrial centers distributed in different regions, as well as public and commercial demands for water.

Final Remarks

The survey of the implementation costs for the proposed MBR presented CAPEX values equal to R$3588.56/m^3 d^{-1} or R$434.93/inh., which agree with other studies addressing the costs of the same technology. The most significant individual contribution to CAPEX is related to the acquisition of membranes and cassettes (47%), followed by land acquisition (42%) and civil construction (11%).

The results obtained from the survey of operating costs also agreed with data found in the literature, presenting values equivalent to R$0.63/m^3 or R$2.10/kg of removed BOD. The most considerable individual contribution to the system's OPEX was characterized by energy consumption (46%), followed by periodic membrane exchange (28%), employee payment (14%) and sludge disposal (12%). Finally, results showed that the proposed system is competitive concerning the production of reclaimed water, as its OPEX is considerably lower than the price for drinking water in the studied region.

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Chapter 13 Evaluation of the Reduction Potential of Pollutant Emissions by Implementing the Start-Stop System in the Internal Combustion Vehicle Fleet of the City of São Paulo, Brazil

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Abstract The Brazilian transportation sector accounts for almost half of the carbon dioxide emissions in the country, and more than 90% of these emissions come from ground transportation. In 2017, Brazil had approximately 97 million vehicles, with 7.8 million in the city of São Paulo, the majority of which were powered by internal combustion engines. Due to CO_2 reduction emission goals, many countries have plans to extinguish combustion vehicles by 2040. The start-stop system, a cheaper technology, became a trend in the hybrid vehicle market with the purpose of reducing fuel consumption and thereby reducing pollutant emissions. The São Paulo Traffic Engineering Company (CET) annually publishes the Volume and Speed Report that presents the characteristics of the São Paulo city traffic. The São Paulo State Environment Company (CETESB) publishes annually the Fleet Vehicle Emissions Report and its data. Using these public data, the present work performed a bottom-up analysis to evaluate the reduction potential of pollutant emissions for the city of São Paulo by changing the lightweight vehicle fleet to include start-stop system vehicles. This study obtained a reduction potential factor of total emissions between 12.3% and 13.8%, and a CO_2 emission reduction potential for São Paulo of 1,338,341 annual tons.

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Introduction

Since the industrial revolution, air pollutants have increased yearly. There is evidence that increasing CO_2 concentration in the atmosphere may increase the planet's average temperature, thereby causing climate changes. In 2016, the Brazilian transportation sector accounted for 45.3% of the country's CO_2 emissions. São Paulo State vehicles emitted 40.29 million tons of CO_2 (EPE 2016; CETESB 2017).

Automobiles, trucks and motorcycles usually use internal combustion engines as its driving power; conversion efficiency is restricted by thermodynamic laws, since it converts chemical energy from fossil fuel or biofuel into mechanical energy in an irreversible way (ANFAVEA 2018; Spiro 2009).

In recent years, the automotive industry has undergone many changes due to new technologies available. In 2017, countries such as Germany, France, England and China had set targets for the extinction of internal combustion engines in their fleet by 2040 (Teixeira and Calia 2013; The Economist 2017).

Hybrid-Electric Vehicles (HEV) became an alternative to reduce fuel consumption and pollutant emissions; they avoid losses while the vehicle is stopped by shutting down the engine (Reynol 2007; Wills 2008).

Hybrid vehicles use more than one driving power. The HEV have both a combustion engine and an electric motor. It has several levels of hybridization, varying according to their ability of performance improvements (Bosch 2005; Ehsani et al. 2010).

Plug-in hybrids can connect to the electric grid to recharge its batteries. The off-grid hybrids recharge their batteries exclusively from the combustion engine's alternator, and the lowest level of hybridization is the start-stop system that shuts down the engine when it is not necessary, acting only at the start of the vehicle (Ehsani et al. 2010). However, in cities such as São Paulo, where vehicles remain standstill for long periods of time, such a system has great potential for reducing both fuel consumption and pollutant emissions (Bishop et al. 2007; Fonseca et al. 2011).

The start-stop system is activated when the vehicle is at standstill, the driver has the foot on the brake and does not the press clutch or accelerator, the car is in neutral gear, and the battery level may be enough to turn on the engine. The engine is turned down, being ready to restart in approximately 350 μs. Once the engine is turned down, the emissions and fuel consumption are ceased too, which allows one to infer that each stopping situation offers an opportunity to reduce emissions, since burning fuel during stops does not provide power to move the vehicle (Verzimiassi 2012).

Several manufacturers have already adopted the start-stop system by installing a button in the vehicles that allows for easy activation. In Brazil, brands such as Fiat, Renault, Chevrolet and Volkswagen have classic lines equipped with the start-stop system. In addition, the implementation of this system in non-hybrid vehicles is possible.

Some authors found increases in the overall vehicle efficiency of around 15% along with a reduction in CO_2 emissions. Other studies showed that this technology is capable of reducing only 2% of fuel consumption. Considerations of each author varied considerably, such as the period of time the vehicle remained stationary, making the comparison difficult (Bosch 2005; Ehsani et al. 2010; Melo et al. 2018).

Energy consumption and CO_2 emissions are directly connected because the energy sector is based on fossil fuels. Road transportation is the largest energy consumer in the transport sector, amounting to 93.7% of total energy consumption.

Several countries have adopted measures to reduce greenhouse gas emissions (GEE). The Copenhagen Accord, signed in 2009, established targets for reducing GEE between 5% and 45% by 2020 in several signatory countries. In Brazil, Law 12,187/2009 sets a reduction between 36.1% and 38.9% by the year 2020 (EPE 2016; Wills 2008; Vonbun 2017; Brasil 2009).

According to November, 2017 data from the Brazilian National Transit Department (DENATRAN), of the 96,790,495 vehicles in Brazil, 52,769,600 were automobiles, 2,716,258 trucks and 21,548,767 motorcycles. In addition, 47.14 million vehicles of the Brazilian fleet were located in the southeast region, 7,805,127 in the city of São Paulo, with 5,442,775 being automobiles (IBGE 2017; DENATRAN 2017).

The mobility of public roads in São Paulo is reported annually by the São Paulo Traffic Engineering Company (CET) in a report called the São Paulo Main Roads Mobility (MSVP). It presents average speeds, average delay time and traffic volume in segments of each main street. The 2016 report issued in July, 2017 with on-site data collection according to Board 13.1 methodologies, indicated an average delay (percentage of travel time with vehicle stopped) of 25% between 7 a.m. and 10 a.m., and 31% between 5 p.m. and 8 p.m. (CET 2017).

Based on the above scenario, this work aimed to evaluate the potential for reducing emissions of air pollutants by analyzing the modification of São Paulo's internal combustion fleet to vehicles equipped with the start-stop system.

Board 13.1 MSVP 2016 measurement methodology

Measurement	MSVP 2016—measurement methodology
Travel time	Global Position System (GPS) (latitude, longitude, every second) Route maps and GPS points reads in QGIS and Mapinfo
Total delay	Stops deducted from GPS points (grouping of points - speeds up to 4 km/h)
Traffic light delay	Stopped time duration records (with stopwatch) and stopped time (according to the GPS clock)
Traffic delay	Calculated by the difference between the total delay and the traffic light delay

Source Author

Methodology

The potential for reducing the atmospheric emissions of personal vehicles in the city of São Paulo was estimated from public databases and reports. The atmospheric pollutants included in the analysis were carbon monoxide (CO), non-methane hydrocarbons (NMHC), methane (CH_4), nitrogen oxides (NO_x), aldehydes (RCHO), particulate matter (PM), carbon dioxide (CO_2) and nitrous oxide (N_2O). Calculations of annual pollutant emissions were carried out on the current fleet of São Paulo, based on the same calculation done by the São Paulo State Environment Company (CETESB). The emission of pollutants from the same fleet in periods of shutdown based on the CET 2016 MSVP report (CET 2017) was also estimated, which informs the average retardation percentage (mean time in which vehicles remain stopped at intersections or congestions of the total time in transit) in the city of São Paulo.

Databases

Information was used from available databases of the CETESB for light-duty vehicles fueled by gasoline or ethanol and three types of engines: gasoline, ethanol and flex-fuel. Therefore, pickups, vans, motorcycles and heavy vehicles were not considered. The databases use weighted average values, which made it possible to calculate values without needing to distribute the power ranges of vehicles. It also presents the current phase of the Air Pollution Control Program for Automotive Vehicles (PROCONVE) and serves as a reference of maximum permitted emission values.

Emission Factor

The 2016 database presents information on how much a vehicle emits per type of pollutant per kilometer as defined in NBR 6601 ABNT (2012), conducting the test controlling temperature, atmospheric pressure and humidity, and using the driving cycle Federal Test Procedure 75. The data is segmented by year and type of fuel used. The values for vehicles named Gasoline/Gasoline type C and Flex-Gasoline/Flex-Gasol.C all consider the mixture of 78% of gasoline and 22% of anhydrous ethanol as standard fuel, according to Law 10,203 (Brasil 2001); the names differ because of the fuel for which the vehicle was designed. Gasoline type C is regulated by Law 13,033 (Brasil 2014), which establishes the mixture of 72.5% of gasoline and 27.5% of anhydrous ethanol. Vehicles named flex-ethanol refer to flex-fuel vehicles using hydrated ethanol as fuel; however, given the lack of information regarding the use of hydrated ethanol compared to gasoline, all flex-fuel vehicles in this analysis were considered using Gasoline type C.

Table 13.1 shows the pollutant's emission factors for the years 2015 and 2016 per year of manufacture and type of vehicle. It also presents the PROCONVE phase,

Table 13.1 Emission factors for new lightweight vehicles

Year	Fuel	PROCONVE Phase	CO (g/km)	NMHC (g/km)	CH_4 (g/km)	NO_X (g/km)	RCHO (g/km)	PM (g/km)	CO_2 (g/km)	N_2O (g/km)	Vehicle Range (km/l)
2015	Gasoline	L6	0.171	0.012	0.005	0.022	0.0015	0.001	187	0.020	11.7
2015	Flex-Gasoline	L6	0.221	0.017	0.004	0.015	0.0013	0.001	167	0.018	13.2
2015	Flex-Ethanol	L6	0.357	0.055	0.025	0.016	0.0076	ND	157	0.017	9.3
2016	Gasoline	L6	0.244	0.015	0.004	0.013	0.0011	0.001	162	0.020	13.6
2016	Flex-Gasoline	L6	0.249	0.018	0.003	0.013	0.0009	0.001	159	0.018	13.8
2016	Flex-Ethanol	L6	0.363	0.049	0.028	0.013	0.0065	ND	151	0.017	9.7

ND data not available
Source CETESB (2017)

Table 13.2 Active lightweight fleet in the city of São Paulo in quantity and type of fuel

Manufacturing year	Vehicles (Gasoline)	Vehicles (Ethanol)	Vehicles (Flex-fuel)
2016	15,178.8	0.0	151,556.1
2015	25,149.8	0.0	187,366.0
2014	16,915.1	0.0	209,672.8
2013	18,671.5	0.0	229,655.6
2012	23,548.9	0.0	230,669.8
2011	33,042.4	0.0	211,868.4
2010	20,420.5	0.0	221,646.5

Source CETESB (2017)

which is the autonomy in kilometers per liter of fuel. The database presents the annual average between 1982 and 2016. The L6 phase of PROCONVE began in 2014 and is the sixth stage focused on light vehicles.

Active Fleet in São Paulo State

The information presented is related to the vehicles that transit in several cities of the São Paulo State. The data was separated by type of vehicle, volume of vehicles circulating for each manufacturing year between 1976 and 2016 and volume for each city in the São Paulo State.

Table 13.2 presents the active fleet in the city of São Paulo, considering only light vehicles, and lists them by production year and type of fuel used for the years 2000 to 2016. Production of vehicles purely fueled by ethanol was discontinued in 2006 through the inclusion of flex-fuel vehicles in the national fleet, which began in 2003.

Use Intensity

The following data shows how much a vehicle travels on average per year. The values presented in 2016 are the same values included in the 2014 and 2015 databases available on the CETESB website (CETESB 2017).

Table 13.3 shows the values in kilometers for each type of fuel and years of vehicle use, between 0 and 40 years. The vehicles are separated annually in three types of fuels: gasoline, ethanol and flex-fuel.

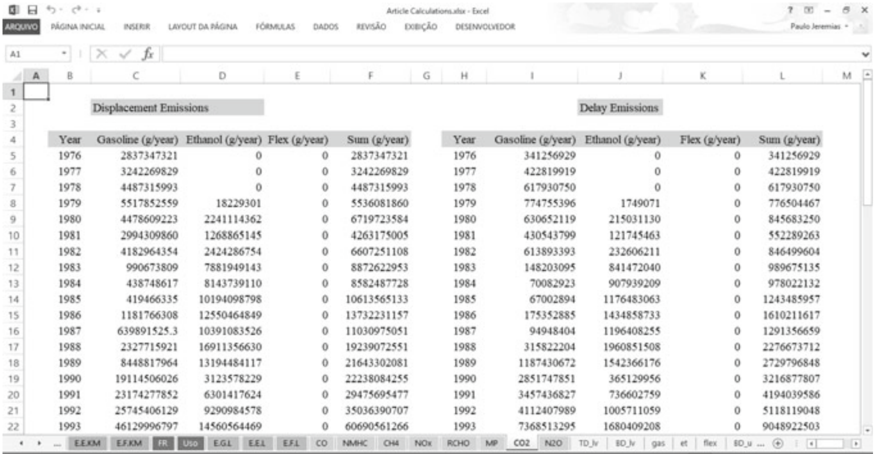
The databases were selected and copied to an excel workbook created by the author. In this workbook, the three databases presented the same structure, separated by the type of fuel used and the manufacture year.

Figure 13.1 shows a screenshot of the worksheets. The sum columns in the visible tab show the calculations for the CO_2 emissions presented in grams of pollutant per year.

Table 13.3 Reference usage intensity

Years of use	Gasoline vehicles (km/year)	Ethanol vehicles (km/year)	Flex-fuel vehicles (km/year)
0	5998	ND	8610
1	11,997	ND	17,220
2	12,632	ND	15,968
3	13,177	ND	15,277
4	13,635	ND	15,001

ND data not available
Source CETESB (2017)



Displacement Emissions

Year	Gasoline (g/year)	Ethanol (g/year)	Flex (g/year)	Sum (g/year)
1976	2837347321	0	0	2837347321
1977	3242269829	0	0	3242269829
1978	4487315993	0	0	4487315993
1979	5517852559	18229301	0	5536081860
1980	4478609223	2241114362	0	6719723584
1981	2994309860	1268865145	0	4263175005
1982	4182964354	2424286754	0	6607251108
1983	990673809	7881949143	0	8872622953
1984	438748617	8143739110	0	8582487728
1985	419466335	10194098798	0	10613565133
1986	1181766308	12550464849	0	13732231157
1987	639891525.3	10391083526	0	11030975051
1988	2327715921	16911356630	0	19239072551
1989	8448817964	13194484117	0	21643302081
1990	19114506026	3123578229	0	22238084255
1991	23174277852	6301417624	0	29475695477
1992	25745406129	9290984578	0	35036390707
1993	46129996797	14560564469	0	60690561266

Delay Emissions

Year	Gasoline (g/year)	Ethanol (g/year)	Flex (g/year)	Sum (g/year)
1976	341256929	0	0	341256929
1977	422819919	0	0	422819919
1978	617930750	0	0	617930750
1979	774755396	1749071	0	776504467
1980	630652119	215031130	0	845683250
1981	430543799	121745463	0	552289263
1982	613893393	232606211	0	846499604
1983	148203095	841472040	0	989675135
1984	70082923	907939209	0	978022132
1985	67002894	1176483063	0	1243485957
1986	175352885	1434858733	0	1610211617
1987	94948404	1196408255	0	1291356659
1988	315822204	1960851508	0	2276673712
1989	1187430672	1542366176	0	2729796848
1990	2851747851	365129956	0	3216877807
1991	3457436827	736602759	0	4194039586
1992	4112407989	1005711059	0	5118119048
1993	7368513295	1680409208	0	9048922503

Fig. 13.1 Print screen of worksheet used for data manipulation. *Source* Author

The road system considered in the 2016 Mobility Report of São Paulo City Main Roads System (CET 2017) had 28 routes chosen in a non-random manner and classified by operational and historical criteria. In operational criteria, the human resources' restrictions make it impossible to perform studies of all the roads at the same period of the year. The system considers both directions, neighborhood to center and center to neighborhood, and covers a total of 220 linear kilometers of roads.

- The Volume and Speed Report (CET 2017) presented average speed and average idle time of the main road system, being the average speed given in kilometers per hour as the average of three samples from the same route at similar times. The average idle time is calculated by dividing the sum of time with vehicle stopped by the total time of the route traveled, considering stopped when the GPS points collected were very close to each other with an average speed between points less than 4 km/h.

Figure 13.2 presented the speed tree and the stratified idle tree for each period

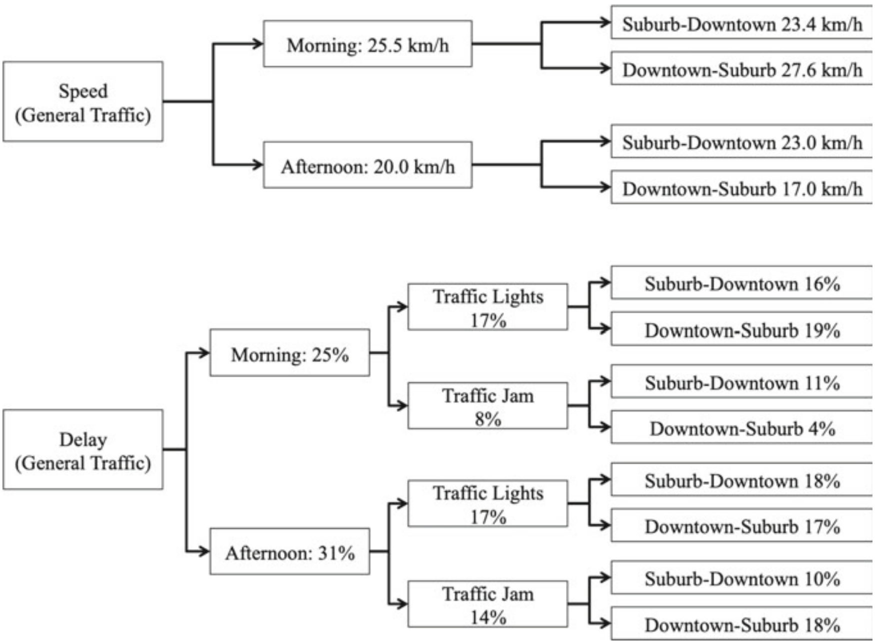


Fig. 13.2 MSVP 2016 traffic speed and delay. *Source* CET (2017)

and flow direction. It also stratified the values in idles caused by traffic lights and by traffic jam.

Yearly Vehicle Emission Calculation

Pollutant particles were calculated and then summed up to establish the emissions of pollutants for São Paulo State. Equation 13.1 gives the yearly vehicle emissions of each pollutant:

$$\frac{gP}{km} \times \frac{km}{year \cdot vehi} = \frac{gP}{year \cdot vehi} \tag{13.1}$$

The gP/km is the emission in grams of pollutant per kilometer from database Emission Factor (CETESB 2017). The term km/(year*vehi) is the average distance of a vehicle for one year originating from the database Use Intensity (CETESB 2017). The result determined the value emitted in grams of pollutant by a vehicle during a year.

To improve the emission estimation model for a city such as São Paulo, the consumption was considered to be at standstill. Equation 13.2 considers periods at standstill and in movement, which included the consumption of the vehicle at idle time.

$$\frac{gP}{km} \times \frac{km}{year \cdot vehi} + \frac{gP}{hour} \times \frac{km}{year \cdot vehi} \times \frac{1}{speed} \times \%Delay = \frac{gP}{year \cdot vehi} \tag{13.2}$$

In Eq. 13.2, before the sum symbol, the term represents the value calculated in Eq. 13.1. After the sum symbol, the hourly emissions of a vehicle resulted in grams of pollutants emitted per year per vehicle. The equation considered the emissions due to the displacement of the vehicle and the emissions due to the stopped vehicle time.

Investigated Fleet Annual Emissions Calculation

The Fleet Database of São Paulo State provided information on the fleet characteristics (CETESB 2017). The average distance traveled by a car, considering the years since its purchase, was obtained from the Intensity of Use and Emission Factor databases (CETESB 2017).

Equation 13.3 shows the emissions segmented in groups by year of manufacture. The sum of the annual emission of all groups according to their respective intensity of use and emission factor results in the total emissions per year.

$$\sum_{n=0}^{40} \frac{gP_n}{km} \times \frac{km_n}{year \cdot vehi} \times vehi_n + \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%Delay = \frac{gP_{fleet}}{year} \tag{13.3}$$

Calculations of Yearly Potential Reduction of Pollutant Emissions by the Start-Stop System

Equation 13.4 includes the annual emission reduction potential of the fleet emission, resulting in a value of grams of pollutant per year which could be reduced during idle periods.

$$\sum_{n=0}^{40} \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%delay = \frac{pot.red.gP}{year} \tag{13.4}$$

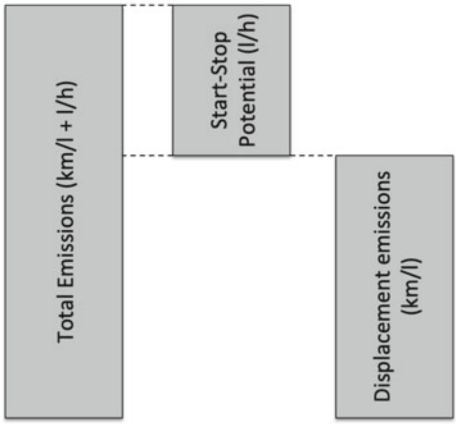


Fig. 13.3 Potential reduction of pollutant emissions gap by the start-stop system. *Source* Author

Calculated emissions can be divided by the kilometers driven and the idle periods. Figure 13.3 shows the potential to reduce emissions through the start-stop system, which does not operate in terms of kilometers per liter of fuel consumed because it operates only in a stopped situation, where there is no distance traveled for the consumption calculation.

Calculation of the Percentage of Potential Reduction of Pollutant Emissions of the Fleet

From the previous calculations it was possible to calculate the percentage relative to total emissions and to verify the potential reduction percentage of emissions (Eqs. 13.5 and 13.6), which allowed the analysis to remain valid regardless of the fleet size analyzed.

$$\frac{\sum_{n=0}^{40} \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%delay}{\sum_{n=0}^{40} \frac{gP_n}{km} \times \frac{km_n}{year \cdot vehi} \times vehi_n + \frac{gP_n}{hour} \times \frac{km_n}{year \cdot vehi} \times vehi_n \times \frac{1}{speed} \times \%delay} = pot\% \tag{13.5}$$

It can also be written in the following reduced form:

$$\frac{\frac{pot.red.gP}{year}}{\frac{gP_{fleet}}{year}} = pot\% \tag{13.6}$$

Calculation Considerations

In order for the databases to provide enough data for the calculations, the following assumptions were considered:

- The mean speed and lag values presented by CET for the main road system represents the whole city of São Paulo.
- The average consumption of a vehicle of the fleet under analysis is 1.098 L per hour. This value was obtained for an ordinary stopped vehicle (gasoline 2.0) from the Argonne National Laboratory (ANL 2018).
- The emission factor base (CETESB 2017) was used to obtain the emission data per stopped hour, multiplying the emissions per kilometer (gP/km) by the autonomy (km/l), obtaining the emission per liter of fuel. This was multiplied by the average fuel consumption of a halted vehicle (l/hour), and hourly emissions were obtained for stopped vehicles.
- Table 1 shows that the particulate matter emission factor has ND values (data not available) for ethanol. These values were changed to zero for calculation purposes, since there are no particulate matter emissions by burning ethanol.
- Data presented as ND in the CO_2 column in the Emission Factor database (CETESB 2017) were considered zero when it represented the absence of flex-fuel vehicles (before 2013) or the extinction of vehicles purely powered by ethanol (after 2006). When the ND values represented an unrealized measurement due to the lack of measurements, but should have a real value, the last values of the nearest year were repeated in order to complete the missing fields.

Results and Discussion

The calculations were performed by equations in the previous sections and the results were obtained for the following pollutants: CO, NMHC, CH4, NO_X, RCHO, PM, CO_2, N_2O. The values in tons and percentage of pollutant reduction emitted during the year 2016, shown in Table 13.4, were obtained through Eqs. 13.1, 13.3 and 13.4. Columns 1 to 4 show the type of pollutant, the total emissions, emissions caused by displacement and the emissions caused by delays. The fifth column presents the potential percentage of emission reduction and was calculated by Eq. 13.5.

In Fig. 13.4 the total emissions and the reduction potential of Table 13.4 are shown graphically for absolute values, sorted by bigger volumes to the smaller volumes, in a logarithmic scale to be able to visualize the magnitude difference between CO_2 and the other pollutants. The markers show the value in percentage in a linear scale.

Among the pollutants considered, there is a greater focus on the potential reduction of CO_2 emissions as it is the main contributor of greenhouse gas emissions. However, the potential reduction of other pollutants could be also interesting, such as PM, which has an impact on the air quality that affects citizens' health.

Table 13.4 Tones of pollutant emitted yearly and respective reduction percentages found by calculations

Pollutant	Total emissions (t/year)	Displacement emissions (t/year)	Delay emissions (t/year)	Emissions reduction potential (%)
CO	48959.6	42865.1	6094.5	12.4
NMHC	5119.9	4474.2	645.7	12.6
CH_4	1368.9	1193.2	175.7	12.8
NO_X	5865.0	5117.6	747.4	12.7
RCHO	270.9	237.6	33.3	12.3
PM	62.4	53.8	8.6	13.7
CO_2	10172427.2	8784086.1	1388341.0	13.6
N_2O	1085.0	935.5	149.5	13.8

Source Author

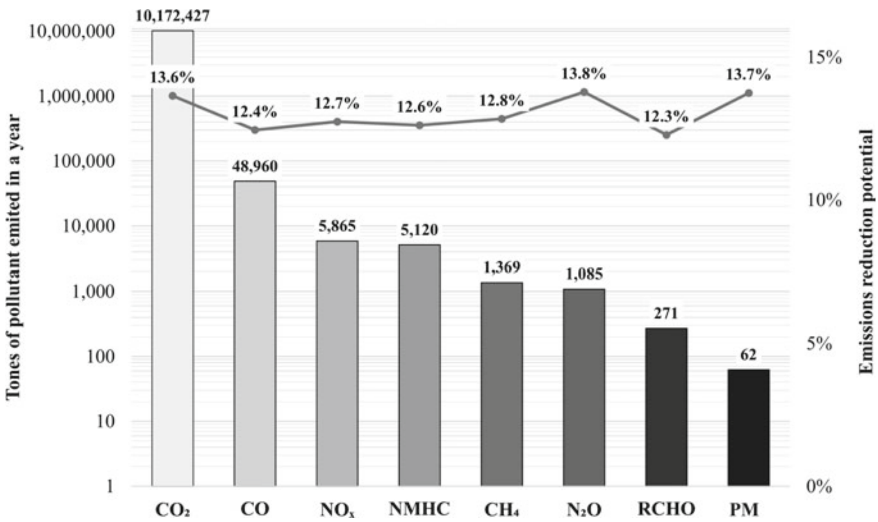


Fig. 13.4 Yearly pollutant emissions and emission reduction potential by pollutant. *Source* Author

No previous study evaluating the potential impact of the start-stop system on the fleet of São Paulo has been found, except for a few studies related to the reduction of pollutant emissions through the start-stop system in Brazil. Da Silva (2013) was the only source that analyzed the emission reduction by the start-stop system. Verzimiassi (2012) evaluated the start-stop operating system and identified the possibility of reducing emissions through the works of Fonseca et al. (2011).

The percentages found in this study are potential and characterize the limit of opportunity for the start-stop system. In simulation, Tsokolis et al. (2016) found a reduction of CO_2 emissions between 2.5% and 4.8% for a turbine medium-sized gasoline vehicle driving the New European Driving Cycle (NEDC). Fonseca et al.

(2011) measured the CO_2 in a diesel vehicle exhaust and found a reduction of 20% in CO_2 emission with the start-stop system switched on compared to the system being turned off.

Verzimiassi (2012) showed that the start-stop system generally reduces 6% of CO_2 emissions, reaching 8% in urban traffic and up to 25% in heavy traffic. Da Silva (2013) found a reduction in CO_2 emissions of 12.8% for the New York City Cycle (NYCC) and 10.1% for the Japanese 10–15 cycle, both testing a diesel vehicle with the start-stop system turned on and off. These authors also tested out-of-laboratory fuel consumption in real traffic situations on Ontario's streets and found a 7% reduction when comparing 1,500 km with the system switched on to 1500 km driven with the system shut down. The CO_2 reductions obtained were almost identical to the percentage reduction in consumption, obtaining 12.7% for the NYCC and 10.1% for the Japanese 10–15.

Differences between reduction potentials for different cycles may be caused by the time at stop situation that each cycle considers. The FTP-75 considers short periods stopped. The NEDC and Japanese 10–15 consider longer stops compared to the FTP-75. The NYCC is based on heavy traffic with long downtime, characteristic of big cities.

Routes studied could also interfere in the results. The routes inspected in the MSVP are characterized by main roads which have fewer intersections, which leads to the belief that adjacent roads have a bigger delay index that could increase the reduction pollutant potential.

Despite vehicle emissions being reduced significantly due to the implementation of the PROCONVE strategies, the imposed targets do not specify how the emissions reduction should occur. However, the need to continue reducing emission factors makes it natural for the market to look for other possibilities besides increasing the engine's efficiency.

To ensure maximum emission limits, the start-stop system has been used even for high power vehicles due to the reduced fuel consumption. However, the global outlook points to the extinction of combustion vehicles, which shows the start-stop system as a transitional technology to the hybrid, leading to the belief that advances in fuel cells and electric vehicles will be responsible for the disuse of combustion vehicles.

Effects of Considered Values

Some values used in the calculations were based on assumptions; how each of the values of these assumptions influenced the final result was verified. A variation of the consumption at standstill, 1.098 L per hour, changed exclusively the delay emissions and presents a direct linear relation: if the consumption at standstill doubles, the delay emissions will double. However, the potential percentage will increase, but not necessarily in the same proportion because it also depends on consumption displacement. The same occurred with the delay percentage increase and with the average speed reduction.

Conclusion

It was concluded that the start-stop system presents relevant potential for reducing vehicular emissions in the city of São Paulo once potential reduction values between 12.3% and 13.8% were found. The efficiency of the transportation sector is a critical factor in achieving the greenhouse gas emissions reduction targets because the sector contributes greatly to global CO_2 emissions.

More studies are needed to increase the accuracy of these work results since no experimental studies were found which test the start-stop system performance in the city of São Paulo. It is believed that more samples of diverse routes, beyond the 28 routes from MSVP, would allow one to obtain more accurate values for speed and delays of São Paulo city traffic, and that data from applications such as Waze and Google Maps could improve accuracy results.

In addition, technical and economic studies are required to obtain costs of implementing the start-stop system and the possible return on investments that can be generated by the inclusion of the system in the fleet of lightweight vehicles.

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Chapter 14
Environmental Justice as a Tool for Dealing with Climate Change Impacts on Food Security in Brazil in the Context of WEF Nexus

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Abstract Water, energy and food are essential resources for human security. Therefore, synergies among these resources are essential to promote food security. Food security refers to the state of everyone, everywhere, having access to sufficient, safe and nutritious food at all times, which relies on the stability of food prices, international markets, food policies and the climate. The effects of climate change in Brazil threaten food security in the country, particularly due to the excessive reliance on rainfed agriculture and subsistence farming, which requires sustainable adaptation policies to manage this scenario. From the social sciences' debates on sustainable policy-making, the concept of Environmental Justice refers to marginalized groups that are more exposed to harmful environmental impacts and do not benefit equally from positive environmental regulations and policies, consequently being placed in a scenario of greater food insecurity. In this regard, this study promotes a review of the literature to investigate the relations and possibilities of considering environmental justice concepts in food security decision-making in Brazil. Including the most vulnerable people in the decision-making process is a crucial tool to promote

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an effective approach for sustainable development, reducing the unintended effects of climate change on water, energy and food resources, essential for everyone's wellbeing.

Introduction

Alongside water and energy, food production is an essential resource for human existence and development (Cordell et al. 2009). Climate change, population growth and mismanagement of water, energy and food (WEF) resources trigger food insecurities, which demonstrates the need to understand food security as a complex phenomenon (Lal 2010). Thus, the term food security emerges as a new global paradigm to be chased by policy makers.

At first, the term "food security" was linked to a country's ability to provide sufficient food to meet the needs of its own population. The Food and Agriculture Organization (FAO 1996) defined that "food security exists when all people at all times have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." Further elaborated, the concept of food security was defined as the access of all people to sufficient food to live a healthy and productive life (Pinstrup-Andersen 2009), and comprises four key dimensions of food supply: *availability*, *stability*, *access* and *use* (Schmidhuber and Tubiello 2007).

Among these pillars, stability influences the entire food security structure. Stability is the temporal factor that affects all other food security pillars, making it essential for ensuring access, availability and use of safe food (Silva et al. 2018). For the French Agricultural Research Center for International Development (CIRAD 2016) the concept of stability for food security permeates the other three pillars, ensuring that they are stable at all times. The possibility of risk to food access due to economic crises, and especially in current times due to climate change scenarios, demonstrates the importance of the stability pillar for global security (Amorim et al. 2018).

The impacts of climate change on food security are profound as they directly alter the agroecological environment, affect the individuals' abilities to use food effectively, and impact food supply stability, price and access to food (Schmidhuber and Tubiello 2007; Liverman and Kapadia 2012). Thus, policy efforts aimed at climate change and food security should be integrated with the understanding that actions for both fields are interdependent, as "climate change is one of a range of threats to food security and interventions designed to increase general food system resilience are highly likely to contribute to climate change adaptation" (FAO 2012, p. 79).

The environmental justice (EJ) concept refers to marginalized groups that are more exposed to harmful environmental impacts and do not benefit equally from positive environmental regulations and policy (Legarda and Buendia 2011). Considering environmental justice principles in policy making is an essential tool to guarantee a more just and sustainable society, in order "to bring people affected by damage—in this case climate damage—closer to the process of making political decisions that directly affect them, and also to the process of dealing with conflicts originated from those damages, establishing itself as an inclusive justice" (Silveira et al. 2018, p. 263).

Climate change has a direct influence on WEF resources, because it pressures ecosystems and increases the competition among the WEF uses. Due to its dependence on agribusiness and hydropower, Brazil faces many challenges regarding economic, environmental and social development. These challenges requires comprehensive public policies to adapt to climate changes, aimed at mitigating the negative impacts on production and management of WEF sectors. The consequences of these impacts affect vulnerable groups, and their recognition, distribution and participation are required for policy planning in order to guarantee inclusive adaptation policies. Therefore, this study aims to investigate: *by embedding the concept of environmental justice in the formulation of Brazilian public policies for food security, what contributions are possible in the context of adaptation to climate changes*?

Environmental Justice

The EJ concept was first introduced in a context marked by struggles for the recognition of civil rights, between the 1950s and the 1980s (Legarda and Buendia 2011), based on a quest for social justice, struggling against racism and poverty (Roberts 1998). Mohai et al. (2009, p. 406) cite that

> environmental justice studies emerged as an interdisciplinary body of literature, in which researchers were documenting the unequal impacts of environmental pollution on different social classes and racial/ethnic groups. Today, hundreds of studies conclude that, in general, ethnic minorities, indigenous persons, people of color, and low-income communities confront a higher burden of environmental exposure from air, water, and soil pollution from industrialization, militarization, and consumer practices. Known variously as environmental racism, environmental inequality, or environmental injustice, this phenomenon has also captured the attention of policy makers.

According to Maroko (2012, p. 533) "EJ describes a scenario where specific populations (e.g. racial and ethnic minorities, less educated populations, lower income populations) bear the burden of increased exposure to environmental pollutants […] when compared to other populations." Pearce and Kingham (2008), Todd and Zografos (2005) and Mitchell and Norman (2012) help construct this concept by adding that the study of environmental justice is aimed at addressing the concerns and the promotion of an even distribution of environmental risks. Accordingly, a society that is environmentally just is a society where risks and resources are equally distributed through its population.

In order to change these unequal and unsustainable patterns, environmental justice investigates ways to include the communities most susceptible to environmental threats in the planning and decision making processes, thereby adjusting the disproportionality to which they are exposed, giving them a voice and increasing their authority in those management processes (Shilling et al. 2009). In order to achieve such inclusion, environmental justice authors propose a trifold approach, which involves: (I) the principle of distribution (equitable allocation of rights and responsibilities); (II) the principle of participation or procedural justice (role of affected individuals in decision-making); (III) the principle of recognition (acknowledgment of the diversity of each individual from affected communities) (Reese and Jacob 2015).

Participation is an essential factor to promote environmental justice. Schlosberg (2004, p. 537) already recognized the need for political recognition and participation of the most vulnerable groups in environmental planning, citing that "demands for the recognition of cultural identity and for full participatory democratic rights are integral demands for justice as well, and they cannot be separated from distributional issues."

Therefore, environmental justice is also accomplished through governmental regulations, policies and actions which take into account the fair distribution of negative environmental risks as well as the environmental benefits (Bullard and Johnson 2000). In this regard, the EJ concept "takes into account not only the environment and promoting the reduction and prevention of pollution and other degrading factors, but also aspects of social justice, throughout a process which increases participation and inclusion, regardless of ethnicity, class, gender, economic and social power, etc." (Silveira et al. 2018, p. 256).

Food Security and Stability

Food production has been changing significantly in recent years, due to climate change and growing food demand. Therefore, ensuring food security for all is a global challenge, particularly in developing countries (Berchin et al. 2019).

The Rome Declaration on World Food Security (FAO 1996) considered poverty as the major cause of food insecurity; therefore, poverty eradication is essential to improve access to food. Poverty causes food insecurity, hunger and malnutrition, leading to poor physical and cognitive development, which may result in low productivity that perpetuates poverty (FAO 2008). Hence, considering that poor people spend a great part of their income on food, famine and food insecurity may result from poverty and the lack of access to financial resources (Bickel et al. 2000; Holden and Ghebru 2016).

The Rome Declaration on World Food Security (FAO 1996) argued that: "food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life." In this regard, despite their inability to intervene in liberal and global markets, national authorities play a key role in ensuring global food security by handling food production between large producers and smallholders, ensuring sustainability patterns and social inclusion (Oosterveer et al. 2014; Shete and Rutten 2015).

There are four main aspects of food security (FAO 2006, p. 1): (1) availability (sufficient quantities of food of appropriate quality); (2) access (access by individuals to adequate resources (entitlements) for acquiring appropriate foods for a nutritious diet); (3) utilization (utilization of food through adequate diet, clean water, sanitation and health care to reach a state of nutritional well-being where all physiological needs are met); and (4) stability (access to adequate food at all times).

These aspects are interconnected and affected by climate change, which challenges global food security by affecting food production (particularly impacting small scale producers due to their lack of resources) and distribution, increasing poverty, inequality and malnutrition (Nelson et al. 2012; Rowhani et al. 2011; Lobell et al. 2011; Faria et al. 2016).

Food stability is critical to maintain and promote food security; it represents "the temporal dimension of food security and includes both the likelihood of experiencing shocks and the ability to recover from them" (Alonso et al. 2018). Food stability is threatened by unexpected shocks (e.g. conflicts, biological, climatic and economic crisis) or cyclical events (e.g. seasonal food insecurity) (FAO 1996; Walls et al. 2019; Berchin et al. 2019; Brück and d'Errico 2019). Therefore, resilient food systems are required to improve food security. The use of innovative technologies and methods coupled with comprehensive policies and capacity building can boost food production and support sustainable and resilient food systems.

Climate change is expected to increase food insecurity worldwide, both in the long term (i.e. through changing temperatures and precipitation patterns) and short term (i.e. through the intensification of extreme weather events), particularly affecting low-income people (FAO 2008; Rowhani et al. 2011; Lobell et al. 2011; Faria et al. 2016). Global climate change has different impacts worldwide, particularly affecting agricultural activities in places where adaptation is not well implemented and in regions which rely on rain-fed agriculture and local resource security (Waongo et al. 2015; Reed et al. 2013; Vervoort et al. 2014; McKune et al. 2015; Misra 2014). Supportive policies for climate change adaptation are necessary at the community and household level to increase resilience and promote development (Vermeulen et al. 2012).

Climate Change Impacts on the Wef Nexus in Brazil

Climate change is a natural phenomenon that represents a change of the climate, which is accelerated by anthropogenic actions and can be analyzed over comparable time periods (UNFCCC 1992, p. 7). Brazil is facing harsh impacts of such changes, mainly because of its fragile and diverse ecosystems (Rong 2010) that are unlikely to be able to adapt to expected new climate patterns (Lucena et al. 2010), particularly considering current policies and the expansion of the agribusiness.

The Amazon region is one of the most vulnerable regions to such impacts (Hirata and Conicelli 2012). Fearnside (1995) and Hirata and Conicelli (2012) state that droughts are forecasted for the region, which would cause grave environmental, social and economic impacts, particularly on small farmers (Szlafsztein 2014). Another impact in the region in a scenario of severe climate changes is the deforestation that would increase by 20% due to the increased needs for irrigated land for agriculture and livestock production (Lapola et al. 2011).

As for the northeastern region of Brazil, which is already characterized by high temperatures and irregular rainfall patterns (Cunha et al. 2014), there is also a risk of large scale migration of its population to other regions due to the predicted climate extremes (Fearnside 1995; Barbieri et al. 2010). The predicted changes involve lower rainfall levels, higher temperatures (Roland et al. 2012) and severe droughts (Fearnside 1999), which depreciate water and food supply (Confalonieri et al. 2014). Such vulnerabilities in the northeast affect diverse products from the agribusiness: soybean production which suffers from rising temperatures (Lucena et al. 2010), sugarcane, which suffers from lower rainfall levels (Carvalho et al. 2015) and the decrease in milk production due to the lack of nutrition for animals (Silva et al. 2009).

Southern Brazil also suffers the impacts of climate changes (Hirata and Conicelli 2012). The intensification of precipitation patterns and extreme weather events affects food production and reduces the period favorable to some crops (Walter et al. 2014; Figueiredo 2013; Marengo 2008); the region experiences an increase in the frequency and intensity of rainfall levels (PBMC 2014) and temperature increases affecting soybean, rice, corn and wheat production (Alberto 2006; Walter et al. 2014).

In the southeast, climate changes have both positive and negative effects on production. Marandu grass production will benefit from a warmer climate (Andrade et al. 2014). However, shifting rainfall will be detrimental to sugarcane production (Santos and Sentelhas 2012). Coffee production will also be drastically reduced due to considerable temperature increases, restricting production to a few municipalities (Assad et al. 2004).

The Brazilian midwest should suffer from long periods of extreme events, such as long extreme rains or drought years (Marin and Nassif 2013). Like the northeast, the region expects an increase in temperature that will decrease its soybean and coffee production capacity (Lucena et al. 2009; Assad et al. 2004). In the midwestern wetlands, the effects can be seen in the La Plata Basin region, which is of extreme importance to world food supply; the region is in danger of reducing its production capacity (Vasconcelos et al. 2014).

On energy matters, Brazil as a whole will suffer from severe temperature increases and reductions in annual rainfall (Falloon et al. 2007). Such changes in the temperature patterns affect the yields and harvests of vegetables used in biofuel production (Lucena et al. 2009), such as the production of sugar cane that generates ethanol, which is affected by rainfall shortages (Carvalho et al. 2015). As the main energy matrix in Brazil, hydroelectric power could lose reliability due to long periods of drought (Borba et al. 2012; Engle and Lemos 2010).

Another possible impact on food production is the increased demand for water in perennial crops (Gondim et al. 2009), which would require efficient and extensive irrigation structures and technologies throughout the Brazilian territory, increasing the costs for production. Future water availability and precipitation rates also vary depending on the location of Brazilian states, such as possible droughts in eastern

Amazonia, the transformation of the northeast semi arid status to an even more arid scenario, and a systematic increase in rainfall in the south (Marengo 2008).

Therefore, despite the fact that Brazil has a large territorial extension, no part of the country is free from the many different manifestations of climate change, affecting mainly the most vulnerable groups, such as people with lower incomes who are exposed to greater risks and hold fewer resources to adapt to such impacts (Burney et al. 2014; Obermaier et al. 2009; Ribeiro 2010). For adaptation, knowledge of these vulnerabilities is essential in order to understand the risk scenarios and plan for adaptation (Nobre 2010).

Discussion

From the standpoint of the environmental justice concept, the literature also recognizes inequalities in the share of risks and resources when it comes to the effects of climate changes. "Climate change reflects and increases social inequality in a series of ways, including who suffers most its consequences, who caused the problem, who is expected to act, and who has the resources to do so" (Mohai et al. 2009, p. 420). Considering that climate changes impacts are distributed unevenly throughout countries, regions and individuals, a scenario of environmental injustice is evident.

When focusing on vulnerability to climate change, it could be defined as the degree in which the systems, or parts of the systems, are susceptible to the impacts of climate change, such as climate variability and extreme events (Bizikova et al. 2009). In order to decrease such vulnerabilities and create a scenario of greater justice in different climate conditions, climate and environmental justice concepts seek a "fairly straightforward polluter pays models (based on historical responsibility), fair share models (based on the equal allocation of emissions), and various rights-based models (such as development rights, human rights, and environmental rights)" (Schlosberg 2012, p. 445).

Brazil is expected to suffer environmental, social and economic impacts caused by climate changes. These effects cause disorders on the production and management of WEF resources, causing both synergies and tradeoffs. The lack of water and the decrease of its quality, as well as the interferences in energy demand, quality and access, can have an impact on the security of such resources. When climate change affects water and energy, it consequently impacts food management, causing a scenario of harmful consequences of insecurity in production, distribution, access and utilization of food, provoked by instable climate patterns.

FAO alerts for instabilities in the Brazilian production of soybean, coffee, sugarcane, corn, rice and wheat, due to the reduction of the quality of the soil and the amount of land, water and energy available for production. "The projected decline in some important crops and livestock risks will have consequences on food security. The food supply could be reduced in quantity and variety, food prices would have to increase, and with it the increase of the population at risk of starvation[1]" (FAO 2019).

With such expectations of damage, it becomes essential for Brazil to invest in adaptation policies to help deal with future scenarios. According to Füssel and Klein (2006, p. 303), "adaptation primarily aims at moderating the adverse effects of unavoided climate change through a wide range of actions that are targeted at the vulnerable system."

Some communities are more exposed to severe insecurity than others, either because they have lower access to WEF or financial resources or because they are exposed to greater risks (such as climate change). The most vulnerable groups include (a) the most poor and the less educated (Maroko 2012),who hold less access to technology and resources for adaptation, (b) smallholder farmers (Burney et al. 2014; Obermaier et al. 2009; Ribeiro 2010), who also have less access to modern adaptation tools, (c) racial minorities (Maantay and Maroko 2009, Jones et al. 2014) and (d) women (Terry 2009; FAO 2011; Silva 2018), who are already placed in a scenario of social, political, economic and environmental disadvantages that can be aggravated because of climate changes. Brazil also adds a regional issue to the vulnerability of its poorest communities: the most affected regions by climate change are usually the ones that have the smallest amount of natural, financial and technological resources to promote development, such as the north and northeastern regions (Hirata and Conicelli 2012).

While environmental justice proposes changes in resource distribution to help these recognized vulnerable groups dealing with risks, it also highlights the need for political change when proposing the principle of participation. In this regard, in order to achieve environmental justice in the context of climate change, the most vulnerable groups should be recognized, have equal access to risk and resources, and have participation channels that allow them to have their needs heard in policy making.

Consequently, besides investing time and resources in the mitigation of damages caused by climate change, Brazil should also plan for policies to recognize the location and population of who is exposed to such risks, in order to understand and evaluate the needs and expectations of the most vulnerable groups. Adaptation policies planned with the engagement of everyone who is influenced by its effects are able to "bridge environmental justice, climate justice, and social justice for the vulnerable more generally" (Schlosberg and Collins 2014, p. 368).

Considering that "vulnerability is intrinsic to households, but can be reduced when there is a legal, institutional and political context aimed at strengthening livelihoods"[2] (FAO 2019), efficient policy making can be an essential tool for Brazil for adapting to the impacts of climate change, particularly on food security.

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[1] "La disminución que se proyecta en algunos cultivos importantes y los riesgos sobre la ganadería tendrán consecuencias sobre la seguridad alimentaria. La oferta de alimentos podría reducirse en cantidad y variedad, los precios de los alimentos habrían de aumentar, y con ello también la población en riesgo de sufrir hambre".

[2] "La vulnerabilidad es intrínseca a los hogares, pero puede reducirse cuando hay un contexto legal, institucional y político orientado a fortalecer los medios de vida".

In a country filled with diversities and inequalities such as Brazil, policies for adaptation for food security cannot be effective if they do not involve different perspectives coming from different groups of risk. As Silveira et al. (2018, p. 263) state, "the most important element when planning for climate change adaptation strategies is to consider the environmental justice principles. Otherwise, climate change adaptation will end up creating more inequalities".

Conclusion

This study intended a review on the role of environmental justice principles in adaptation policies to assure food security, even with the effects of climate changes on WEF resources. In this regard, this paper presented the essential need to recognize the groups and regions at risk, to balance the distribution of natural resources and technology to help these people dealing with the impacts of climate change, and to engage them in policy planning and management.

Involving the most vulnerable people in adaptation policy making is an effective way of keeping track of the needs and experiences of a population, enabling a government to perceive and deal with different realities happening in a country. This is no different in Brazil, where climate changes are expected to make food access, availability and utilization unstable after harmful impacts on water, energy, land demand and availability, climate (i.e. rising cases of droughts, shifts in rainfall patterns, inundations and landslides) and health conditions.

In Brazil, the most poor and less educated, the racial and ethnical minorities, women and smallholders are cited as the most vulnerable populations to climate changes and consequent food insecurity. Therefore, these people should be taken into consideration when managing policies that directly and indirectly affect them, in order to make adaptation planning a tool for promoting sustainability and equity. Accordingly, Brazil is expected to evolve in order to guarantee that policies for vulnerable people are not ruled exclusively by traditional owners of huge agribusinesses with great availability of wealth, technology, water, energy and land, who might not be as concerned with climate changes as those in greater danger and less power to deal with their impacts.

This paper finds its limitation in citing which are the programs and actions that can be planned in order to generate the involvement of vulnerable people in adaptation policy making. Considering the role higher education institutions carry in recognizing and involving vulnerable people through research and extension programs, a partnership amongst civilians, higher education institutions and governments would be an effective way of involving every interested part in policy making. This partnership is suggested as exploration in future research, with the aim of understanding the ways to involve all the affected people in integrated and interdisciplinary policies. Thus, governance for sustainable development requires the creation of effective and permanent communication tools for dialogue between local communities and other stakeholders.

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Chapter 15
Environmental Impacts of the Brazilian Energy Mix—An LCA Approach to Past, Present, and Future Scenarios

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Abstract The compositions of the world's energy mix undergo modifications over time. Fossil resource depletion and the high rates of greenhouse gases related to non-renewable energy-based matrixes influence adaptation processes. Under these circumstances, in 2007 the Brazilian Ministry of Mines and Energy (MME) published the National Energy Plan (PNE 2030), which directs the future development of the Brazilian electricity mix. Knowing that different energy sources generate different environmental burdens, the objective of this work was to characterize the potential impacts (e.g. greenhouse gases and land use) of the configuration of the Brazilian energy mix in the years 2005 (baseline), 2010, 2018, 2020 and 2030. Thus, it is possible to understand how the expansion of energy production influences the environmental impacts of the electrical sector. The impacts were evaluated through Life Cycle Assessment, employing the OpenLCA 1.9.0 software, and based on the ecoinvent 3.5 database alongside literature data. The current energy mix's impact is more significant than it was in 2005 (greenhouse gas emissions, for example, increased by approximately 20%). If the PNE 2030 projections are correct, the impact of the future Brazilian energy mix will be significant than it was in 2005, and as it is today. The main contributing factor to this situation is electricity production by biomass and natural gas. To reverse this scenario, more investments should be made in cleaner sources, especially in wind farms.

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Introduction

Coupled with the ongoing population growth comes the need to ensure access to electricity, and this is the function of Sustainable Development Goal #7, which aims to ensure affordable and reliable energy for all (UN 2017). Worldwide efforts to tackle energy insufficiency show positive results. The number of people without access to electricity fell to around 1 billion in 2016 (IEA 2018). Nearly 1.2 billion people have gained access to energy since 2000. However, despite positive developments, population growth and uneven progress mean that, based on current efforts, 600 million people will remain without access to energy in 2030 (IEA 2017).

To ensure energy availability, governments constantly review and adjust their electricity mix. The search for the best options leads nations to seek different paths to fulfill their energy demand. The rise of renewables, such as wind and solar energy, and other decentralization solutions describe the current scenario that governments face in the task to find better results in the electrical sector (UN 2018).

The main challenge faced by the energy sector is to create a system that combines affordability, reliability, and sustainability (IEA 2018). The current outline, when it comes to electricity production and supply, describes a rapidly evolving scenario undergoing a disruptive transformation that is fueled by decentralized renewable electricity generation (UN 2018). Since 2012, the new generating capacity driven by renewables has exceeded that of non-renewables by a widening margin (IRENA 2017). However, according to the World Energy Council (2019), the world electricity mix is still highly dependent on non-renewables. Global energy demand is still mostly being met by fossil fuels, with 30% coming from oil, 27% from coal and 20% from gas. The main sources of electricity production (in TWh) are carbon (38%), gas (23%) and hydroelectric (16%) (IEA 2018). As stated by the World Energy Council (2019), although fossil fuels remain an important part of the energy mix across the majority of future plausible scenarios, the rapid growth of renewables continues to be the key assumption in the shifting energy mix.

Brazil seems to be one step ahead in the race for a cleaner electricity mix. More than 80% of Brazilian electricity comes from renewables. Hydroelectric power is the main driver of the current framework, contributing to circa 65% of the energy supply (289 TWh) (MME 2007). The rise of wind power and other renewables has become substantial in the Brazilian energy mix. Wind energy, for example, contributed only 0.2% of the total electricity production in 2005. Against all predictions, wind energy grew exponentially during the last decade, composing circa 8% of the current Brazilian production (ANEEL 2019).

To develop flexibility and avoid setbacks, Brazil regularly reviews its electricity mix. The National Energy Plan (PNE 2030) directs the development of the Brazilian electricity sector by analyzing global trends and tracing projections for the next decades (PNE 2007). The document uses 2005 as a baseline and presents the energy scenarios for the years 2010, 2020, and 2030. Substantial shifts in the energy mix can be noticed through the projections. These alterations are reflected in different environmental trade-offs, which have to be explored to understand the environmental burden and real sustainability of the electricity sector in the race to achieve SDG 7.

Life Cycle Assessment (LCA) is the main methodology for the quantification of environmental indicators, compiling the inputs and outputs of a product or service and quantifying its potential impacts (Galindro et al. 2019; ISO 2006a). According to Elia et al. (2017), LCA is one of the most complete environmental assessment methodologies, as it includes several impact categories related to human health and consequences on the ecosystem and resources. The literature of energy-related LCAs is vast. It has been applied to evaluate the environmental burdens of coal power plants (Yu et al. 2019), wind turbines (Schreiber et al. 2019) and electricity generation options and technologies (Gagnon et al. 2002; Turconi et al. 2013). Based on the information hereby presented, this work aims to characterize the potential environmental impacts of the Brazilian energy mix by taking an LCA approach in the evaluation of the four scenarios present in the PNE 2030, plus the current Brazilian energy outline. The rationale enables a better understanding of how the expansion of the electricity mix influences the environmental impacts of the Brazilian energy sector.

Methodology

Considering that LCA was the environmental impact assessment methodology chosen to evaluate the Brazilian energy mix, this work follows the four phases defined by ISO 14040 (2006a): (1c Definition of goal and scope; (2) Inventory analysis; (3) Impact assessment; and 4. Interpretation of results. Steps 1, 2 and 3 will be described in this section. Step 4, since it is the analysis of results, will be presented in Section "Interpretation of the LCA Results".

Definition of Goal and Scope

Part of the first phase of LCA consists of defining the goal and audience of the study. The objective of this study was to evaluate the environmental impacts resulting from the expansion of the energy mix in Brazil. The main motivation is to understand how the incentives to develop a specific type of mix influence the environmental burdens of total electricity production. Finally, the target audience is the general community.

For the scope, ISO 14040 (2006a) presents a series of items that must be considered and described, which will be highlighted in the following: i. Product system's function: electricity production; ii. Functional unit: defined as the production of1 KWh; and iii. Impact assessment methodology: in this case, the ReCiPe 2016 (H) method (RIVM 2016) and the Cumulative Energy Demand method (PRé Consultants 2013) were selected.

In addition to the highlighted items, it is necessary to describe the scenarios taken into consideration here (Table 15.1). This paper initially presents five scenarios that were defined based on two documents of the Brazilian government: The National Energy Plan (EPE 2007) and the National Energy Balance (EPE 22019a). As previously explained, PNE 2030 outlined future scenarios at the time it was launched. The 2005 (baseline), 2010, 2020 and 2030 scenarios evaluated in this work follow the beforementioned document. A fifth scenario was defined by BEN 2019 (the base year 2018). The variations of these scenarios are nothing more than the variation in the composition of the national energy mix for the evaluated years.

Two assumptions were made for the constitution of the scenarios. In the first situation, PNE 2030 does not account for the energy generated through petroleum derivatives fuels. To pair with the BEN 2019 (which provides for these fuels), this class was added in this study.

For the second assumption, PNE 2030 divides the mix between public service and self-production. For PNE 2030, cogeneration is the most traditional form of self-production and consists of the simultaneous generation of thermal and electrical energy from the same primary energy source (usually biomass). Also, according to PNE 2030, the cogeneration market consists of the industrial segments that use large amounts of steam from biomass in the production of goods such as paper, cellulose, sugar, alcohol and food sectors, due to the large availability of by-products

Table 15.1 Defined scenarios (Brazilian energy mix compositions)

Category	2005	2010	2018	2020	2030
	(TWh)				
Public service	363.29	494.9	536.35	704.7	1022.3
Hydro	325.1 (80.65%)	395 (73.71%)	388.97 (65.06%)	585.7 (74.61%)	817.6 (70.87%)
Natural gas	13.9 (3.45%)	58.4 (10.90%)	54.62 (9.14%)	61.5 (7.83%)	92.1 (7.98%)
Nuclear	9.9 (2.46%)	15 (2.80%)	15.67 (2.62%)	30.5 (3.89%)	51.6 (4.47%)
Others*	8.2 (2.03%)	9.9 (1.85%)	14.42 (2.41%)	5.4 (0.69%)	12.5 (1.08%)
Coal	6.1 (1.51%)	13 (2.43%)	14.2 (2.37%)	15.6 (1.99%)	31.4 (2.72%)
Wind	0.09 (0.02%)	3.6 (0.67%)	48.47 (8.11%)	5 (0.64%)	10.3 (0.89%)
Waste	0 (0.00%)	0 (0.00%)	0 (0.00%)	1 (0.13%)	6.8 (0.59%)
Self-production (Biomass)**	39.8 (9.87%)	41 (7.65%)	61.55 (10.29%)	80.3 (10.23%)	131.3 (11.38%)
TOTAL	403.09 (100%)	535.9 (100%)	597.9 (100%)	785 (100%)	1153.6 (100%)

(wood waste and bark, bleach and black liquor, sugarcane bagasse, etc.). Accordingly, self-production and biomass were aggregated in the same class.

Inventory Analysis

Inventory analysis involves data collection to quantify the inputs and outputs of a product system. These may include the use of resources and emissions to air, water or soil that are related to the system. The inventory data is later used in the Life Cycle Impact Assessment (LCIA). Thus, to compose the inventory of this study, the process of 'electricity production' was created with the assistance of the database ecoinvent 3.5, balanced with the proportions in Table 15.1. The datasets used are shown in Table 15.2.

Table 15.2 Used datasets (ecoinvent)

Category	Dataset
Hydro	Electricity production, hydro, reservoir, tropical region| electricity, high voltage| Cutoff, S–BR
Natural gas[a]	Electricity production, natural gas, combined cycle power plant| electricity, high voltage| Cutoff, S–BR
	Electricity production, natural gas, conventional power plant|electricity, high voltage| Cutoff, S–BR
Nuclear	Electricity production, nuclear, pressure water reactor|electricity, high voltage|Cutoff, S–BR
Others	Electricity production, oil| electricity, high voltage| Cutoff, S–BR
Coal	Electricity production, hard coal| electricity, high voltage| Cutoff, S–BR
Wind	Electricity production, wind, 1–3 MW turbine, onshore| electricity, high voltage| Cutoff, S–BR
Self-production (Biomass)	Heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014| electricity, high voltage| Cutoff, S–BR
Waste	Treatment of digester sludge, municipal incineration, future| electricity, high voltage| Cutoff, S–CH

[a]Oil derivatives were allocated in this category
[b]Self-production and biomass were aggregated in the same category

Impact Assessment

The impact assessment phase aims to evaluate the significance of potential environmental impacts. This process associates inventory data with specific environmental impacts. The impact assessment may include the assigning of inventory data to impact categories (classification) and the modeling of the inventory data within impact categories (characterization). Specific software is used to conduct the classification/characterization processes. In this study, the OpenLCA 1.9.0 (Noi et al. 2017), an open-source LCA software, was used.

Two impact assessment methods were selected: ReCiPe 2016 (H) (at midpoint level) and CED. Considering that the aim of this study is focused on technological alterations of the Brazilian energy sector, the chosen LCA impact categories relate to impacts on land use (the 'Land use' impact category) and on food production (the 'Terrestrial acidification' category), as the increase of soil acidification may compromise soil productivity. Regarding energy, the method (and hence the impact category) applied was 'Cumulative Energy Demand.' Impacts on water quality were evaluated by the 'Freshwater ecotoxicity,' 'Freshwater eutrophication' and 'Water consumption' categories for water use. Finally, to assess the greenhouse gas generation, the impact category 'Global warming' was chosen.

Results and Discussion

The results section was divided into two parts; the first focuses on the analysis of the energy mix composition (related to the scenarios studied), while the second addresses the main objective of this work, which is to present the potential environmental impacts of the Brazilian energy mix through the LCA approach.

Evolution of the Energy Mix

Based on the previously established scenario, it was possible to elaborate Fig. 15.1 to highlight the historically renewable composition of the Brazilian energy mix (hydro in blue and biomass, which is basically sugarcane, in brown). Regarding the hydropower plants, the PNE 2030 (EPE 2007) stated that 70% of the Brazilian hydroelectric potential that was to be exploited was in the Amazon. This is proof that one of the PNE's directives has been consolidated with the implementation of the Belo Monte hydropower plant, which contributed to the addition of more than 11 MW in the Brazilian installed capacity (NORTE ENERGIA SA, 2019).

On the other hand, the PNE did not count on the substantial advance of the wind energy plants (in dark blue). According to data from the Brazilian Wind Energy Association (ABEEólica 2019), in 2018 alone, for instance, 75 new wind farms were

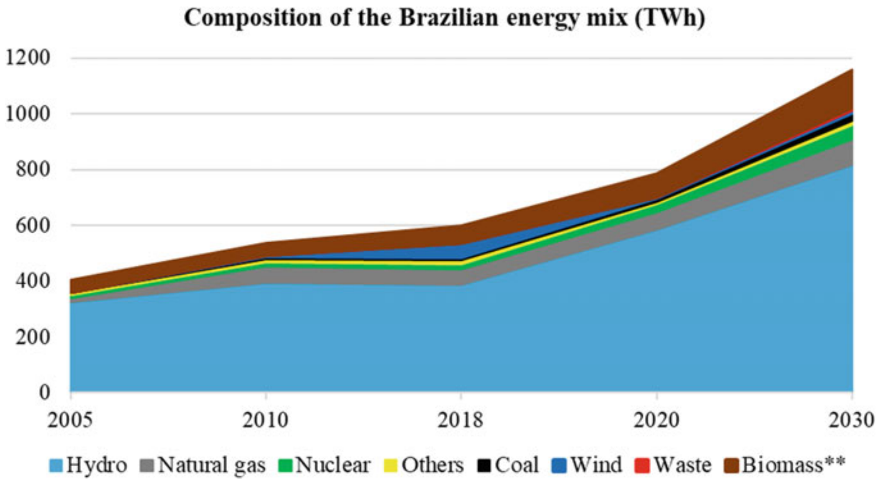

Fig. 15.1 Composition of the Brazilian energy mix

installed in Brazil. Also, since the launch of PNE 2030 (in 2005), the installed capacity has jumped from 27.1 to 14,707.5 MW, which represents an approximate average increase of 4200% per year. This situation limits the results of this study, as the future scenarios of 2020 and 2030 are likely to undergo some kind of change in composition as a result of the expansion of wind farms, and possibly solar plants. This alteration may influence the potential environmental impacts presented here. However, as shown next, the impacts of wind farms are small compared to other sources. Therefore, in the projected scenario, proportional impacts only tend to decrease (at least for wind farms).

Finally, in contrast to renewable sources, we highlight the expansion of the use of natural gas (in gray), a fuel that has received investments in recent years, mainly in infrastructure, with the evaluation or construction of new pipelines throughout Brazil. (EPE 2019b). Nonetheless, growth in natural gas use is welcomed when compared to oil or coal, which have higher greenhouse gas emission factors to provide the same energy as natural gas (IPCC 2006).

Interpretation of the LCA Results

According to ISO 14044 (2006b), interpretation is the phase of the LCA in which the findings from the inventory analysis and the impact assessment are combined. This combination aims to provide subsections so that the findings of the interpretation may take the form of conclusions and recommendations to decision-makers, consistent with the goal and scope of the study.

First, the potential environmental impacts of the Brazilian energy mix for the defined scenario concerning the previously selected impact categories are presented quantitatively (Table 15.3). For example, to obtain the defined Functional Unit (1 KWh) in the years 2005, 2010 and 2018, the table shows that 0.205, 0.219 and 0.242 kg CO_2 eq, respectively were emitted. Plus, if the PNE 2030 projections are confirmed in 2020 and 2030, the contribution of the Brazilian energy mix to 'Global warming' will be around 0.218 and 0.245 kg CO_2 eq, respectively.

To favor the interpretation process, the information in Table 3 was explored graphically. For this purpose, the year 2005 was defined as the baseline and the following years are presented with its related variation. Continuing with the example of 'Global warming,' by looking at Fig. 15.2 it can be noted that the impacts of the energy mix increased in comparison to the baseline. For the year 2018, it was almost 20% higher than in the base year. According to the PNE 2030 (EPE 2007) projections, the matrix's greenhouse gas emissions for 2020 should be similar to 2010. Also, the contribution to 'Global warming' in 2030 would be similar to that of 2018. However, following the growing trend, this is unlikely to happen.

Table 15.3 LCA results

Impact category	2005	2010	2018	2020	2030
Freshwater ecotoxicity (kg 1,4-DCB)	6.73E−03	5.58E−03	7.66E−03	7.39E−3	9.33E−03
Freshwater eutrophication (kg P eq)	3.25E−05	3.31E−05	3.93E−05	4.23E−05	7.16E−05
Global warming (kg CO_2 eq)	2.05E−01	2.19E−01	2.42E−01	2.18E−01	2.45E−01
Land use (m^2a crop eq)	9.55E−04	8.11E−04	1.07E−03	1.01E−03	1.18E−03
Terrestrial acidification (kg SO_2 eq)	3.02E−03	2.47E−03	3.24E−03	3.05E−03	3.46−03
Water consumption (m^3)	6.71E+00	6.13E+00	5.47E+00	6.24E+00	5.99E+00
CED Total (MJ)	4.44E+01	3.58E+01	4.64E+01	4.60E+01	5.08E+01

[a] According to Coelho (2014), 50% of Brazilian power plants are conventional and 50% are combined cycle, so both were used in the same proportion
As there is no such dataset adapted in Brazil, the Swiss dataset was used

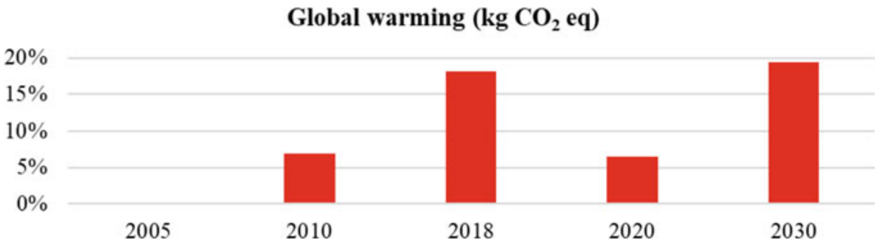

Fig. 15.2 CO_2 eq emissions to produce 1 KWh in the Brazilian energy mix

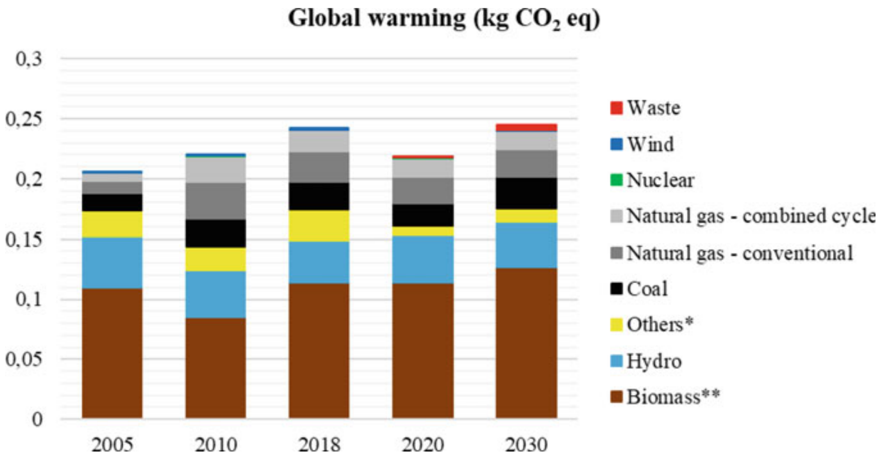

Fig. 15.3 CO_2 eq emissions in the Brazilian energy mix by type of production

To better understand the composition of CO_2 eq emissions presented in Fig. 15.2, the composition of the types of electricity production was elaborated in Fig. 15.3. It can be noticed that the main reason for the 2018 disparity, besides biomass, is the category 'Others,' in which, as explained in the methodology, the electricity production by oil derivates was included, contributing to the 'Global warming' potential of the category. Consistent emission growth can be identified from the baseline to 2030. That increase happens due to the expansion of biomass (9.87–11.38%) and natural gas (3.45–7.98%) use (Table 1). According to the datasets used in this study, these fuel options have a high emission of greenhouse gases. Energy production from biomass, for example, emits 1.52 kg CO_2 eq for every 1 kWh produced. As for natural gas, emissions are at the rate of 0.51 kg CO_2 eq for conventional cycle power plants, and 0.35 kg CO_2 eq for plants that work in a combined cycle.

Continuing the analysis of the impact categories, Fig. 15.4 presents categories related to land use, food production, and energy. It is possible to observe a trend amongst the three categories. The discussion, in this case, focuses on the 2010 scenario, which was the least impactful of all scenarios, including the baseline. The

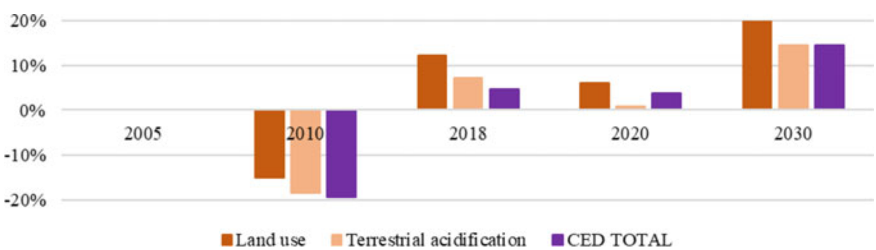

Fig. 15.4 Impacts on land use, acidification and CED in the Brazilian energy mix

rationale for this situation is that 2010 was the year with the lowest share of biomass as an electricity source (7.65% of the total mix). According to the characterization factors adopted by the impact assessment methods, biomass—before being processed to generate energy—uses the area for its cultivation, thereby strongly affecting the 'Land use' category.

In parallel to this observation, for biomass cultivation it is necessary to use chemical fertilizers, which contain NH_4, NO_x, and SO_2 among other substances, according to the models. These contribute to the 'Terrestrial acidification' category and consequentially to the possibility of compromising soil productivity. Thus, as the use of biomass for energy production increases, so will the environmental impacts of the mix for these impact categories (see the 2030 columns in Fig. 15.4).

Figure 15.5 was elaborated to display the potential environmental impacts of energy production on water bodies. The most striking result comes from the 'Freshwater eutrophication' category, which had a 120% increase in the 2030 projection in comparison to the baseline. Following the same procedure as presented for the 'Global warming' category, a new chart was prepared to explore the results related to 'Freshwater eutrophication' (Fig. 15.6).

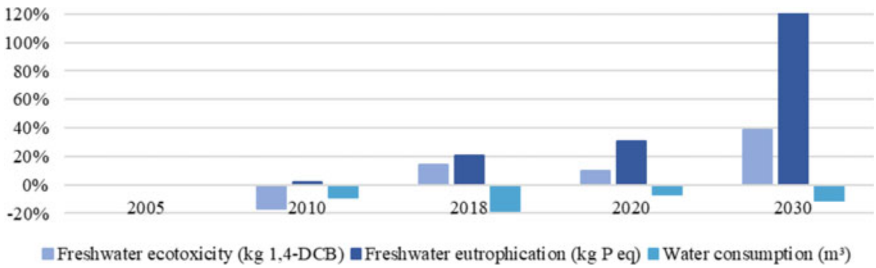

Fig. 15.5 Impacts on water in the Brazilian energy mix

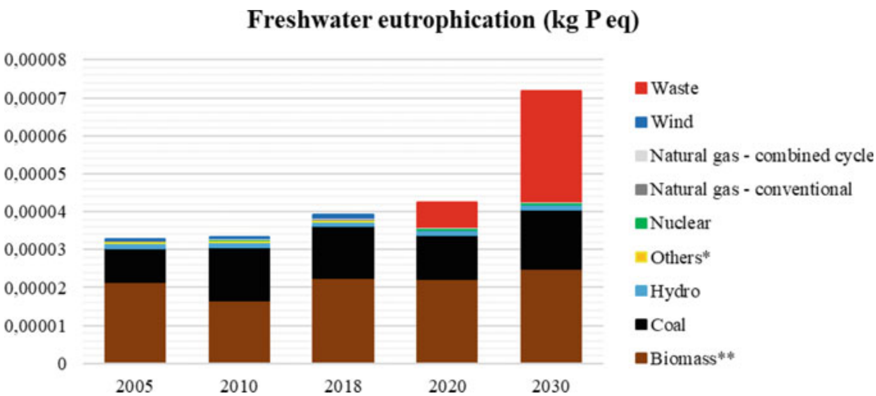

Fig. 15.6 P eq emissions in the Brazilian energy mix by type of production

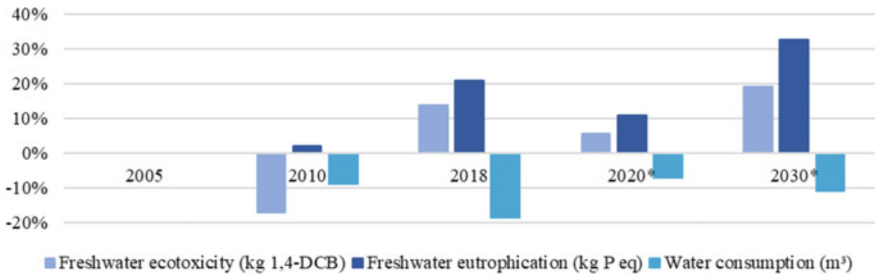

Fig. 15.7 Impacts on water in the Brazilian energy mix (without energy production by waste)

Through the bars presented in Fig. 15.6, it becomes evident why the 'Freshwater eutrophication' results grew excessively. The main contributing factor is energy production generated by waste incineration, which according to the PNE 2030 (EPE 2007), is expected to grow by an average of 68% per year between 2020 and 2030 (Table 1). This waste treatment method tends to release chemical substances, in particular large concentrations of phosphate, which is the main eutrophication agent.

Nonetheless, Table 2 shows that the waste generation dataset used in the modeling process considers only digestion sludge (which tends to have fewer compounds compared to common solid waste). It is worth mentioning that this dataset represents the Swiss reality (CH), which, due to the lack of information regionalized for Brazil, was the closest option. Therefore, considering that the interpretation phase is an iterative process of reviewing the scope of the LCA, as well as the nature and quality of the data used as consistent with the defined goal, a sensitivity analysis was applied to the results.

The objective of the sensitivity check is to assess the reliability of the final results and conclusions by determining how they are affected by uncertainties in the data, etc. The sensitivity analysis tries to determine the influence of variations in assumptions, methods, and data on the results (ISO 2006b). 'Waste' was then excluded from the modeling, and the new results are presented in Fig. 15.7.

The sensitivity analysis shows that the variation of the impact categories from the baseline is less. The analysis also shows that the 2020 prediction has better environmental performance compared to 2018 and 2030. However, although the variation decreases, 'Freshwater eutrophication' still goes up, even without energy generation through waste incineration. Like in the other categories, the main contributing factor is energy production by biomass, which also emits phosphate (1.31E-5 kg P eq).

It is important to note that for 'Water consumption,' it presents negative results both in the initial modeling (Fig. 15.5) and in the sensitivity analysis (Fig. 15.7). This happens due to the high amounts of water consumed by hydropower plants (5.76 m^3 KWh^{-1}). Since the PNE 2030 (EPE 2007) foresees a reduction of hydroelectric plants (in the proportional mix share) from 80% to 70% between 2005 and 2030 (Table 1), the 'Water consumption' is consequently reduced. The reduction in the percentage of hydroelectric power is translated into a positive impact in future Brazilian energy mix trends in regards to water preservation, as the projections tend to show better environmental performance.

Conclusions

The main objective of this study was to evaluate the potential environmental impacts of the Brazilian energy mix. An LCA was carried out to assess the impacts of electricity production on land use, food production, water use and climate change.

The Brazilian energy mix is known worldwide for having the cleanest compositions of all. The PNE 2030 aims to honor that status in its future projections. However, even renewable electricity production has environmental burdens. According to the LCA's results, the future energy mix will have higher environmental impact ratios in the impact categories analyzed.

Biomass is the main contributing factor for the potential decrease in the energy mix's environmental performance. Massive land use, high volumes of fertilizers applied in farming, and CO_2 emissions generated in the incineration process are the main drivers of these results. Along with biomass, natural gas has also played an important role in relation to CO_2 emissions, presenting high impacts in the 'Global Warming' category. In this case, an alternative for emission reduction lies in the expansion of the energy mix. The investment in combined-cycle natural gas power plants, which emit 30% less CO_2 than conventional technology, would help to lower such impacts.

Waste incineration is another energy source that might hinder the Brazilian energy mix environmental performance. If the PNE 2030 projections come true, attention should be given to incineration emission control, since the emission of phosphates can compromise the water quality of hydric resources close to the power plants.

Ultimately, this study highlighted the staggering growth of wind energy contribution in Brazil. Results show that wind energy did not contribute effectively to any of the impact categories, even when counted with the unpredicted rise of 8% in the total mix. Thus, it can be inferred that a strategy for cleaner energy would be to invest in this energy source. It is worth mentioning that this study did not evaluate the impacts of solar energy since it has low representation in the Brazilian energy mix.

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Chapter 16
Food from Somewhere: School Kitchen Garden Programs, Food Sovereignty and Food System Resilience

James Ribeiro Duthie

Abstract This research demonstrates how small, inexpensive programs can contribute to sustainable development while also building household and community resilience. The relationship between the engagement of primary school aged children in urban agriculture through School Kitchen Garden (SKG) programs and household food sourcing habits was explored. The research highlighted the ability of SKG activities undertaken by children to inform changes towards more sustainable food sourcing habits. This paper draws on a thesis written as part of the requirements of a master's degree in Environmental Management. The methods included the use of surveys and interviews of parents and caregivers of children participating in SKG programs at two Australian primary schools. The research findings indicated changes to food sourcing habits, diets and attitudes towards food that contribute to increased household and community food resilience and food sovereignty, as well as increased concern for social-ecological challenges. This study highlights how small investments can have positive multiple-layered social impacts that contribute to sustainable development innovations and transitions to more sustainable lifestyles. Increased understanding of such programs allow researchers and policymakers to better design and implement programs that increase awareness of the importance of food, water and energy and also contribute to sustainable development and household resilience.

Themes: Sustainable development, Urban agriculture, School kitchen gardens, Food sovereignty, Water Energy Food nexus

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Introduction

Food from Nowhere

Social justice, culture, economics, international aid and trade, poverty, and biodiversity are all directly or indirectly related to food: its production, its consumption, who gets what food, when, where and how. As stressed in the recent paper from the IPCC (2019) focusing on climate change and land, every aspect of the food system - how, where and what is grown, distribution and wastage - is linked to the climate crisis, and as such, so is any action undertaken to mitigate and adapt to it. As attempts to transition to a more sustainable society gather pace, it is important not to overlook potential impacts that changes have on food access and food sovereignty. Food, together with water and energy, is located at the center of our daily experience. Given this centrality, it is also important not to overlook the contribution that food-related interventions may contribute to the needed transition to a sustainable and just future.

We live in a world that produces enough food for the current population; yet nearly one in six people on the planet suffer from chronic hunger, while one in six are overweight or obese (Ehrlich et al. 1993; McMichael 2009). More than half the global population now lives in urban areas and with a spatial and temporal disconnection between where food is produced and where it is consumed. Control over production and distribution of what we eat is increasingly being concentrated; food, plants, animals, and their genetics are being altered and commodified (Holt-Giménez et al. 2009). The current global food system has removed much of the individual consumer's control of what is eaten and how it is produced and distributed. The ability for urban agriculture to provide multiple social, environmental and economic outcomes is well documented. School Kitchen Garden (SKG) programs,—the use of urban agriculture within the academic environment—have been shown to provide a unique teaching and learning environment (Graham 2005). This environment has the potential to enable a wide range of positive outcomes not just for students, but also for teachers, volunteers and school communities. These benefits include improving students' attitudes towards food and food literacy (Townsend et al. 2014), improving parents' confidence, social skills and sense of community (Blair 2009), increasing local biodiversity (Fischer et al. 2019), improving the sense of family and community (Knapp et al. 2018), challenging 'traditional' gender roles, and increasing practical life skills for students and parents (Narayan et al. 2019, Townsend et al. 2014).

SKG programs are being increasingly adopted in countries such as Australia and in U.S. states such as California due to their relatively low cost and the benefits they provide to student and school communities (Burt et al. 2017).

Food Sovereignty and Food Systems

Food sovereignty is a concept that looks at democratizing and restoring control of our food space, including the many areas that it interacts with. Food sovereignty recognizes the multi-faceted and interconnected relationships between people, the greater environment and food. Using a food sovereignty lens to analyze the current food system allows for greater understanding and provides a fuller context for analysis and actions in this arena (Patel 2009, Schiavoni 2009). Together with an increased understanding of the interconnected nature of the food system within greater social, economic and ecological environments, there is an emerging recognition of the fragility of the contemporary food system and a call to embed greater resilience within it (McManus 2005, Connelly et al. 2011).

Many people are familiar with the concept of food sovereignty via the work of the 'La Via Campesina,' the international peasants' movement which fights for the rights of small producers and the right for people to have some control over their food and an awareness of those that produce it. As such, it is understandable that some may not immediately link the importance of food sovereignty with urban area populations. However, the currently dominant neo-liberal model of capitalism—the source of many of the risks to food sovereignty—has adverse outcomes for food systems, producers and consumers at the global and local level. This includes urban populations in the global north and south alike.

The concept of food sovereignty has been growing in importance. While much of the discourse on hunger and food systems has generally revolved around food security, there is a crucial difference between food security and food sovereignty. Food security is achieved when all people at all times have access to sufficient, safe and nutritious food (FAO 2002; Rehber 2012). Food sovereignty, however, is also concerned with the means, not just the end. Via Campesina concerns itself with the many areas that intersect with food, and can be summarized as the "*right for people to define their own food agriculture; to protect and regulate domestic agricultural production and trade in order to achieve sustainable development objectives; to determine the extent to which they want to be self-reliant*" (Campesina 2009).

Food from Nowhere

Traditionally, food is one of the most primal connections people had with their environment. In hunting and gathering times the sourcing of food probably accounted for a large portion of necessary activity; the adoption of agriculture and the resulting changes to the nature of civilization brought about physiological and psychological changes (Wells 2010; Pereira 2005). Until relatively recently, the cultivation and preparation of food still provided individuals and communities with an intimate connection to their environment, the seasons and ecological processes. The contemporary food system of the global north, rapidly being replicated and refined in the global south together with the technologies it relies upon (such as input intensive industrial agriculture and global scale logistic networks), has contributed to a large degree to the breaking down of connections with food (Litt et al. 2011; Bhatti and Church 2001).

It is understandable that some would view favourably the situation that allows for an apparent cornucopia of choices in regards to food: all foods at all times, independent of season or locale as a ringing endorsement of the current food system (Patel 2007). However, when viewed through a food sovereignty lens, the picture is not as rosy. The structures and relationships that enable the current food system are marked by concentrations of control and power, exclusion and damage to public health and the environment (IAASTD 2009; Garnaut 2008; PMSEIC 2010; Olshansky 2005; Pollan 2008; Holt-Giménez et al. 2009). In the global north and increasingly in the global south, almost all food types are available all year round; albeit at a price, a food's availability is no longer linked to the local environment, seasons or weather events (Patel 2007). Much of the supermarket's apparent bounty could be classed as 'food from nowhere,' only made possible through a temporal spatial separation between the source of the food and its consumption; this results in potential for what Friedmann (2008) describes as the destructive power of distanciated and socially disembedded food relations, both hallmarks of the greater contemporary food system (Campbell 2009). In addition to this dislocation and separation, a paradox has occurred in which the 'consumer' has a seemingly ever growing amount of choice as to what foods they select, yet there is a continuing reduction in the diversity of suppliers with much of the food passing through what Holt-Giménez et al. (2009), Carolan (2018) and other authors have referred to as the hourglass of the food system (IAASTD 2009). Even amongst countries of the global south, the concentration of grocery sales in Australia is very high, with the top four supermarket chains accounting for 96% of sales and the largest two chains for 70% of food sales alone (Bartos et al. 2012; Hambur and La Cava 2019; Pulker et al. 2018). The resulting concentration of power over production and distribution not only leads to a reduction in choice and food sovereignty for the consumer, but, more importantly, it puts pressure on primary producers and suppliers by those at the narrows of the hourglass, resulting in a loss of resilience in the food system as a whole (Grimmer 2018; Clapp and Scott 2018).

The Urbanization of Australian's Relationship with Food

An enduring myth of Australia is that it is a rural nation, largely composed of and reliant on outback stations, farms and mining. However, Australia has long been a mostly urban country, with over 80% of the population residing in urban centers since 1960, a level forecasted to keep increasing from the current 90% + (ABS 2019). In addition to the increasingly urban nature of the modern Australian experience, the last thirty-plus years have seen a change in the structure of urban areas as well, with a decrease in residential plot sizes towards smaller plots often with larger houses on them (Baker et al. 2000). The reduction of yard sizes for urban and suburban dwellings has not only seen the productive potential of yards decline but has also witnessed decreased potential exposure to ecological processes. These changes, together with the increase in people relying almost solely on supermarkets for their food, and in concert with expanding suburbs, have brought about an urbanization of the population and their relationship with food.

Health Impacts of Decreased Food Sovereignty and the Current Food Environment

Morgan et al. have shown that many school-aged children lack a practical knowledge of food, often unable to name even common vegetables (Morgan 2010). Often children not only lack an ability to identify many common vegetables, but also an understanding of the origins of much of the food they eat (Somerset and Markwell 2009). The amount of vegetables and fruit a child consumes can be influenced by their ability to recognize those foods (Bere and Klepp 2005). This lack of food literacy has the effect of compounding a move towards the 'Western diet' (Cordain et al. 2005). The Western diet is hallmarked by monetarily cheap, calorie-rich convenience foods, often with high levels of salt, sugars and fats which, in addition to changes in lifestyle, have resulted in a large increase in the prevalence of diet related diseases such as type 2 Diabetes and cardiovascular conditions (Olshansky 2005; Pollan 2008; Pereira 2005; Melaku et al. 2019; Zadka et al. 2019).

Globally, a positive link has been identified between the level of overweight/obese residents and the level of disadvantages of an area, with income levels as well as environmental factors and access to food choices as contributing factors (King et al. 2006, p. 286; Kimbro et al. 2017). Given that more than half the Australian population is now overweight or obese, with an increase in categories across all social economic groups, diet-linked maladies are not solely due to economic restrictions of access to healthy food, but to the Australian population's changing relationship with food (Bambrick et al. 2008).

Resilience Within Food Systems—Strength Through Diversity

The level of resilience within a system can be measured by the system's ability to withstand and recover from shocks and provide the same or similar outcomes, even if that is achieved through re-organization of the system. In a food system, the primary desired outcome or service is the provision of food for a population. If the food system has a high level of resilience, it could be expected to withstand shocks and still maintain this outcome or be able to quickly recover this outcome after or during a shock. System shocks can be acute or long-term in nature and effect, and can be natural, manmade or a combination of both; economic disruption, prolonged drought, anthropogenic climate change and geopolitical events have the potential to act as shocks to food systems.

Sustainability Transitions and Food System Resilience

Just as food is intertwined with a wide range of social, ecological, and economic issues, food, water and energy are intertwined with each other and with the efforts to transition to a sustainable future. Given the many challenges facing current food systems, as outlined above, there is a recognition of increasing levels of uncertainty in food system resilience. The ability to identify activities that simultaneously embed resilience in a community's food system while improving levels of food sovereignty should be encouraged.

An indicator of resilience in food systems can be found in the level of diversity of food sources and distribution networks; all other things being equal, the greater the diversity, the greater resilience of the system. With the trend for consolidation of food supply and distribution as the hallmark of global food systems, some national and sub-national governments have recognized this change as an area of vulnerability and are making efforts to address it through actions designed to result in increases in food chain and consumer resilience (Stephen et al. 2012). Such efforts can include reinforcing the current food system architecture through multiplicity, including decentralization of distribution points and transport routes; however this approach runs counter to the prevailing idea of economic rationalization (Hendrickson and Heffernan 2002). This deep concern in relation to weaknesses in the food system due to the increasing possibility of a no-deal Brexit—a political, intentional event—underlines the potential fragility of food systems.

Research Aim and Methodology

Involvement in SKG programs has the potential to influence the participants' epistemological view in relation to food: how they view food and what they hold as "truths" in regard to food. The nature of these 'truths' informs their relationship with food. By exploring the change in food-sourcing habits and the motivations, drivers and barriers of change, while building an understanding of the utilization or development of alternate food sources at the household level, there is potential to indicate changes in households' perception of food. Changes in the food-sourcing habits, demonstrated by a greater recognition and utilization of potential food source points, has the potential to affect the level of food sovereignty at both the household and community level. Changes that occur provide an indication of the ability of school-based programs such as SKG to enable children to be vehicles of behavioral change at a household and community level.

The aim of this research was to investigate the potential of activities at the school and household level, such as the SKG program's ability to influence evolving food system architecture, and by doing so, assist in the identification of points of potential intervention and leverage for change within the evolving food system.

This research involved the use of a mixed methodology research design consisting of the collection of quantitative and qualitative data; the analysis of that data was conducted with relativist ontology. Data was collected through the use of a questionnaire, with follow-up phone interviews with households. The questionnaires were completed by the parents or caregivers of the students; no data was collected from the students themselves. Questionnaires, participant information sheets and consent forms were provided to approximately 280 households across two schools where children participate in SKG programs. The research packs were provided to the households via their children's school. The completed questionnaires of the parents/caregivers were returned to the schools in the envelope provided, along with the consent forms.

The research consists of two sections. A literature review explored links between the greater food environment, food sovereignty, food regime theory and the social and ecological context of the current food system. The second part of this research was designed to explore the potential for students' involvement in SKG programs to affect change to their household's food sourcing habits. The research design sought to identify both the extent and motivation for changes in food sourcing habits that relate to students' involvement in SKG programs, and the development of an understanding of the influences, drivers and barriers to change. Given the limitations of this research, it is important to note that this study did not intend to answer these questions definitively, but rather to explore the potential for interventions. Specifically, the research tests in a very limited manner whether influence exists in the context of SKG programs and household food sourcing habits.

Results and Findings

Increased Diversity of Households' Food Source Points

The surveys were distributed to households by the schools and were returned to the schools in sealed envelopes. A delay in receiving permission from the state education department resulted in a very short window between distribution and collection. Of the 280 surveys distributed to the schools, 42 were returned. The questionnaire focused on food sourcing habits, with the respondents asked to indicate their household's food source points prior to having their child involved with the SKG program (Fig. 16.1) and to indicate current food source points (Fig. 16.2).

Changes were indicated in all categories except for the use of supermarkets; all households reported use of supermarkets prior to and during their child's SKG program involvement. A significant increase was indicated in households that identified growing some food at home, increasing from 26.5 to 54.5%. A mild increase

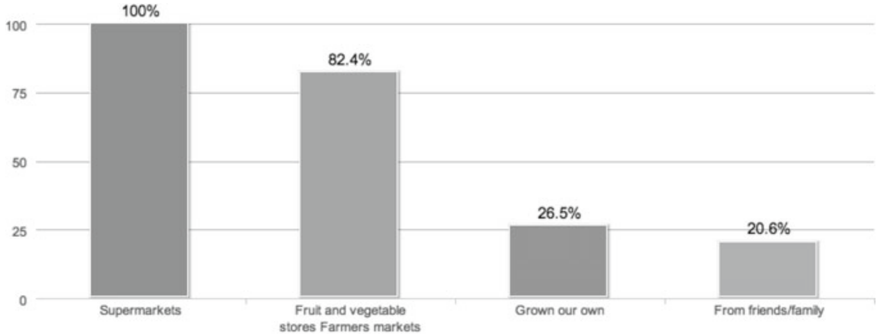


Fig. 16.1 Food source point % for households, prior to child's involvement in SKG program

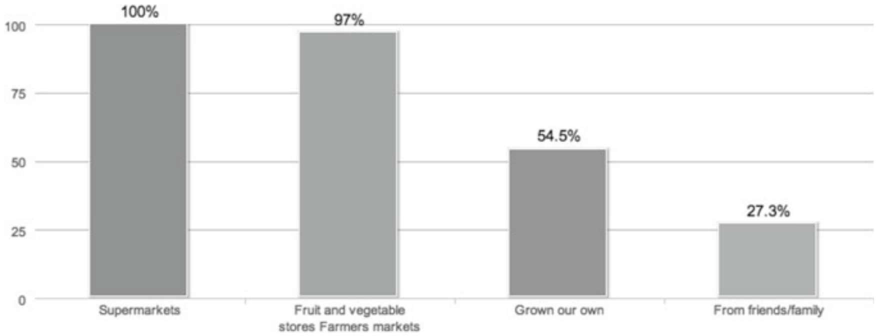


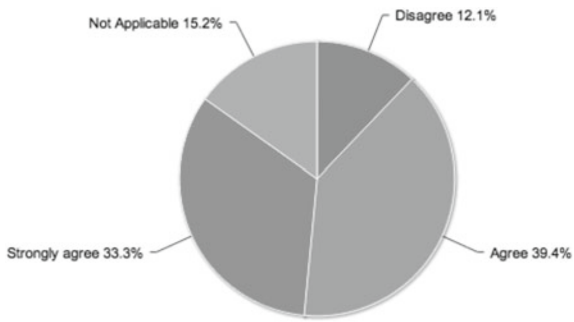
Fig. 16.2 Food source point % for households, at time of survey with child/children involved in SKG program

was reported in households sourcing food from 'fruit and vegetable stores/farmers' markets', and 'from friends/family' of 11.7 and 13.4%, respectively. An increase in diversity in the households' food source points is shown. There was also a reported increase in the type and diversity of food produced at home; most common were herbs (73.5%), then fruit (39.4%), vegetables (36.4%) and finally eggs (6.1%); no households indicated they produced meat at home (Fig. 16.3).

Motivations and Barriers to Growing Food at Home

Another central finding was the significant increase in the number of households practicing urban agriculture (Fig. 16.4). A recognized obstacle to a greater uptake of urban agriculture is the lack of access due to time constraints and/or a suitable space (Kantor 2001), a finding that was replicated in this research. School-based kitchen garden programs negate (at least in part) this lack of access for children attending the schools with SKG programs.

Fig. 16.3 Households agreeing with the statement: 'Since our child/children has been participating in the SKG program they have asked to grow food at home'



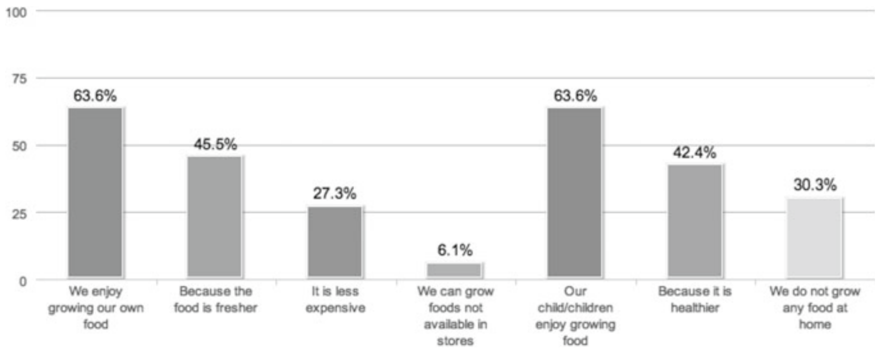


Fig. 16.4 Household's responses to: 'Our household grows food at home because:'

Enjoyment was the most prominent motivation self-identified by research participants, including enjoyment for themselves as well as the enjoyment of the household's child/children. Freshness of food and health are the next most common reasons given, and more than a quarter of respondents indicating that the decrease in expense is a motivation. The high recognition of enjoyment as a motivator for growing food at home may indicate the parents/caregivers' ability to be influenced by their children's enjoyment of the activities at school. Primary barriers to growing food at home were also identified (Fig. 16.5).

Very few of the participants reported no desire to grow food at home. However, given the increasing visibility and popularity of urban agriculture in Australia, it is important to acknowledge the potential for perceived social desirability to bias results (Bertrand and Mullainathan 2001).

Influencing the Participants' Relationship with Food

Previous research has suggested that education in conjunction with enjoyable activities has the potential to enable desirable changes in behavior (Orams 1998).

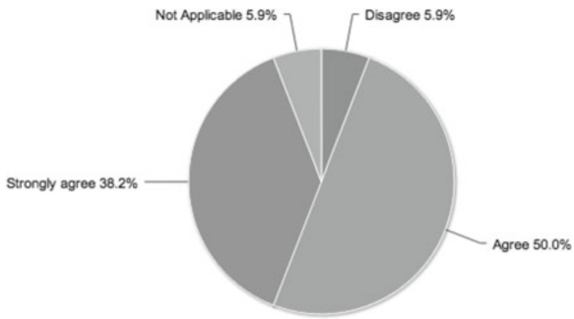


Fig. 16.5 Agreement with the statement: 'Since our child/children have been participating in the SKG they are: more likely to try different foods'

The number of households that reported an increase in the likelihood of their child/children trying different foods since their involvement in the kitchen garden program was very high, with 88.2% of households either agreeing, 50% strongly agreeing, and 38.2% agreeing that their child/children were more likely to try different foods since being involved in the program. This mirrors the results of a garden-enhanced nutrition program for primary school students in California (Morris et al. 2001). Confidence that the changes are due to the SKG program is reinforced by comments that the parents/caregivers provided on the returned questionnaires and interviews such as, "*The program has been extremely beneficial in encouraging the kids to try new foods & to participate at home in its creation*". "*They love the it [the KGP], we don't have space at home, but they learn all the things there.*" All respondents indicated their children as talking positively about the SKG program; see Fig. 16.6. A single mother of two, with one child in the program, explained how she doesn't let her children eat sweets unless they make them themselves. Now instead of asking for sweets and lollies, "They just give me a list of the ingredients they need (Fig. 16.5)."

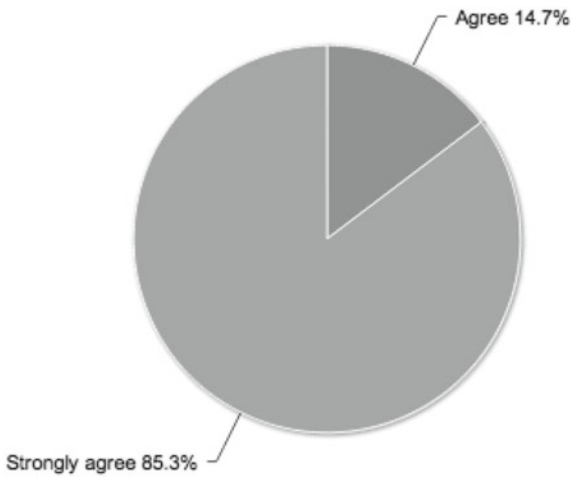


Fig. 16.6 Agreement with the statement: 'Our child/children talk positively about the SKG program'

Conclusion

The particular experiential and participatory learning environment offered by well-designed SKG programs allows for educational outcomes that would otherwise not be possible. Some research has also been undertaken to explore the outcomes of urban agriculture and SKG programs on environmental attitudes (Skelly and Zajicek 1998).

The research findings indicated changes to food sourcing habits, diets and attitudes towards food that contribute to increased food sovereignty, household and community food resilience, as well as increased concern for social-ecological challenges. Participants reported changes to their children's attitudes towards food and their knowledge of it. These changes where often marked by a reported increased interest in food in general—different types, where it comes from, and a desire to grow food at home in particular. Participants also reported a general increase in knowledge of and concern for environmental issues, a change that participants associated with the SKG program.

The changes identified included increased diversity in household food source points and the willingness for participants in the SKG program to try different foods, suggesting that households are either aware of new source points or now recognize them as viable and/or valuable choices. This suggests a greater level of food sovereignty at the household level, as well as a potential strengthening of food system resilience. The level of change suggested in the households' food source habits indicate that SKG programs have the significant ability to provide spaces for the development of different relationships and alternative experiences with food, changes that have potential consequences for food sovereignty and food system resilience.

By increasing knowledge, concern and awareness of the importance of food, well-designed SKG programs have the potential to positively influence the food, water and energy nexus. Increased understanding of how many different aspects of food are interlinked with water and energy, as well as countless current and emerging social and environmental challenges, provide for a more aware, conscientious and informed community which may be more open to other interventions and less likely to act in detrimental ways. The low cost of SKG programs provides local governments and policy makers with a foundation on which other interventions can be built.

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Chapter 17
Towards an Analysis of Frugal Innovation: An Important Way to Achieve Sustainability

Simone Sehnem, Aléssio Bessa Sarquis, Denise Del Prá Netto, Graciella Martignago, and Diogo Amarildo da Conceição

Abstract This research seeks to analyze the scientific publications on frugal innovation regarding the context, focus, sector in which they are operationalized, method adopted, innovative practices, benefits and contributions to society. A systematic literature review was conducted, focusing on the mapping of the specificities of publications on frugal innovation. Our results show an emerging theme that has grown substantially over the last three years. Frugal innovation has generated significant changes for people, especially in the aspect of products and services offered to society. The societal benefit of frugal innovations in socially vulnerable communities still has potential for exploration in forthcoming studies, particularly with regard to tangible indicators of impact measurement. Despite the gradual evolution of publications on the theme over the years, the focus of the studies is still centered on conceptual investigations and descriptive case studies. Some propositional and evaluative approaches appear in the studies, but there is still a need to use management theories to instill an awareness of management precepts that recognize the social dynamics of the operationalization of frugal innovation. Future studies can

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generate breakthroughs with analytical categories that explore the perspectives of a resource-based view: institutional theory, contingency theory, learning theory, and actor network theory.

Introduction

Frugal innovation emerged in the late 2000s as an appropriate for-profit technology (Kaplinsky 2011). The movement emphasizes the role of the private sector, which is a key innovation partner in the contemporary global economy and the economy operating in developing nations (United Nations 2015). Frugal innovation brings together multiple stakeholders from formal and informal sectors in geographic regions and combines their contributions with bottom-up approaches (Knorringa et al. 2016). It can contribute to the development of remote communities in developing countries with its localized, easy-to-maintain, and simple-to-implement solutions (Rosca et al. 2018), and it can also be successfully implemented in transition economies (Tian et al. 2019).

The literature associated with frugal innovation reveals a number of characteristics of the concept. The most commonly cited characteristics include these descriptors: functional and focusing on the essential; considerably reduced initial purchase cost; lower cost of ownership; minimization of the use of material and financial resources; user friendly; robust, of high value and quality; and possible to be commercialized in scale (Rosca et al. 2018). Frugal innovations are products that target emerging middle-income consumers and producers in developing economies (Knorringa et al. 2016). Substantial cost reduction, a concentration on core features, and optimized performance are criteria for classifying an innovation as frugal (Weyrauch and Herstatt 2016). Zeschky et al. (2014), in turn, classify frugal innovation using the criteria of technical novelty and market novelty. Soni and Krishnan (2014) define frugal innovation as a monolithic entity of three types: innovation as a mentality or way of life, as a process, or as a result in the form of products or services.

Frugal innovation allows for more inclusive development processes by meeting the following assumptions: the production and marketing of more economical products and services, the engagement of low-income actors in value chain activities, and natural resources being utilized in a frugal way (Baud 2016; Knorringa et al. 2016). Frugal innovation has a medium level of sophistication, medium sustainability, and medium emerging market orientation (Brem and Wolfram 2014).

Although the scientific literature presents previous studies conducted in the form of systematic literature reviews, Rosca et al. (2018) developed a systematic review of literature that analyzes current research to relate the constructs of frugal innovation and sustainable development. They highlight approaches and conditions in which frugal innovations contribute to sustainable development. Wehn and Montalvo (2018) drew up a special issue on the dynamics of water innovation. Weyrauch and Herstatt (2016) developed a systematic review and interviewed 45 company managers from different research institutes to determine what frugal innovation is and what it is not.

Tiwari et al. (2014) developed a study whose objective was to examine the use of inventive analogies in the creation of economic solutions and their impact on the project result. Brem and Wolfram (2014) published a study in which they sought to distinguish frugal innovation and related terms such as frugal engineering, constraint based innovation, Gandhi innovation, jugaad innovation, reverse innovation, catalytic innovation, grassroots innovation, and innovation in indigenous communities. The authors consolidated a conceptual framework based on a literature review of 363 previously published articles on innovation. Its structure classifies frugal innovation and related terms using three aspects: sophistication, sustainability, and orientation to emerging markets.

Several empirical studies, such as Pansera and Sarkar (2016), explored several cases of green technologies and frugal innovations driven by local entrepreneurs in the energy sector and pursued how new technologies generate jobs, income, and productivity. Anurag (2018) explains the indigenous innovations and also makes it accessible to a wider audience. Prashantham and Kumar (2019) explains that the context of startups represent "business as unusual."

We understand that there are still gaps in the literature on frugal innovation, especially in the areas of development, types of innovation, and the main contributions generated for society. These topics are especially relevant, because Pansera (2013) points out that frugal innovation minimizes the role of government and Knorringa et al. (2016) finds that frugal innovation can fill important service gaps in cases in which the government has failed. Thus, our study seeks to contribute to the systematization of data that will allow us to understand in greater detail the specificities of scientific publications dealing with frugal innovation, a subject so relevant to society.

After this introduction, we present a theoretical section that recaptures recent studies and theoretical aspects pertaining to the topic of frugal innovation. Section "Methodology Procedures" of the article details the methodological course followed to elaborate this systematic literature review. Section "Presentation, Analysis, and Discussion of Results" presents, analyzes, and discusses the research results. Section "Final Remarks" offers final considerations of this research and highlights the results' implications for the different stakeholders of the organizations. We conclude with the references that were consulted to elaborate this work.

Frugal Innovation

Frugal innovation provides solutions in remote sites that cannot be achieved by regular local government initiatives (Prabhu and Jain, 2015). Frugal innovation has the potential to bring together public and private sectors for the creation of learning and knowledge (Kahle et al. 2013). Scholars often connect the discourse of frugal innovation with elements of technological development (see Rosca et al. 2018). Therefore, a vital perception is that the state and citizens can play an important role in the innovation cycle, especially in one that meets emergency demands of vulnerable people (Wehn and Montalvo 2018).

Innovation is linked to sustainable development by: (1) reducing resource use at various points in the production and consumption chains; (2) providing renewable resources and technologies to billions of low-income consumers; (3) influencing product design to promote green and life cycles; (4) encouraging ecological awareness and education; and (5) furthering frugality as a mentality (Rosca et al. 2018). Frugal innovations often create positive ecological impacts beyond their value propositions, because they engage local communities in education and awareness campaigns (Rosca et al. 2018). Initially, frugal innovation studies emphasized consumers moving from the bottom of the pyramid to the middle class in emerging markets (Soni and Krishnan 2014). However, more recent studies have focused on the economic use of resources in process innovation, which allows the creation of products, services, and environmentally-friendly, high-quality systems to be accessible to low-income people (Wehn and Montalvo 2018).

Frugal innovation has direct effects on the health of low-income actors (Howitt et al. 2012). Examples of implementations generated by frugal innovation in society include eRanger ambulances, water purifiers, clean cooking stoves, car air purifiers, management of solid wastes and effluents, and sanitation systems (Rosca et al. 2018; Uduji and Okolo-Obasi 2018; Raimi et al. 2019). In addition, Nahi (2016) argues that frugal innovations in sectors such as energy or health care have a major impact on quality of life and enable social growth. Analogies can have a significant impact on the successful development of frugal innovations in environments characterized by severe resource constraints and high price sensitivity. For example, the development of a frugal artificial heart was based on the heart structure of cockroaches; this frugal device led to a cost reduction of some 20 times (Tiwari et al. 2014).

The use of frugal innovation as a management philosophy brings a different approach to increasing the quality of life; there is a greater emphasis on free time and self-realization than on materialism and consumption (Roiland, 2016). At the same time, frugal innovations initiated by multinational or local firms have the potential to increase low-income economic access to critical products and services and to address inequality in labor markets (Rosca et al. 2018).

Frugal innovation increases accessibility, ensures impact in social settings, and uses limited resources. The active role of citizens as co-producers in the innovation process allows small-scale local entrepreneurs to tailor their products and services to their customers' needs and price expectations (Wehn and Montalvo 2018). The specific attributes of frugal innovations depend heavily on the defined context, such as the environment, the specific needs, or the market structure (Weyrauch and Herstatt 2016). Lastly, social responsibility initiatives in organizations influence the organization's license to operate in the Ghanaian business environment (Famiyeh et al. 2019).

Methodology Procedures

This study consists of a systematic literature review. A four-step approach according to Tranfield's methodology (2003) was followed to conduct this study.

Figure 1 illustrates the steps that were followed to conduct this study. In Stage I, several databases were researched to map the existing scientific publications on the topic of frugal innovation. The key search terms were "frugal innovation" in the Portuguese, English and Spanish languages. Only one key search term was used, since, in consultation with specialists, no other term was mapped in the academic literature that could be a direct substitute for frugal innovation. Although it is generally recommended to conduct systematic literature reviews with multiple key search terms, this research only adopted the one term that best expresses the mapping of scientific literature that could answer the objective of our study: to analyze the scientific publications on frugal innovation's context, focus, sector in which it is operationalized, method adopted, innovation practices, benefits and contributions to society. The search for the articles occurred by mapping the titles, abstracts, and keywords of the studies. The types of material mapped were articles, articles in press, reviews, and research articles. The databases consulted were Scopus, Web of Science, Sage, and Science Direct, and the time of publication selected was 2008–2018. The first search provided a map of 350 academic articles.

In Stage II the articles were read in full and a spreadsheet was completed taking into account the categories of analysis described in Table 17.1.

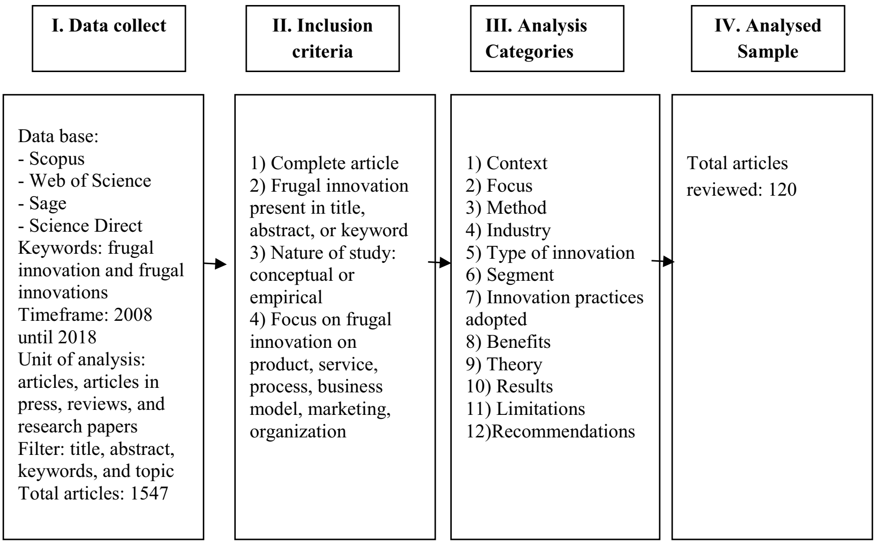

Fig. 17.1 Research design

Table 17.1 Classification meaning codes for alternatives

Ranking	Meaning	Codes for alternatives
1	Context	A—Developed country B—Underdeveloped country C—Comparison between countries D—Not applicable
2	Focus	A—Only frugal innovation B—Frugal innovation and other innovation practices C—Frugal innovation and other management practices D—Frugal innovation is not predominant in the analysis
3	Method	A—Quantitative B—Qualitative C—Conceptual D—Quantitative/qualitative or qualitative/quantitative E—Experiment F—Cases
4	Activities	A—Manufacturing/Industry B—Services C—Other: which D—Not applicable
5	Type of innovation	A—Product Innovation B—Innovation in services C—Process Innovation D—Marketing Innovation E—Organizational innovation F—Business model innovation G—Not applicable
6	Sectors	A—Primary: involves the extraction and/or production of raw materials, such as corn, coal, wood, or iron. Examples of primary sector workers may be a coal miner and a fisherman B—Secondary: involves the transformation of raw materials into goods, such as the manufacture of steel for cars or textiles for clothing. Examples of secondary sector workers may be a civil builder and a couturier C—Tertiary: involves the provision of services to consumers and/or companies, such as babysitting, cinema, or banking. Examples of workers in the tertiary sector may be a shopkeeper and an accountant D—Not applicable

(continued)

Table 17.1 (continued)

Ranking	Meaning	Codes for alternatives
7	Innovation practices adopted	A—Organizational and planning practices B—Operational Practices C—Communication practices D—Other: which E—Not applicable
8	Benefits of frugal innovation	A—Top management B—Other employees C—Other stakeholders D—Other, what E—Do not quote in the study
9	Theory or conceptual approach used in the study	Mention in this field what theory or conceptual approach was used to develop the study
10	Main outcome of the study	Present here the answer to the objective of the study
11	Limitations of the study	Present the research limitations

In Stage III we use the categories of frugal innovation analysis described by Weyrauch and Herstatt (2016) to evaluate the type of innovation mapped in the articles analyzed.

Figure 17.1 shows the steps that were followed to conduct the study.

Then, Table 17.2 presents the most representative journals which published the studies that were analyzed.

Presentation, Analysis, and Discussion of Results

Figure 17.2 presents an overview of the main research results.

Figure 17.2 shows that 44.72% of the studies analyzed were conducted on emerging countries and another 7.32% of the studies did a comparison between countries. This signals that frugal innovation tends to be studied more intensely in underdeveloped countries. The populations in underdeveloped countries represent the more common users who benefit from the technologies, products, infrastructure, and processes derived from frugal innovation. On the other hand, Weyrauch and Herstatt (2016) have pointed out that frugal innovations have also penetrated developed countries and are often referred to as reverse innovations.

Furthermore, 71.66% of the studies approached frugal innovation as the main analysis objective or associated it with management or innovation practices. This shows that there is an emphasis on conceptual and empirical writings that explore frugal innovation in depth. Frugal innovation provides for the redesign of output, production processes, and the business model (*The Economist*, 2010), which creates a new context for innovation that values social attributes, individual competencies,

Table 17.2 Periodicals that published the analysed studies

Journal	Total	Impact factor
Journal of Cleaner Production	8	5651
The European Journal of Development Research	8	1323
Procedia CIRP	6	0
Technological Forecasting & Social Change	5	3129
Technology in Society	5	0
Journal of Indian Business Research	4	0
Sustainability	4	2075
Technovation	4	4802
European Journal of Development Research	3	1323
Research-Technology Management	3	1796
BMJ Innovations	2	23,295
Environmental Innovation and Societal Transitions	2	5265
Globalization and Health	2	3031
Health Affairs	2	5.23
IEEE Engineering Management Review	2	1.94
International Journal of Innovation Science	2	0
Journal of Innovation Economics & Management	2	0
Journal of International Management	2	3.85
Long Range Planning	2	3221
Procedia Manufacturing	2	0
Research Policy	2	4661
Technology Innovation Management Review	2	0
Outros	46	
Total	120	

and group experiences to stimulate co-production and to contribute to the innovation ecosystem. The co-production process brings the local entrepreneur closer to the end user, thereby reducing costs typically borne by users (Wehn and Montalvo 2018). Above all, the process highlights the attributes of frugal innovation, which are significantly lower manufacturing costs, ease of use, limited resources, and low impact on the environment (Weyrauch and Herstatt 2016).

Methodologically, there was a predominance of qualitative studies, followed by conceptual studies, corresponding to 29.75% and 23.97%, respectively. This shows that the frugal innovation theme is still in an embryonic stage. Exploratory, qualitative and case studies tend to be characteristic of emerging research themes. Conversely, conceptual studies typically seek to understand and problematize the theory, inspiring the validation of research propositions. A mature topic tends to consolidate articles that present models of analysis, surveys, and structured statistical analyses.

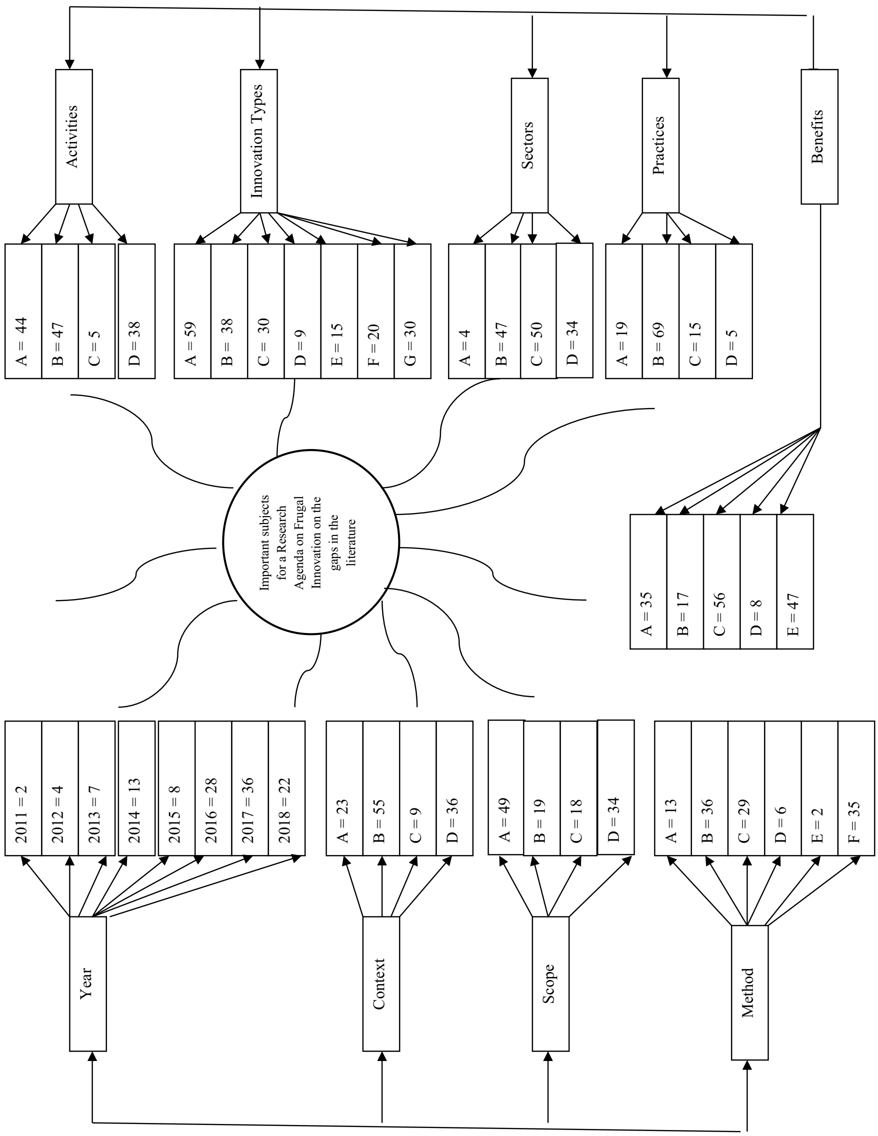

Fig. 17.2 Main results

Regarding the sectors surveyed, there was a predominance of the services segment, followed by manufacturing/industry, with shares of 35.07% and 32.84%, respectively. Subsequently, 29.35% of the studies focused on product innovation and 18.91% on service innovation. Regarding the innovation practices adopted, it is evident that operational ones (46.62%) were the practices most frequently highlighted, followed by the planning of organizations (12.84%). This evidence correlates with the study of Tiwari et al. (2014), who point out that frugal innovation tries to minimize the use of material and financial resources in the various stages of the value chain. This reduces the initial acquisition cost and the total cost of the product, including usage and maintenance, and hence requires less of society's natural and financial resources. The result is to make available products that are inclusive and suitable for people in situations of social vulnerability. Product service systems are alternatives that provide access to the product (Tukker 2015), without blocking ownership, and can be efficient alternatives for emerging countries to invest into meet their basic needs in health, education, infrastructure and the environment.

With regard to the benefits of frugal innovation, 34.36% of the respondents had different levels of attention, and 21.47% of the studies indicated that frugal innovation benefits top management. Such evidence is in accord with the frugal innovation criteria defined by Weyrauch and Herstatt (2016): substantial cost reduction, concentration on basic functionalities, and optimized performance level. The analysis also links to another emerging theme, sustainable development, as provided in the study of Rosca et al. (2018).

The use of theory in studies dealing with frugal innovation is an opportunity for further exploration. Only one study explored the resource-based view, and another study indicated that it used the Theory of Innovation Diffusion. All others focused on diverse and superficial theoretical aspects, which makes it difficult to promote advances in the construction of theory, to test theory in the cases analyzed, or to validate empirical data in light of theory. None of these approaches can build a consistent conceptual paper. Above all, as Rao (2013) emphasizes, the adoption of frugality implies design principles that advocate the minimum use of resources to achieve efficient functioning of products.

Discussion of the Results

Frugal innovation plays an important role in democratizing access to goods and services, especially for the most vulnerable populations (Jha and Krishnan 2013). The simple, labor-intensive, scale-specific technologies directed (Winnink et al. 2018) to the target audience of low-income consumers bring relief to people living in extreme poverty (Kaplinsky 2011). They provide solutions in remote sites that cannot be achieved by regular local government initiatives (Prabhu and Jain 2015). In terms of meeting the goals of sustainable development, frugal innovations provide developing communities with the possibility of purchasing products that suit their needs and their purchasing conditions (Rosca et al. 2018). These are products that have been developed and formulated with a view to reducing the use of natural resources and allowing the creation of inclusive economic growth (Knorringa et al. 2016), and further, to contributing to the motivations, challenges, and opportunities of successful problem solvers participating in virtual teams of innovation contests (Hossain 2018).

For entrepreneurs, frugal innovations provide the opportunity for business profits that serve a specific niche; these consumers are thirsty for innovations and products that are accessible to their income condition (Tata and Matten 2016). However, there are scholars who are critical of frugal innovations, especially since they do not address the problem of poverty. As Nahi (2016) says, the provision of affordable products and services does not solve the structural roots of poverty. On the other hand, scholars do recommend palliative solutions that contribute to the improvement of people's living conditions, despite being unable to solve the social asymmetries that exist in society. In a way, frugal innovation is a low-cost survival strategy (Pansera and Owen 2015).

Frugal innovations comprise technologies popularized by non-governmental organizations and by development agencies (Rosca et al. 2018). There are several solutions for health care sectors, which seek to provide access to treatment and minimum care. This sector is cited in Wehn and Montalvo's editorial (2018) that deals with innovations of water. The energy segment also benefits from frugal innovations by providing alternatives that make use of renewable energies and require low maintenance, including solar, wind, and biogas (Nocera 2012). Co-design and co-production of frugal innovations enable local small-scale entrepreneurs to customize their offerings. They can consider the designation of origin, proximity of production and place of consumption, along with factors related to local beliefs, traditions, cultures, and habits. For Weyrauch and Herstatt (2016), frugal innovation has the potential to reduce costs, concentrate on basic functionalities, and optimize performance.

Nevertheless, there are criticisms of frugal innovation's level of contribution towards sustainable development. Rosca et al. emphasize that using fewer natural resources is not synonymous with environmental protection (2018). Still, the benefits of frugal innovation appear more significant. Those benefits include: increased inclusion of people in the labor market, a boost in entrepreneurship and local capacity building, reduced inequalities, protection through an approach of efficiency and sufficiency, the generation of solutions based on the local dynamics, access to the considered community's resources with frugal innovation, access to scarce products and services for poor people, and contributions to people's motivation and well-being.

Frugal innovation can generate development, considering the different actors in the private sector (Rosca et al. 2018). However, frugal products, services, and systems do not address the root of the poverty problem; this factor is considered a huge flaw of this type of product. Products that have a focus on functionality and a radically reduced cost structure offer certain advantages; they offer a value proposition that incorporates a reduction of the total price of property, and they offer robustness, ease of use, and economies of scale (Tiwari et al. 2014). Moreover, frugal innovation creates an interesting pathway to internal innovation activities while working with limited resources to manage such open innovation processes (Radziwon and Bogers, 2018). The overarching goal is to generate and ensure an effective adoption of innovations that address the needs of the underserved (Ramani et al. 2017).

Final Remarks

This study examines scientific publications on frugal innovation in terms of their context, focus, sector in which they are operationalized, method adopted, innovation practices, benefits, and contributions to society. Evidence shows that this issue has been expanding in the last three years, corresponding to 71.66% of the period's publications. It is a subject explored as an object of analysis in emerging countries, with an emphasis on studies developed in India. Predominantly qualitative and conceptual studies were done. This shows the potential of the area for advances in meta-analyses, surveys, experiments, ethnographies, phenomenologies, comparative studies among countries, and so forth. Moreover, the type of technology and the infrastructure resources derived from frugal innovation and societal benefits are elements that need further academic exploration.

The implications of this research are directly associated with the scientific advances of the subject. There is potential for comparative studies between emerging and developed countries. There is an opportunity to proceed with longitudinal studies, mapping a database of frugal innovations per continent, in order to identify the different types of technology, scientific expertise, and social benefit that the mapped innovations can bring to the communities in which they are targeted. A categorization that identifies the social, economic, and environmental benefits of frugal innovation is relevant, since communities in situations of social vulnerability tend to have different fragilities. A category that measures benefits to health, food, well-being/leisure, and/or labor/work can include elements not mapped in previous studies.

As a limitation of the research, we assume the restricted scope of investigation mapping. We used only the term frugal innovation. Future studies may investigate in depth the nature of frugal innovation in associated mindsets (such as jugaad, bricolage, effect, improvement, Gandhian innovation, inclusive innovation), process (frugal engineering and Lean), and outcome (appropriate technology, disruptive innovation, bottom of pyramid innovation, and reverse innovation).

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Chapter 18
The Beauty Industry and Solid Waste

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Abstract The annual revenue of the beauty industry amounts to many billions of dollars, this being a prominent and constantly growing market with consumers ever more willing to invest in their appearance. Parallel to this, it is known that excessive consumption generates high levels of waste, affected by many factors from the selection of raw materials to the means of disposal by the consumer. With regard to the cosmetics industry, microplastics are the most commonly reported issue. These are derived from packaging or directly from the products (e.g., exfoliating, cream) and an estimated 93% of the microparticles associated with this industry are composed of polyethylene. Regarding the textile industry, another economically important sector on a global scale, it is known as one of the most polluting industries due to the excessive use of water, energy and chemicals and inadequate waste disposal. Thus, the possibilities for research on the treatment of these types of waste are extensive, with the need for cleaner technologies coupled with treatment processes that are cheaper and more widely applicable, aiming to reduce the environmental impacts.

Initial Considerations

The world's population of seven billion people generates approximately 1.4 billion tons of municipal solid waste per year, an average of 1.2 kg per day per capita. Half of this waste is generated by fewer than 30 countries. The richest countries have increased their per capita waste generation rates by 14% since 1990 and by 35% since 1980, according to a World Bank report. These rates generally increase at a slower rate than the increase in gross domestic product (GDP). The United Nations (UN) and the World Bank have presented a prospective scenario for 2050, when there will be 9 billion inhabitants and 4 billion tons of urban waste produced per year.

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The generation of urban waste brings socio-environmental and economic costs to the planet, and around 800 million tons of these residues are disposed of in landfills per year. The US Waste Power Generation Technology Research Council estimates that one square meter of land is permanently occupied for every ten tons of landfill waste.

In this chapter, the focus is on industrial waste, specifically that associated with the beauty industry, represented by the areas of cosmetics and textiles. Industrial waste is considered an environmental problem, since the volumes generated are significant and many of the materials are hazardous to the environment and public health. Obtaining areas for the final disposal is becoming increasingly difficult, and the improper disposal of industrial waste causes air, water and soil degradation.

In this context, the search for a sustainable industry has never been more urgent, and solutions are required to reach the objectives of social, environmental and economic sustainability. The Declaration of the World Summit on Sustainable Development, held in Johannesburg in 2002, divided the concept of sustainability into three pillars: economic development, social development and environmental protection (UN 2002), aimed at the economic and social development of humanity in a way that is compatible with the obligation to keep the planet livable for future generations (Sachs 2002). The term 'sustainable development' emerged in 1980 and gained special attention in 1987, in the Brundland report titled "Our Common Future." It is defined as the meeting of current needs without compromising the needs of future generations (UN 1987; Berchin 2017). Thereafter, the practice of attempting to move toward the sustainability concept was incorporated into governmental, corporate and community planning (Góes and Magrini 2016; Adams et al. 2017).

Aligleri (2016) noted that the integration between the three dimensions (social, environmental and economic) has been adapted for the business sector by John Elkington in his book "Cannibals with Fork and Knife: The Triple Baseline in twenty-first Century Business", published in 1997, using the term triple bottom line (TBL). The TBL guidelines relate the economic dimension to profits and losses, the social dimension to the quality of life of people in organizations and the environmental dimension to the care of the planet.

Ensuring sustainable production and consumption patterns is one of the main challenges of the millennium, with the goals of sustainable development set by the UN. More precisely, Goal 12 proposes, by 2030, to substantially reduce waste generation through prevention, reduction, recycling and reuse. Concern about the quality of water bodies is also on the UN agenda, and Goal 6 proposes, by 2030, to eliminate dumping and minimize the release of chemicals and hazardous materials. Given these concerns, investment in technologies to minimize or eliminate waste production is increasing.

In recent decades, there has been a major change in the corporate universe. Companies that were seen only as institutions with economic objectives started to incorporate new roles, including greater social and environmental commitments. Among the different variables that affect the business arena, a concern with beauty and well-being while at the same time considering the environment has gained significant prominence, affecting the corporate image and economic results. From this new perspective, companies are gradually changing their attitude toward environmental aspects, in a process of reconciliation between production and environmental concerns, aimed at achieving sustainable development. In this context, some production procedures have been reviewed, seeking alternatives that can eliminate or reduce waste generation and improve socioeconomic gains.

The Cosmetics Industry Waste

Currently, there is a growing number of consumers of skin care products, due to the gradual awareness of early ageing and, more importantly, skin diseases. With the progressive expansion of this branch, in the last two decades the world production of cosmetics has increased by 4.5% annually. According to Research and Market (2019), the global market for cosmetics and personal care products amounted to US$ 128.9 billion in 2018. Considering a growth rate of 4% per year, by 2024 this could reach US $ 165.9 billion (Market 2019). Based on these data, it can be predicted that with the increase in cosmetic products there will be a significantly higher level of waste generation.

According to Juliano and Magrini (2017), cosmetics are divided into two major classes, the leave-on products, which are applied directly to the skin for hydration and decorative purposes, and the rinse-off products, mainly personal hygiene products (toothpastes, shampoos, soaps and gels). Observing the variety of products available and considering the high levels of consumption, there is concern about the destination of these products after their use.

The main hygiene and personal care products, such as shampoos, UVA blocker, deodorants, creams, facial cleansers, make-up removers and toothpaste, may have heavy metals in their composition, such as lead, chromium, nickel, aluminum, copper and cadmium (Fischer et al. 2017). Additionally, some formulations contain fatty acids, surfactants, petroleum derivatives and detergents. Therefore, part of these compositions generate industrial by-products along with wastewater and are characterized by relatively high values for chemical oxygen demand (COD) (>100.000 mg/L) (Bautista et al. 2007; Abidemi et al. 2018). Thus, appropriate treatment is required to avoid environmental damage.

Each country establishes its own regulatory stipulations. In Brazil, for instance, there is an environmental technician's guide based on regulatory norms issued by ANVISA (Health Surveillance Agency of Brazil). This was based on the recommendations of chemical engineers, environmental personnel and other professionals working in the cosmetics and personal care products, qualified people involved in the production process and specialists in solid and liquid waste treatment. This guide considers all of the stages from the receipt of raw materials to the dispatch of the products and details the residues generated in each one of them (Souza et al. 2005). An overview of these stages can be observed in the flowchart in Table 18.1.

This general flowchart is not necessarily applicable to all industries, and it represents only a small part of the production and waste aspects. In addition, other residues

Table 18.1 Overview of stages involved in the cosmetics industry

ENTRIES	STEPS	OUTPUTS
Raw material and materials	RECEIPT OF RAW MATERIALS	-
Packaging materials; Pallet, Pallets; Electric power; Emergency Kit.	STORAGE	Packaging waste; Residue of floor sweeping; Absorbent Material; The Pallets.
Packaging materials; Raw materials; Electric Power.	WEIGHING AND SORTING RAW MATERIALS	Packaging waste; Material retained in ECPA[3] (POST); Waste and wastewater from cleaning of equipment and floors.
Packaging materials; Raw materials; Electric power; Auxiliary inputs.	PRODUCTION	Packaging waste; Waste and wastewater from Cleanings of equipment and floors; Atmospheric emissions.
Laboratory materials; Microorganisms; Chemical products (solvents, preservatives, emulsifiers and the like).	ANALYSIS PHYSICOCHEMICAL AND/OR MICROBIOLOGICAL (WHERE APPLICABLE)	Waste samples analysed; Autoclated Material and Culturemedia; Out-of-date and/or contaminatedsolutions.
Packaging materials; Plastic and glassjars and jars; Electric power; Auxiliary inputs; The stickers.	FILLING/PACKING	Packagingwaste; Vials and jars with defects; Waste and wastewater from Cleaning of equipment and floors; Adhesive residue.
Packaging materials	STORAGE THE FINISHED PRODUT	Packagingwaste; Residue of floor sweeping; Products expired/returned or damaged.
-	EXPEDITION	-

Source Souza et al. (2005)

continue to emerge, including metals, fatty liquids, volatile organic compounds, solvents and odors (Souza et al. 2005).

To maintain strict quality control in cosmetics, the cleaning of machinery requiring the use of water is extremely important. In addition, there is a demand for pure water in the formulations and water is used in cooling systems. All of these result in the generation of residual liquids from the cosmetics production process, and the components of this wastewater can be of low biodegradability, especially if they contain dyes, traces of UVA protector, fragrances and surfactants, and particularly if they are non-polar molecules. Thus, the application of biological degradation by microorganisms is not feasible (Abidemi et al. 2018).

Therefore, new technologies have been implemented to mitigate the impacts of this highly pollutant industry. These processes address environmental, energy and economic issues and are carried out prior to waste disposal in landfill. The waste is often treated by pressure flotation or coagulation/flocculation to separate the sludge, pH correction, flake separation by decantation and filtration. After this, the industrial effluent joins the sanitary effluent and undergoes biological treatment using anaerobic or aerobic systems (Bautista et al. 2007; Demichelis et al. 2018).

In addition, researchers have demonstrated the concentration of polyethylene microplastics in facial exfoliants and toothpaste which reach the oceans through wastewater discharge to a large extent. These particles bioaccumulate, making their degradation and treatment extremely difficult (Chang 2015; Brausch and Rand 2011). Another issue is that cosmetics products are commonly packaged using plastic, paper and cardboard, and the waste generated is one of the most significant impacting factors of the sector, with waste originating both during the production process and post-consumption (Souza et al. 2005). Thus, it can be observed how significant the environmental impacts of the cosmetic industry can be.

The term microplastic was first used by Thompson in 2004 to define small-sized plastic particles (<5 mm). This dimension was proposed in 2015 at the international workshop organized by the National Oceanic and Atmospheric Administration (NOAA) (Peng et al. 2020). Although 5 mm is defined as the maximum size, smaller dimensions, including nanoparticle-sized particles, are likely to be present in the environment. The term microspheres is used in the industrial context to describe microplastics, but they can also be referred to as nanospheres or plastic particles. 93% of the microparticles used in the cosmetics industry are comprised of polyethylene (Napper et al. 2015). Microplastics can be classified into primary and secondary, according to the origin of the material. The primary microplastics, also known as "pellets," are produced with a small size to be added to the formulation of certain products, including some developed by the cosmetic industry, such as skin cleansing products, exfoliating soaps and toiletries like toothpaste and shaving creams (Thompson 2016).

Microparticles can also be used in medical applications, the pharmaceutical industry and in dental polishers (Napper et al. 2015; Peng et al. 2020). These products are normally used in households and are subsequently transported to watercourses in domestic effluents. Even with the application of waste treatment, millions of plastic particles pass through the filtration systems due to their small size. Recent studies in the USA have shown that microspheres are not completely removed in wastewater and, therefore, they are present in treated effluents (Wu et al. 2017). The per capita consumption of microparticles used in cosmetic products in the US has been estimated to be approximately 2.4 mg per person, which leads to 263 tons per year of polyethylene microplastics, corresponding to approximately 25% of the annual amount of plastic waste present in the oceans (Napper et al. 2015). In 2015, the US government introduced a law called the Free Water Law, prohibiting the sale of personal care products containing plastic microspheres; and other countries, such as Canada and Australia, are moving toward a similar measure, thus eliminating a large source of microplastics (Wu et al. 2017).

The use of microplastics in cosmetic formulations has been banned in the United Kingdom and Brazil since 2016. In Brazil, Federal Law PL 6528/2016 has been discussed and approved, which prohibits the handling, manufacture, importation and marketing, nationwide, of personal care, cosmetics and perfumery products containing the intentional addition of plastic microspheres (Montagner 2018).

The other type of microplastics is secondary, resulting from larger plastic products disposed of improperly in the environment and these can also be found in aquatic environments (Thompson 2016). The human population is generally located in terrestrial environments, but studies indicate that the entry of microplastics into the ocean occurs via 3 main routes: winds (known as airways), the soil, and water, since rivers receive plastic waste in sewage, soil runoff and direct disposal by individuals. The microparticles are thus transported to the oceans and through ocean currents and turbulence caused by vessel traffic; these low density residues can be transported over long distances (Peng et al. 2020).

It has been proven that the amount of microplastics present in marine waters is increasing, and the microspheres that are used in cosmetics are easily released into the marine environment and are being ingested by marine organisms, such as fish, crustaceans, birds and mammals. Researchers have investigated the occurrence of microplastics in biological samples of mussels collected in the Santos Estuary (Brazil), and 75% of the samples analyzed showed microplastic contamination (Montagner 2018).

The presence of microplastics in the marine environment is a global issue, and mitigation requires cooperation from national and local governments around the world. The removal of microplastics from the marine environment is inhibited by their size. Also, the particles are widely dispersed and the costs of removal would be prohibitively high. It is estimated that the quantities are increasing, and most of the microspheres found are blue and white, similar to various types of plankton, which are the main sources of fish food. Analysis has shown that these residues are present in the stomachs of these organisms (Napper et al. 2015).

Studies have also found the presence of 50–280 microplastic particles per kilogram of salt, for a total of 21 salt samples marketed in Spain (Olivatto et al. 2018). Only with a change in society's consumption patterns in relation to synthetic products will it be possible to reduce microplastic contamination and thus guarantee the quality of natural resources that will benefit future generations. Some of the biodegradable materials that are being developed may replace the production of microspheres, including polylactide (PLA) and polyhydroxyalkanoates (PHA) (Wu et al. 2017).

Besides microplastics, Brausch and Rand (2011) warned of other issues associated with environmental contamination by cosmetics residues, and they summarized their considerations as follows: "(1) environmental concentrations of triclosan and triclocarban, preservatives, and UV filters, (2) chronic data for toluamides and preservatives, (3) endocrine effects of fragrances, (4) bioaccumulation and biomagnification of UV filters, and (5) acute data for triclosan and UV filters." As the global trend is toward increased consumption of cosmetics, the effect of the disordered release of effluents containing these residues is of great concern. In this context, surfactants, parabens and triclosan have gained attention due to the large amounts released into aquatic environments.

Surfactants represent an especially challenging group as there are several different classes and each behaves differently during urban wastewater treatment. In general, surfactants stick to microbial flakes in conventional biological wastewater treatment and are transferred from the effluent to the final disposal site of the sludge. Commonly mentioned approaches are removal by adsorption/desorption techniques onto zeolites and magnetic compounds, electrostatic micelle aggregation and micellar ultrafiltration (Palmer and Hatley 2018).

In relation to parabens, the microbial resistance factor is a major obstacle to be overcome, as parabens have antimicrobial properties. According to Wang and Kannan (2016), the mechanisms for the removal of parabens and their metabolites in wastewater treatment plants can vary depending on the chemical structure, sorption, treatment method and season, among other factors. Advanced oxidative processes can be applied in the treatment of parabens, including ultraviolet treatment and heterogeneous ultraviolet-activated photocatalysis (Mishra et al. 2017).

Triclosan is widely used as a preservative in toiletries. According to Holzem et al. (2017), triclosan dispersed in biological effluent treatment plants acts as an inhibitor of several enzymes and it has a notable effect on the nitrogen cycle. Another concern is that the partial degradation of triclosan can lead to the formation of polychlorinated biphenyls, dioxins and chlorophenols, which are persistent organic pollutants that cause serious harm to human health even at low concentrations (Tiburtius and Scheffer 2014). Triclosan is also considered as a persistent organic pollutant, but it can be removed in treatment by advanced oxidative processes that have the power to degrade resistant compounds (Mishra et al. 2017; Anupama 2018).

Advanced oxidative processes are not applied in isolation but rather as a complementary treatment for resistant organic molecules which are not removed by conventional processes. They involve the use of energy sources (e.g., ultraviolet light), and reagents, such as hydrogen peroxide, ozone, plasma, and photocatalytic agents (titanium dioxide) (Cubas et al. 2016; Anupama 2018; Magureanu et al. 2011). These processes generate hydroxyl radicals, which have one of the highest oxidative potentials of the species used as pollutant degraders. In addition, traditional methods, such as the Fenton process, have been used in combination with other advanced oxidative processes.

The research horizon on the treatment of this type of waste is wide. New technologies have been studied to make treatment processes less expensive and more widely applicable, aimed at reducing the environmental impact of the cosmetic industry.

Coupled to the waste treatments, many scientific studies have focused on the sustainable development and optimization of the cosmetics industry. In general, the focus is based on the preparation of products that are increasingly effective in their goal, i.e., allow better spreading and/or absorption when applied to the skin, better tactile and visual properties and greater cleansing efficiency, but without creating adverse effects on the skin, mucous membranes or hair.

In addition, with technological advances and increased access to and dissemination of information, consumers are becoming more demanding with regard to cosmetic formulations. They are concerned not only with the composition, but also the place where the raw material is acquired, how the product was manufactured and the whole life cycle of the product, in order to assess the environmental impacts associated with acquiring the product (Feng 2016).

In order to fulfill the requirements of the consumer, Cosmetics Europe is working with its members to encourage cosmetics companies that operate in tandem with sustainable dynamics and the promotion of good practices, including the adoption of life cycle analysis (LCA) and eco-design products. The producers are increasingly adhering to methodologies for environmental assessment, linked to social and ethical positions, and there is also considerable interest in replacing petroleum derivatives with biodegradable and renewable ingredients (Secchi et al. 2016).

There is still much advancement to be achieved and analysis to be carried out, mainly in relation to the impact currently associated with the cosmetic industry, since unfortunately, scientific data and information is not always available. These advancements could represent the first steps towards a less polluting industry, which adopts cleaner and more renewable technologies that ensure the implementation of environmentally acceptable procedures aimed at reuse and zero waste policies.

Textile Industry Waste

The growing increase in textile consumption is due to the increasing world population and the various manifestations of cultural patterns (Dissanayake et al. 2018; Parisi et al. 2015; Yasin and Sun 2019). Due to the importance of economic growth around the world, the use of technological advances that fulfill the consumer demands without concern for the environment is leading to adverse environmental impacts, such as resource depletion and pollution through the generation of waste and the use of harmful chemicals (Fischer and Pascucci 2017; San et al. 2018).

The textile industry is one of the largest providers of products and jobs in developing countries, mainly due to the occurrence of the Fast Fashion production model (Haslinger et al. 2019; Pinheiro et al. 2019). However, the textile sector is among the most pollutive markets, due to the overuse of water, energy, chemicals and inappropriate waste disposal (Hu et al. 2018). However, since 2015, the textile industry has had an annual textile fabric manufacturing capacity of approximately 100 million tonnes, with around 32 kg of textile materials per person currently being rejected worldwide each year. This represents 85% of the total volume disposed of in landfills or incinerated, contributing to an increase in environmental impacts, such as the excessive use of water, energy and chemicals and the improper disposal of waste (Hu et al. 2018; Nikolic et al. 2017). When solid (such as fabric waste) and liquid (through dyeing processes) wastes are not properly disposed of, there are numerous environmental consequences, including the contamination of soil and water bodies and the obstruction of canals and drainage systems (Peña-Pichardo et al. 2018; Oliveira Neto et al. 2019).

In the dyeing process, for example, substances associated with environmental problems, such as naphthol, sulfur, enzymes, soap and dyes are used, and chlorine can react with disinfectants during the manufacture of clothing, resulting in carcinogenic compounds (Peña-Pichardo et al. 2018). Consequently, one of the major concerns for the textile industry is the wastewater generated, which can contain dyes, metals, phenols, toxic compounds and/or phosphates, which are not properly treated in traditional water treatment plants (Yukseler et al. 2017).

These concerns associated with textile waste are global, involving both developed and developing countries, and the environmental degradation results from a production chain that interconnects various processes and also has social and economic implications (Pinheiro et al. 2019). In this context, research has been carried out to find mitigating measures and cleaner technologies to solve the problems associated with the textile and clothing industries (Oliveira Neto et al. 2019; Sarwar et al. 2017).

In Australia in 2016, for example, the government together with the New South Wales Environmental Protection Authority (NSW EPA) invested in economic resources to propose that textile waste be returned to the industrial system for new uses. The project was named the Circular Threads Initiative (Echeverria et al. 2019). In Belgrade, Serbia, a group of researchers conducted a study on bioethanol production using cotton waste. They analyzed the fibers and performed procedures such as mercerization and corona pretreatment. It was concluded that mercerized cotton was one of the best starting materials for the manufacture of bioethanol (Nikolić et al. 2017).

Research on the reuse of textile waste for building materials has also been carried out. In Sydney, municipal textile waste mixed with sawdust from the furniture industry (as a secondary material) was analyzed by inductively coupled plasma mass spectrometry (ICP-MS-IC) and Fourier transform infrared spectroscopy (FTIR). The results confirmed the possibility of using this approach to obtain a low-carbon, non-toxic commercial alternative material for construction applications (Echeverria et al. 2019).

For the treatment of textile wastewater, a review was carried out in Poland on the different types of treatments possible with advanced oxidation processes (AOPs) and biological processes. The conclusion was that biological processes are cheaper than chemical oxidation because biodegradation with the use of microorganisms, practiced under industrial conditions, forms an activated sludge or a biofilm (the latter less frequently) (Paździor et al. 2017). In Phnom Penh, the capital of Cambodia, a study was conducted on the use of the Industrial Pollution Projection System (IPPS), which is an archetype for calculating industrial pollution in developing countries. This city has over 1302 textile factories but no proper processing procedure, and this system serves to provide data for regulatory agencies to prioritize and reinforce monitoring practices (San et al. 2018).

Valuing the potential of the textile industry as a source of income and economic development for both developing and developed countries is of paramount importance, but there is an urgent need to modify industry standard models to make the practices more sustainable (Parisi et al. 2015; Sarwar et al. 2017). Therefore, investments in projects that act effectively in the waste treatment of the dyeing process are required in the textile industry (Chen et al. 2015). Also, partnerships should be sought with other sectors to reuse textile waste in other technologies, such as for producing alternative building materials (Peña-Pichardo et al. 2018; Echeverria et al. 2019).

Final Considerations

According to the World Health Organization, health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity. Addressing concerns regarding beauty through the use of cosmetics and fashion helps people feel healthy. However, it is necessary to produce cosmetics and textiles without harming the environment, by working together with green chemistry initiatives in the areas of cosmetics and textiles, using new biodegradable materials from renewable sources and lowering the water consumption required during production.

A circular economy is also a concept that merits discussion in the cosmetic and textile industries, considering that the waste from one company could be used as a raw material for another.

In addition, it should be emphasized that sustainable development practices need to be applied not only in order to provide new green alternatives for these industries, but also to prioritize the environment effectively while considering both social and economic aspects.

This requires changes in terms of the market guidelines, by viewing sustainability and the circular economy as providing new possibilities for growth and achieving environmental and social responsibility, encouraging incentives for sustainable practices provided by government and private institutions.

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Chapter 19
The Importance of Women's and Girl's Education for the Achievement of Sustainable Development: A Literature-Based Review

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Abstract Gender equality and the empowerment of girls and women became a popular debate within the discussion on sustainability since its establishment in 2015 as a sustainable development goal by the United Nations 2030 agenda, due to the fact that several issues related to the economic, social and environmental spheres impact women and men differently. In this sense, education emerges as a gender equality driver once it improves women's access to productive assets, resources and opportunities, such as sustainability education, training and employment; this results in an adequate standard of living that contributes to women's bargaining power within the family and the community, and the creation of a sustainable equality. From this perspective, this article uses a literature review to present the importance of women's education for the promotion of sustainable development, contributing to future studies and the creation of public policies related to gender equality.

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Introduction

Gender equality lies at the heart of the 2030 Agenda for Sustainable Development, an ambitious and universal plan of action to achieve the 17 Sustainable Development Goals (SDGs) within 15 years, with a central pledge to leave no one behind (2015). The Agenda recognizes that achieving gender equality is a matter of human rights and is crucial to progress across all the goals and targets. Besides being a goal itself, gender equality is included in all 17 Sustainable Development Goals, and it is reflected in 45 targets and 54 indicators for the SDGs (UNDP 2018). Gender equality can also be a catalytic policy intervention that triggers positive multiplier effects across the spectrum of development. From this perspective, gender equality is necessary for achieving a wide range of objectives pertaining to sustainable development: promoting economic growth and labor productivity, reducing poverty, enhancing human capital through health and education, attaining food security, addressing climate change impacts, strengthening resilience to disasters and ensuring more peaceful and inclusive communities (UNDP 2018).

Gender equality recognizes that although women are not inherently vulnerable, they are the agents of transformative change. Achieving gender equality requires that the needs, capabilities, experiences and contributions of both girls and boys and women and men are taken into consideration, while also acknowledging their diversity. It is not about transferring opportunities from men to women, but about creating conditions where each person regardless of his or her gender has the right and ability to realize their human potential (Kabeer and Natali 2013; OSAGI 2001).

Gender inequalities are manifested in every dimension of sustainable development (UN WOMEN 2018a). According to UN Women (2018a), when households cannot access sufficient food, women are often the first to go hungry. While girls are increasingly doing better in school and university than boys, this has not translated into gender equality in the labor market; the gender pay gap stands at 23% globally, and without decisive action, it will take another 68 years to achieve equal pay. While women have made important inroads in politics across the world, their representation in national parliaments at 23.7% is still far from parity, and women politicians and voters face threats and attacks, persistent sexual harassment and online abuse. Despite the increasing presence of women in public life, women continue to do 2.6 times the unpaid care and domestic work that men do. Women and girls are also the main water and solid fuel collectors in households without access to an improved water source and clean energy in their homes, with adverse implications for their health and safety. In the Resolution on the 2030 Agenda, the General Assembly declares that the realization of the gender equality issue and the empowerment of women and girls will be a crucial contribution to the achievement of all the goals and targets (EU 2016).

Table 1 It summarizes the articles that were selected for analysis according to their relevance to the research question

Keywords	Science direct		Scopus	Web of science
women + sustainable development	140,228		1805	74
women + sustainable development goals 3	200		17	0
women education + sustainable development goal	55		8	0
Total of selected articles			57	

Methodology

The development of this article happened in the context of a literature review, as proposed by Arksey e O'Malley (2005) and corroborated by Levac et al. 2010. This method was chosen, as this article seeks to evaluate how women's education can contribute to sustainable development, using an analysis of the literature. Considering that the topics of sustainability and gender equality are vast, this type of research was considered as adequate.

The process of literature review presented by this article was inspired by the Arksey e O'Malley (2005) process. The first step is the identification of the research question; in our article it was defined as: How can women's education contribute to sustainable development? The second step refers to identifying relevant literature to help answer the research question. In order to do that, research was conducted for articles in three databases, chosen for their level of international relevance: Scopus, Science Direct and Web of Science.

For the literature review, the following keywords were chosen: "women education," "sustainable development" and "gender equality." In each database, a search was conducted using each individual keyword and their combinations.

The third step corresponds with the selection of articles for reading; due to a great number of articles found by the Boolean equation, only the 20 most relevant and 20 most cited for pre-analysis of material were selected. After pre-selecting the articles in databases and reading titles and abstracts, 68 articles were selected for analysis according to their relevance to the research question. The results of this research are summarized in Table 1.

From that, 21 complementary articles were used to expand the discussion and develop the analysis presented in the following sections.

Women in Sustainable Development

Sustainable development became popular in the mid-1980s. The term sustainable development results from the change of human perspective on what development is, an understanding that has gradually changed over the years until it became the concept of sustainable development known today. In the 1950s and 1960s, the emphasis was on the growth and potential of a country in terms of production, but since 1970 the concept also began to address issues such as social development and income distribution (Bayeh 2016). There are many different perspectives on sustainable development. We can distinguish two views; one is portrayed by ecocentrism that links the environment to the socioeconomic point of view, moving towards social and economic equality, while on the other hand ethnocentrists are more likely to support the economic and political status quo (Domańska, Żukowska and Zajkowski 2019).

Thus, with the impact of economic growth on the environment, the concept of sustainable development started to be cited as the development that meets current needs without compromising the ability of future generations to meet their own needs (WCED 1987). In addition, sustainable development is understood to have three interlinked pillars: social, economic and environmental (Warth and Koparanova 2012; UN 2007).

Since sustainable development incorporates these three aspects, the United Nations documents of the 1990s highlight the fact that the presence of women is indispensable for the progress of sustainable development (Vargas 2002) and that sustainable development is impractical without women's empowerment and equity of gender (Alvarez 2013). In 2015, the Sustainable Development Goals (SDGs) were recognized by a total of 193 United Nations member states, and they reflect an overall perception of the relevance of gender equality in the process of sustainable development. Although the path of women is recognized in managing the scope of sustainable development, it is not well defined. Ecofeminism, feminist political ecology, gender and hegemonic masculinity literature provide guidelines for what is believed to be the main difficulties and contributions of women leading sustainable development (UN 2015). Women's movements, especially feminism, that work within and outside transnational spaces have historically contributed to changing and mainstreaming gender discourse in sustainable development spaces, such as the United Nations (Shinbrot et al. 2019).

Sustainable development requires the socio-economic and environmental contributions of women, which tend to intensify when women are healthy, valued, strengthened and empowered, and on the path to achieving their fullest development in all areas of their lives, including their health care posts (Langer et al. 2015). When women have a good quality of life and health over the years, gender equality can also be achieved. In addition to their productive capacity, women's ability to choose alternatives and control their fertility is a critical factor in achieving healthy development (The Lancet 2015; Kim and Evans 2015); that is, when women are able to acquire their human rights and enjoy them to the full potential, the economy and society will gain long-term benefits (Langer et al. 2015).

On another level, over the years much evidence has revealed that women are uniquely positioned as administrators of natural wealth (Quisumbing et al. 2001; Nightingale 2011). In all corners of the world, females are intensively engaged in growing food for self-consumption and also for export. The food that women produce usually represents basic nutritional needs, including crops such as rice, maize and pulses. All of this will contribute to sustainability, beyond what we can imagine (FAO 2011).

According to the World Commission on Environment and Development (1987), when a woman is healthy, educated and motivated, she is prepared for many roles such as being a mother, caregiver, worker, volunteer and leader, influencing the organization of societies and fostering sustainable development. Under these conditions, women will not only be empowered to provide better services with greater support, but also to seek education and employment opportunities, thereby developing their essential human rights and contributing to sustainable development (Langer et al. 2015).

However, women's fertility has been pointed out as an element that significantly influences the three pillars of sustainable development (Dasgupta and Ehrlich 2013). High fertility increases population growth and pressures on the environment and can restrict women's chances of reaching their full economic potential (The Lancet 2015), besides affecting consumption patterns, which generates consequences for environmental sustainability. Moreover, the persistent exclusion of women and the restriction of their chances to build and realize their human capital may be the result of the intense economic, social and health impacts of high fertility, generating impacts that extend into the next generation (World Health Organization 2015).

By giving women greater control over their fertility and rigorously addressing the gender discrimination that extends over many years, there will be greater support for their self-reliance and greater scope for training and work opportunities (UN and UNFPA 2012), in both the social and political contexts. Women's reproductive health is affected in times of war. At the time of the Iraq-Kuwait conflict, for example, child and maternal mortality increased to more than double in Iraq from 1990 to 1996 (Webster 2013). In this regard, eight of the ten countries with the highest maternal mortality rates are affected by political instability and confrontation (Black et al. 2014). The Sustainable Development Goals (SDGs)—which emerged in 2016 with the great expectation that they could promote social, economic and environmental development (Kim 2017)—consist of 17 objectives that involve environmental sustainability, social inclusion, economic development, peace, justice, good governance and partnership. Goal #3, which stipulates health and well-being for everyone at any age, consists of nine main targets, including the decline of maternal and child mortality, substance abuse and car accidents (Gómez-Olivé and Thorogood 2018).

Sustainable development is and will continue to be just a dream that will not become reality if women's development is not put on the agenda. Over the years, women have been greatly affected, and it is time to change this reality. Thus, states and international bodies must address the specific needs and problems of women and put their issues at the center of the international community's priorities. Their rights must be demanded as a matter of the utmost urgency and be placed at the top of the global human rights agenda, because the prerequisite for sustainable development is the development of women (Zahedi 2008; Shailaja 2000). In addition to women, who are historically engaged in the preservation and care of natural resources (Singh 2014), community participation is also key to sustainable development (Pandey 1998).

Women's Education

Since the UN Decade for Women of 1975–1985, several techniques and practices aimed at women's empowerment and gender equality have been adopted around the world to promote a sustainable development method that encompasses all social spheres (Stumpf 1984). Later, the Millennium Development Goals included "gender equality and women's empowerment" in its objective 3. Subsequently, that agenda inspired the adoption of the same theme within the sustainable development goals created from the UN 2030 agenda (UN 2015). In this regard, it is evident that gender equality is extremely necessary to ensure a future of growth beyond the economic sphere, one which aims at improving the quality of life of their populations and environmental preservation, since women are the most affected by employability issues and working conditions (Wyndow et al. 2013).

From this standpoint, women's education emerges as a driver for gender equality and women's empowerment as it promotes female emancipation in contexts of inferiority, violence and financial and psychological dependence, making them not only actors in sustainable development but also decision-makers, acting to ensure an improvement in the quality of life of the general population and to strengthen democratic principles (Shields 1987).

In the context of public health, Jones and Frick (2010) point out that women's education promotes not only the prevention of unplanned pregnancies but also the dissemination of knowledge related to nutritional, mental and physical improvement of the household, since women are still primarily responsible for raising children. Thus, female education plays a key role in controlling population growth and birth rates in countries such as China and India, as well as in helping to guarantee children's rights (Susinos et al. 2008). From this, Weitzman (2017) uses a case study to show that women's education is directly linked to the decrease in maternal mortality, since obstetric safety rises from cognitive development and increased material resources promoted by female income growth.

The education of girls and women is essential for the creation of an environmental awareness that goes beyond the academic sphere, becoming practical in different social and climatic contexts. Due to women's greater vulnerability to the previously mentioned issues, it is necessary to promote incentive programs for the creation of environmental awareness that exposes the differences in the context of gender (Peterson and Merchant 1986).

In the economic sphere, education emerges as an equality driver since women's education plays a key role in the achievement of equal payment and treatment, and an increase of autonomy, salaries, savings, life expectancy and employment rate. In this sense, women's education affects all of society, since the inclusion of women in the labor market gave voice to a different perspective from that observed during the previously male business monopoly. The spread of this new vision contributes to the creation of public policies that promote female education and employability, contributing to the empowerment of future generations (Schultz 2002).

Importance of Women's and Girl's Education for the Achievement of all the SDGS

Access to education for girls and women helps to achieve SDG #1 (No Poverty) and SDG #2 (Zero Hunger). According to Klasen (2002), for every extra year of primary education, a girl's individual wage rate increases an average of 10–20%, and by 25% with an extra year of secondary school. 90% of a mother's wage goes towards care for her family, thus lifting a household out of poverty and hunger (Klasen 2002). When women obtain education, they are able to earn an income and engage in productive activities, hence raising the living standards of their families (Loewe and Rippin 2015). Investments in better education for women positively affect the children's well-being and development, which contributes to creating a healthier, more educated and more productive workforce, decreasing the risk of poverty (UNDP 2018).

In addition, women are more involved than men in agricultural productivity and feeding families. Better use of agricultural biodiversity can contribute to more nutritious diets and generate decent incomes. If women have access to the right information, then there will be reduced hunger and malnutrition (McGuire 2015). Women play a critical role in food production, processing and distribution, but they are more likely to suffer from food insecurity than men. Empowering women is essential in order to achieve the agricultural productivity and nutrition targets of SDG #2 (UN Women 2018b). Education is vital to eliminate malnutrition in the long term, especially education that empowers women. Malnutrition is the underlying cause of more than a third of global child deaths. Mothers who are educated are more likely to ensure that their children receive the best nutrients to help them prevent or fight diseases; they also know more about appropriate health and hygiene practices (UNESCO 2013).

On achieving SDG #3 (Good Health and Well-being), according to a study by UNESCO (2013), if all women had a primary education, there would be 15% fewer child deaths. If all women had a secondary education, child deaths would be cut in half, saving almost 3 million lives across the globe. Furthermore, the study showed that an educated mother improves nutrition. If all women had a primary education, 1.7 million children would be saved from malnutrition; 12 million would be saved if all mothers obtained a secondary education (UNESCO 2013).

Besides the care for their children, a mother's education is crucial for her own health. Almost 800 women die every day from preventable causes related to pregnancy and childbirth, including pre-eclampsia, bleeding, infections and unsafe abortion. Educated women are more likely to avoid these dangers by adopting simple and low-cost practices to maintain their hygiene, by reacting properly to symptoms, and by making sure a skilled attendant is present at birth. If all mothers completed a primary education, maternal deaths would decrease by 60%, saving approximately 98,000 lives. In sub-Saharan Africa, if all women completed primary education alone, maternal deaths would be reduced by 70%, saving 50,000 lives (UNESCO 2013).

Adolescent girls and young women around the world face gender-based inequalities, such as exclusion, discrimination and violence, which put them at increased risk of acquiring HIV, the leading cause of death for women of reproductive age worldwide (GBD 2016). More engagement in productive activities and increased income for women, mainly through education (Loewe and Rippin 2015), leads to an increased investment in the family's well-being, thereby improving the physical and mental health of family members. Better education among women and girls also contributes to lower mortality from weather-related disasters (UNDP 2018).

SDG #4 is about quality education; education can play a part in raising awareness of unjust treatment and can provide skills and experience that give the psychological boost for a person to take action. If a woman knows of positive role models or has the support of a community, then she would feel more empowered over her life. Women in different parts of the world are forced to discontinue their education due to poverty, poor infrastructure or lack of awareness. This resulted in low literacy levels among women all around the world (UNAPCICT 2016). The presence of female teachers in schools is also important to provide the girls with a role model UNESCO (1993).

According to Somani (2017), educated girls tend to become role models and inspire others to pursue education. Education gives them the ability to positively influence their lives and the lives of their families and wider communities. Educated women tend to take leadership roles, especially within the community, and focus on societal development. In summary, educating girls is critical for the development of communities and broadly for society as a whole. It is necessary to increase awareness about the importance and impact of educating girls, enabling communities to make appropriate choices and provide an enabling environment to achieve gender parity in education. Education is the most sustainable way to address global challenges like poverty, health issues, ignorance, lack of tolerance and conflicts, among others (Somani 2017). According to UN Women (2018b), each additional year of post-primary education for girls has important effects, such as expanding their employment outcomes, decreasing the chance of early marriage and improving their health and well-being.

SDG #5 sets gender equality and the empowerment of all women and girls as a goal. According to UN Women (2018a), women's rights advocates fought hard to achieve not only the specific goal on gender equality, but also to integrate it across other goals and targets, drawing attention to the gender dimensions of poverty, hunger, health, education, water and sanitation, employment, climate change, environmental degradation, urbanization, conflict and peace, and financing for development. Besides that, to mitigate climate change impacts, gender equality is critical. Women's inclusion in climate discussions leads to improved outcomes of climate-related projects and policies (UN Women 2018b).

One of the many targets of SDG #5 is to ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic and public life (UN 2015). Poor women living in rural areas and indigenous populations, who are dependent on local nature resources for their livelihood, are disproportionately affected by climate change. The majority of female agricultural workers also face severe inequalities in their access to land, credit and essential assets such as fertilizers, irrigation, technology, and even information (UN Women 2018b).

According to UNESCO (1995), formal education provides substantial contributions to improved gender identity through the removal of sexual stereotypes in textbooks, the fostering of positive gender identities through the curricula, the retraining of teachers to be gender sensitive, and the provision of nonsexist guidance and counseling. Today, women and girls continue to suffer discrimination and violence in every part of the world. Gender equality is not only a fundamental human right but a necessary foundation for a peaceful, prosperous and sustainable world. Providing women and girls with equal access to education, health care, decent work and representation in political and economic decision-making processes will fuel sustainable economies and benefit societies and humanity at large (UN 2010). Gender equality is central to the achievement of all the SDGs. If it is not achieved, the implementation of the 2030 Agenda will be jeopardized (UN Women 2018b).

SDG #6 is about ensuring access to water and sanitation for all. For women, gender discrimination magnifies and adds to the risks. In general, natural disasters kill more women than men and kill women at a younger age than men. If she survives a disaster such as a flood or earthquake, a woman will likely have fewer options to recover (UN Women 2016). Women and girls already play a central role in the provision, management and safeguarding of household water and sanitation, and it would only get better with the help of education and more information. Addressing the water and sanitation needs of women would benefit the health and well-being of entire communities (UN Women 2018a).

SDG #7 focuses on affordable and clean energy, and as primary energy managers in households, women can play a powerful role in the successful transition to sustainable energy for all (UN Women 2018a). Engaging women in the use, development and distribution of renewable energy-based agricultural technology can improve crop yields, thereby resulting in the increase of women's incomes and productivity and contributing to children's education and health (UNDP 2018).

On the topic of SDG #8, Decent Work and Economic Growth, women with an education are more likely to work, create economic growth and develop their communities. Gender equality contributes to economic development in several ways, one of which is the direct link of female education and participation in the labor market. Gender inequality in education and employment affects economic growth, because it reduces the average amount of human capital in a society and thus harms economic performance (Klasen 1999, 2002). It does so by artificially restricting the pool of talent from which employers can draw, thereby reducing the average ability of the workforce (Dollar and Gatti 1999; Esteve-Volart 2004). This also impedes the development of new ideas, which is critical for entrepreneurship and economic diversification, the important drivers of sustainable growth (Herrington and Kew 2017; Kazandjian et al. 2019). Women are less likely to participate in the labor market, and when they do, it is often in informal settings, with insecure and low-wage employment. Occupational segregation and gender pay gaps persist everywhere in the world (UN Women 2018b). The reduction of gender gaps in the labor market and the increase of gender-equal access to resources, assets and technologies have positive effects on employment generation, labor productivity and economic diversification. Reducing gender gaps in the labor market could increase global employment by 189 million, or 5.3%, by 2025. (UNDP 2018).

SDG #9 is about industry, innovation and infrastructure. Women's access to education and employment contributes to industrialization (UNDP 2018). Increasing women's participation in technology, science and innovation is critical for meeting the global challenges ahead (UN Women 2018a). SDG #10 is about reducing inequalities. One of the barriers to women's empowerment is related to the socio-cultural traditions that have prescribed specific roles for women and men. In that scenario, different discriminatory social and cultural norms/practices usually define the boundaries for women, confining their movements, actions and opportunities within a limited space. But when individuals are better able to make strategic choices in their lives, it has consequences for their economic and social well-being. Empowered women are an integral part of a developed society. As women gain better access to healthcare, education, livelihood and political participation, they feel more empowered, and in turn, they are better able to contribute to social and economic development (UNAPCICT 2016).

According to UNESCO (2013), education empowers women to overcome discrimination. When educated, girls and young women have greater awareness of their rights, and greater confidence and freedom to make decisions that affect their lives, improving their own and their children's health (including their chances of survival) and boosting their work prospects. Ensuring that girls stay in school is also important and one of the most effective ways of avoiding child marriage and early birth. Reducing inequality is crucial for improving economic efficiency, productivity and environmental sustainability (UN Women 2018b).

Educating women and girls also helps to achieve SDG #11: Sustainable cities and communities. Providing gender-equal access to public spaces and basic services in cities (such as education) is vital to making human settlements and livelihoods inclusive and sustainable (UNDP 2018). As a country's inhabitants become better educated, they are more likely to make cities and settlements safer, sustainable, and resilient. According to a study in 100 countries, every 1% increase in the number of women with a secondary education yields an increase of 0.3 percentage points in the country's annual per capita income growth rate. For example, if India had a 1% increase of girls in secondary school, their gross domestic product would increase by $5.5 billion (Chaaban and Cunningham 2011).

According to UNDP (2018), women tend to make the majority of consumer decisions and are more likely to be sustainable consumers, having a higher inclination to recycle, save energy and reduce waste. Besides that, the improvement of gender equality and women's presence in senior positions fosters the creation of gender-sensitive approaches and initiatives in environmental management and efficient use of natural resources, improving conservation efforts and achieving more sustainable consumption and production. When girls can access information about how to adapt to a changing climate they can play an instrumental role in reducing consumption (UNICEF 2013). This implies the achievement of SDG #12 (Responsible consumption and production). They can also contribute to the resilience of their families and communities. In addition, UNICEF (2013) affirmed that educating girls and women is one of the best ways to strengthen communities on climate change. Furthermore, as girls' prospects improve through education, they can support the family economically. By doing so, they could help make families more resilient to climate change.

SDG #13 puts climate action in the spotlight. According to UNESCO (2010), education is an integral part of the global response to climate change—it helps young people understand the impacts of global warming, encourages changes in behavior towards the environment, and helps people develop new habits and attitudes to help protect the environment. People with more education tend be more concerned about the environment, and they also tend to take action that promotes and supports political decisions that protect the environment. By increasing knowledge and shifting attitudes, education has considerable power to change environmentally harmful lifestyles and behavior. Education can also encourage people to use energy and water more efficiently and to recycle household waste. In poor countries affected by climate change, education helps people adapt to its effects (UNESCO 2013). Gender equality is critical to mitigating climate impacts: women's inclusion in climate discussions leads to improved outcomes of climate-related projects and policies (UN Women 2018b). Due to women's knowledge, skills and experiences regarding management of food, water and natural resources, women are critical actors in climate change mitigation and adaptation, as well as disaster risk reduction (UNDP 2018).

Ensuring access to education for women and girls also help to ensure the achievement of SDG #14, life below water, and SDG #15, life on land. Enabling women to have decision-making power in local fisheries leads to better governance and conservation of resources (UN Women 2018b). According to UN Women (2018b), women's specific knowledge of and dependence on forests make them key contributors to forest conservation and regeneration, helping in the achievement of SDG #15. Furthermore, women's active participation in community institutions is associated with greater probability of forest regeneration, more equitable sharing of benefits, and improvement of forest sustainability (UNDP 2018).

Education for women and girls also helps to achieve SDG #16 (Peace, justice and strong institutions). According to UNESCO (2013), tolerance towards immigrants, homosexuals, people of a different religion and race and people who speak another language is greater amongst children who receive a secondary education than amongst those with a primary education alone. Furthermore, if the enrollment rate for secondary school is increased by 10%, the risk of war is decreased by 3%. Also, women play a vital role in preventing conflict and maintaining peace; by fully protecting women's rights, such as education, there will be more peaceful and inclusive societies (UN Women 2018b).

According to Banigo et al. (2017), access of girls and women to education contributes positively to national development and achieving national transformation. The deprivation of quality formal education to women in a society could result in an irreparable and uncountable loss in most sectors of the economy. This great loss affects science, technology, engineering, and mathematics, among other workforces around the globe. In conclusion, the ability of girls and women to acquire quality education greatly contributes to the growth and development of the whole nation.

SDG #17 is about creating partnerships for the achievement of the goals. Education is indispensable in strengthening communities and societies together. Education helps people understand the democracy process and promotes tolerance, besides motivating people to participate in politics. Education's role is especially vital in regions and countries where lack of tolerance is associated with violence and conflict (UNESCO 2013). According to UNESCO (1993), countries will need to assess their own socio-cultural and economic situation when determining effective strategies for girls' education, and a national commitment is important for the recognition of girls' education as a public responsibility.

According to UNDP (2018), countries with increased women's participation and leadership in politics and civil society have the tendency to be more inclusive, responsive, egalitarian and democratic. A higher number of women in parliaments is more likely to lead to the repeal of laws that discriminate against women. Women's movements have resulted in better protection of women's rights, realization of their citizenship and more gender-equitable access to civil law. The participation of women in political processes is shaping the process of policy making in ways that reflect the needs of families and communities more. When included in peace processes, women advocate for land ownership, inheritance, health care, and decreases in gender-based violence and human rights violations. Women also play an important role in preventing conflicts, violent extremism and terrorism. Female law enforcement officers tend to be better at building trust with community-oriented policing, and United Nations women peacekeepers help to improve situational awareness of missions by strengthening the understanding of female victims or young girls and boys (UNDP 2018).

According to UNAPCICT (2016), efforts need to come from government, citizens, non-governmental organizations and private education services, making sure that gender parity in education is achieved not only at the primary level, but also on the other levels, with sufficient post-education employment opportunities for women. According to UNDP (2018), improving women's access to productive assets, resources and opportunities—including in education, training and employment—results in an adequate standard of living and an increase in women's bargaining power within the family and in the community. This strengthens the women's voice and participation in decisions that affect their lives, making governance systems more gender-responsive. Women's empowerment in economic, social, environmental and political domains can help address negative gender stereotypes, decreasing violence against women and girls.

Conclusions

It is then understood that by ensuring health, education, and a good quality of life for women and girls, and by stimulating their empowerment, they will therefore generate a greater contribution to sustainability and the SDGs. In other words, empowering and valuing women and girls so that they can enjoy their fundamental human rights and realize their full potential is a matter of priority and urgency. Moreover, the SDGs promote women's empowerment through compliance with the principle of inclusion, whereby development must ensure that no one is left behind. Sustainable Development Goal #5 places special focus on promoting gender equity and women's empowerment.

In conclusion, education enhances job opportunities, and by doing so, it helps households to escape poverty. Educated men and women are more likely not just to be employed, but to hold jobs that are secure and provide good working conditions and decent pay. By benefiting women in particular, education can help close gender gaps in work opportunities and payment. It also helps to lift households out of poverty permanently, as education protects them from falling—or falling back—into poverty (UNESCO 2013).

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Chapter 20
A Comparative Environmental Assessment Between Fixed Bed Gasification Reactors and a Boiler Fueled with Biomass Waste

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Abstract In southern Brazil, heat and power generation is performed mainly in boilers by direct combustion of fossil fuels (coal/oil) or renewable fuels (biomass/biogas). Regarding biomass, direct combustion may present a low burning efficiency, in addition to the emission of atmospheric pollutants. In this context, gasification may be a solution to this problem; this process consists of a controlled burning of the fuel, increasing the burning efficiency and reducing the emission of hazardous atmospheric pollutants, since those are concentrated in order to be burned and not simply emitted to the atmosphere. The present study focused on applying a Simplified Life Cycle Assessment (with *Ecoinvent 3.5* database adapted with primary data of a pilot gasifier, using *OpenLCA 1.8* software) to evaluate the potential reduction of environmental impacts by comparing a gasifier with a boiler (both fueled with biomass). The functional unit defined for this study is the production of 1MWh of energy obtained from the biomass burning justificar.

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Introduction

Renewable sources like biomass waste are alternatives for the reduction of fossil fuel consumption and greenhouse gaseous emissions. Biomass wastes are mainly constituted of agricultural and wood residues, and are considered a versatile additive to generate heat and electricity from biochemical and thermochemical conversion routes, thereby responding to the demands from industries, residences and transportation (Prakash et al. 2019; Ge et al. 2019).

The bioenergy supplied from biomass residues can be sent to the electric grid, used in vehicle biofuels, or used to generate thermal energy in paper mills. This energy corresponds to an important percentage of the Brazilian energy matrix. According to the International Energy Agency (IEA), Brazil is the most important consumer of biomass for power generation, generating approximately 16% of the energy from sugar cane or wood. However, due to climate change and dependence on the energy matrix of hydroelectric plants in Brazil, the country is not prepared to use the energy supply from biomass power plants (Silva et al. 2018; Corcelli et al. 2018; Darmawan et al. 2018).

The generation of electricity from biomass in the Brazilian energy matrix is responsible for approximately 8% of electricity use in 2016, equivalent to 47,384 GWh. Energy generation is mainly obtained from sugarcane and alcohol residues (which represent 89% of the biological sources used), while firewood represents only 2%, with 1200 GWh of participation in electricity generation (EPE 2017; Ferreira et al. 2018).

Biomass thermochemical treatments include combustion, pyrolysis, gasification, co-firing, carbonization and liquefaction; each one ensures the generation of fuels with different yields appropriate to electricity and/or heat, presenting advantages or disadvantages with economical and socio-environmental aspects (Patel Zhang and Kumar 2016).

Methodologies to measure the interference in the environment are crucial and necessary in order to choose the most sustainable technology. One methodology that presents the different environmental impacts throughout all the phases of production and which is accepted and utilized by the International Standard Organization (ISO) is the life cycle assessment.

Life cycle assessment (LCA) consists of a methodology to investigate environmental impacts, from raw material extraction to treatment and final disposal. Its importance is to evaluate impacts in all the processes and/or product steps, designing scales, parameters or percentages in baseline systems to characterize factors in individual environmental impacts, such as acidification, eco-toxicity, eutrophication, fossil resource depletion and global warming (Dong et al. 2018; Maier et al. 2019)

The present work uses LCA methodology to discuss the influence on environmental aspects in the comparison of direct combustion in boilers to the updraft and downdraft fixed bed gasification process, consulting the *Ecoinvent* database and utilizing simulation in *OpenLCA 1.8* software version.

Combustion and Gasification for Biomass Waste Treatment in Electricity Generation

Boiler combustion is the technology most commonly used with firewood in dairy, agriculture and textile industries, followed by diesel consumption. During wood processing, a surplus of biomass is generated that can be used to complement the production of electric energy produced by hydroelectric plants from the installation of boilers in the wood industry. Nevertheless, with the use of wood waste treated for energetic use in the form of pellets, its energy potential is improved, due to the homogeneity of the material and better calorific value that increases the efficiency of this thermal system (De Lima et al. 2018).

Gasification in relation to direct combustion in boilers presents many environmental advantages in producing heat and electricity, as it generates lower harmful gaseous emissions and enables the integration of biofuel generation through the combined cooling, heat and power (CCHP) module. However, the current technology has problems with the formation of tars, which reduce the heating value of the gas, and consequently, the synthesis gas yield for electricity generation; it is also more complex, costly and difficult to operate and maintain (Hajabdollahi et al. 2015; Guercio and Bini 2016).

Boiler and Gasifier reactors present different control techniques and costs for the same biomass types, thus it is necessary to evaluate which equipment is most appropriate, depending on the project and desired products in processing and payback times (Mena et al. 2017; Dong et al. 2018).

The carbon conversion ratio (CCR) of the bioenergy systems regulates the system price and worldwide market application; the combined heat and power (CHP) components can optimize thermal and electrical yield, mainly due to the CCR factor which increases generally from 0.6 to 1, providing better gains for biomass power plants. This growth changes the performance indicator, which contributes to the emissions reduction ratio (ERR) and total annual cost saving correlation (ATCSC), increasing the flexibility of the power plant and market demand. This parameter in the present study will be disregarded because the CHP module in the combustion boiler is deactivated (Hajabdollahi et al. 2015; Zhu et al. 2016; Zhang et al. 2018).

The main mechanical machines to convert biomass to movement energy in electricity on all scales (small, medium and large power plants) are internal combustion engines (ICE), steam turbines (ST), Stirling engines (SE) and gas turbines (GT). All have particularities in energy efficiency, and each one has a thermal dynamic modeling that can change the environmental impacts on the carbon conversion chain and bioenergy yield (Borji et al. 2015; Pantaleo et al. 2015; Sharma et al. 2015).

According to Hagos et al. (2017) that make a comparative analysis of biomass syngas in ICE and GT from thermochemical modeling, they evaluated that these two machines present efficiency values of 31.1% and 40.7%, respectively.

According to Maier et al. (2019), who compared boilers with steam turbines in relation to gasifiers and internal combustion engines with the same power potentials of 0.5, 2, 3 and 5 MW, the best carbon conversion efficiencies by gasification have an important role and its upstream process contributes to lower impacts on global warming, human health, and fossil resource depletion. However, due to higher carbon conversion efficiency, gasification needs a lower feedstock demand, and they observed that it increases emissions in illegal and uncontrolled combustion, contributing to a higher influence on soil acidification and human health respiratory effects.

The present study evaluates a water tube boiler installed in Lages, localized in the Plateau region of Santa Catarina State (SC), southern Brazil, with input and output products and wastes in comparison to an updraft and downdraft reactor in a future gasification modeling process.

The wood industry in the SC Plateau region is considered one of the main employment sectors of the state. It is estimated that the industry generated approximately 250,000 tons of woodchips, 16,000 tons of bark and 50,000 thousand tons of sawdust in 2015 (Deboni et al. 2019).

In the SC Plateau region, the wood waste of sawmills (chips, sawdust and bark from pine trees, with 75%, 20% and 5% ratios respectively) is designated for thermal treatment in a central boiler coupled with a steam turbine and it produces 28 MW of electric potential (Hagos et al. 2017; Henne 2018).

This boiler uses water tube technology and has a steam generation capacity of 120.000 kg/h. According to Deboni et al. (2019), the chips volume from 2005 to 2011 represented 40% of the total treatment volume. However, after 2011 the production and discard in sawmills increased, reaching more than 70% in chips volume in relation to the biomass waste ratios appropriate for electricity generation in this power plant.

These large boilers work with steam expanded through the turbine and are posteriorly inserted in a turbo-generator, converting mechanical energy to power generation from the Rankine cycle, which ranges up to 8 MW and is better than the Organic Rankine Cycle (ORC) because of greater electric efficiency. ORC is feasible and studied in small-scale power plants due to its simpler operation and reduced operational and maintenance costs (Guercio and Bini 2016).

The paths and distribution of fuel in the steam boiler components enable one to calculate the flowrate and heat load to evaluate energy conservation. However, it is necessary to first determine the costs of recovered steam in low and high pressure and the eco-efficiency of the system according to the ash content and water consumption in relation to the steam generated, in order to present the cost reduction and environmental benefits in relation to energy conservation (Sun et al. 2016; Jarenkow 2018).

The particulate size of the biomass changes the energy efficiency of the conversion process and the yield of the different raw materials, due to the surface area in the thermal reactions. In addition to size, the efficiency of the system depends on other characteristics of the fuel sample, such as moisture and ash content (James et al. 2016).

Compared to large-scale power plants with higher technical and economic requirements, some small-scale decentralized power plants can contribute to the treatment of waste on site and the simultaneous energy generation. Nowadays, gasifiers are considered to be economically feasible alternatives in distributed generation. Currently, the most common machines in syngas systems are micro gas turbines (mGT) and ICEs because the knowledge regarding these machines ensures ease in control, performance and manufacturing (Stylianidis et al. 2017).

The denomination of an updraft reactor configuration means that the biomass is feeding in the top of gasifier and the oxidant (air, pure oxygen or water steam) occurs at the bottom, thus providing the biomass with a counter current movement to the gases and sustaining the subsequent thermal zones (drying, pyrolysis, reduction and oxidation) until the biomass generates syngas, bio-char, ash and tar contents (Arena 2012).

Updraft fixed bed gasifiers are the cheapest system and produce an elevated heat efficiency (approximately 5% of heat losses) in comparison to the different gasifier configurations. This configuration allows for high moisture and ash content in biomass, with 60% and 25% maximum ranges, respectively. However, this model is limited because of high tar production, and consequently, there is difficulty with filtration and gas insertion in the internal combustion engine. In contrast, downdraft gasifiers have lower tar average concentrations, the gas is easily inserted into the ICE, but it is limited by the high moisture content of the biomass and by lesser efficiency in heat purposes (Mena et al. 2017).

Technological changes in the wood energy conversion would change the energetic sector by contributing more and more to the electric matrix and by providing developmental collaborations regarding water consumption, land use change, global yield efficiency process and greenhouse gaseous emissions, thus reducing environmental impacts in the supply chain.

Water consumption is an important variable in the processes in determining effluents and losses. The investigation of where the lower efficiency of the thermal energy occurs and the knowledge of heat transfer behavior allow for an increase of gains in the heat exchangers and cooled walls and help with the determination of the air inlet on biomass boilers. It is important to evaluate mainly the radiation parameter in particular, since biomass boilers are in high temperature systems. The radiation consists occurs in the most important mechanism of heat transfer between the solid particles and with the fixed bed flame in relation to convection and conduction (Guerra et al. 2018; Gómez et al. 2019).

Land use changes are mainly associated with forest management to produce woodchips and disposal of solid waste after energy conversion. In this context, decentralized power plants of smaller scale and energy conversion efficiency can minimize the negative impacts of deforestation and waste generation, when compared to current conventional practices.

Atmospheric emissions in the thermochemical treatment processes occur at different stages and depend on the efficiency of energy conversion and evaporative losses. The emissions treatment system needs to be designed taking into account the standards and restrictions to maintain the air quality of the area of influence in the power plant. In this case, decentralized plants on a smaller scale may be more economically viable, as they need less robust treatment systems and are technically efficient to treat emissions.

Materials and Methods

To compare the potential environmental impacts of the gasifier and the boiler, an LCA was developed to compare both sets of equipment. Therefore, the methodology of this work consists in the application of the steps standardized by the ISO 14040 and ISO 14044 standards.

These ISO standards divide an LCA study into 4 steps:

1. Definition of objective and scope
2. Life cycle inventory analysis
3. Life cycle impact assessment
4. Interpretation of results.

For this study, the defined objective was to compare the potential environmental impacts of a gasifier versus a boiler. Since the main function of both processes, in this case, is to generate electricity, the functional unit (FU) is defined as "generation of 1 MWh of electricity."

The biomass' volume per hour and the boiler's transport influence area were evaluated by Henne (2018), who estimated that the maximum capacity of the power plant is 58,000 kg/h and the longest distance is 120 km. These values were inserted as reference values in the present study.

Carbon dioxide, nitrogen oxides and methane emission factors obtained by Ahmed et al. (2019) in the boiler and gasification processes (Tables 20.1 and 20.3) were acquired from the literature to compare the different processes of decomposition, open burning, boilers, gasifiers and the integrated gasification combined cycle (IGCC). All these values are shown in Table 20.1:

The water consumption of a boiler was found by Jarenkow (2018), who evaluated the boiler eco-efficiency in Lages on Santa Catarina State. The author presented different parameters such as steam/human operation (t_s/h/man), energy/ash (kWh/t_a), steam/consumed energy (t_s/kWh), etc. One of these parameters was water consumption in relation to electricity generation (kWh/m^3), which indicated higher optimization with 36% improvement gains in 2017 in comparison to 2013, reaching 0.245 kWh/m^3 in January, 2017, thereby showing a reduction losses of steam generated in the water tube boiler. This average value was inserted in the simulations.

System boundaries and reference flows are shown in Figs. 20.1, 20.2, 20.3 and 20.4. In Fig. 20.1, it was observed that water consumption and the conversion of wood chips to steam presented less efficiency in converting this product into power, when compared to the gasification process described in Fig. 20.2.

Ash contents in the boiler of Lages on Santa Catarina State were obtained from Henne (2018), which evaluated ash formation and characterized the composition

Table 20.1 Boiler + ST input and output products

Boiler + Steam turbine (ST)				
Input products	*Reference value*	*Volume (ton/h)*	*Volume (ton/month)*	*Volume (ton/year)*
Biomass	58,000 kg/h	58	1392	508,880
Water	0.245 kWh/m^3	114,285	2,742,857	1,001,142,855
Output products	*Reference value*	*Volume (kg/h)*	*Volume (kg/day)*	*Volume (ton/year)*
Steam	120,000 kg/h	120,000		
Total produced ashes	0.93% of mass production	269.7	6472.8	2362.572
Soot	2.04 g/kWh	57.12	1370.9	500.37
Carbon dioxide (CO_2)	738.8 kg/ton	42,804	1027,296	374963.04
Methane (CH_4)	0.20916 kg/ton	12.18	292.32	106.6968
Nitrous oxide (N_2O)	0.02789 kg/ton	1.74	41.76	15.2424

Source Henne (2018), Jarenkow (2018), Ahmed et al. (2019)

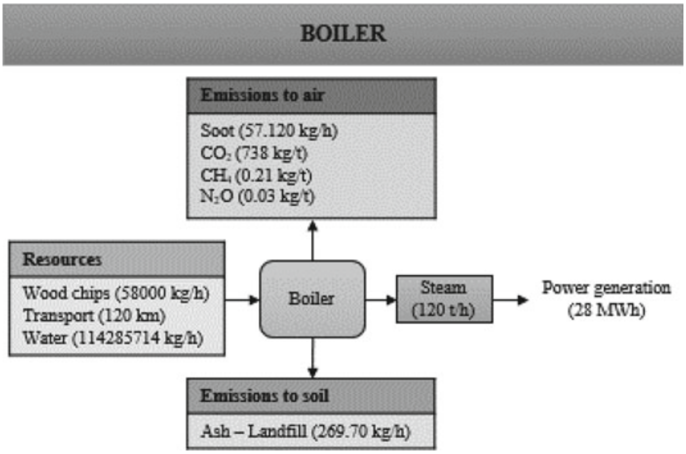

Fig. 20.1 Boiler data flows (28 MWh)

with their associated problems in combustion in the boiler of the cogeneration unit in Lages on Santa Catarina State. The generated ash types are in Table 20.2:

The gasification flowchart as represented by Fig. 20.2 presents the output of greenhouse gaseous emissions (CO_2 and NO*x*) and solid wastes represented by ash, usually disposed in the landfill. The input is synthesis gas (syngas) converted into power generation.

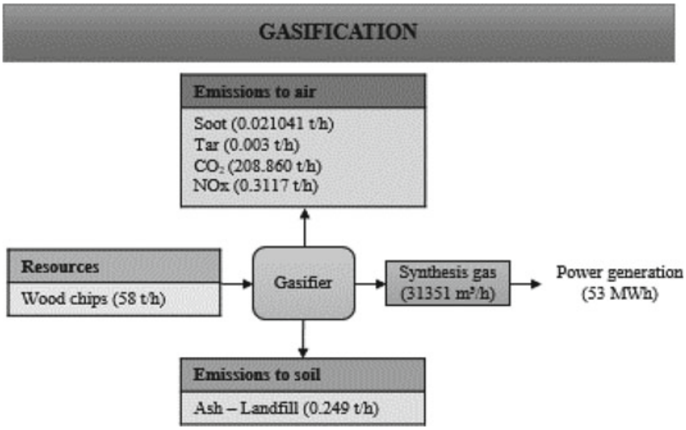

Fig. 20.2 Gasification data flows (54 MWh)

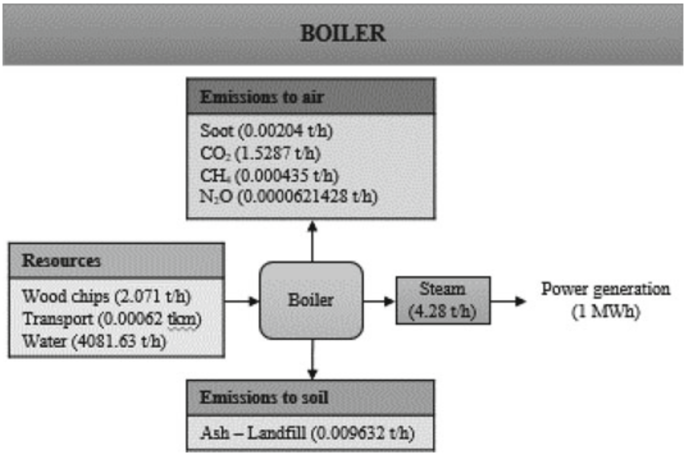

Fig. 20.3 Boiler data for the functional unit (1 MWh)

In the calculation results from Ayyadurai et al. (2017), which studied updraft and downdraft gasification performance, it was estimated that the power generation of 54 MW in both gasifier reactors was double the performance in relation to biomass boilers, showing that by comparing the output power with the same biomass volume, gasification is the best technology for yields.

The total produced ashes and tar reference value, 0.86% of mass production and 9 g/m^3 respectively, were calculated on the basis of updraft and downdraft reactor averages from Liu et al. (2012) and Ayyadurai et al. (2017) data. An estimation of the production in kg/h up to ton/year are presented in Fig. 20.2 and Table 20.3.

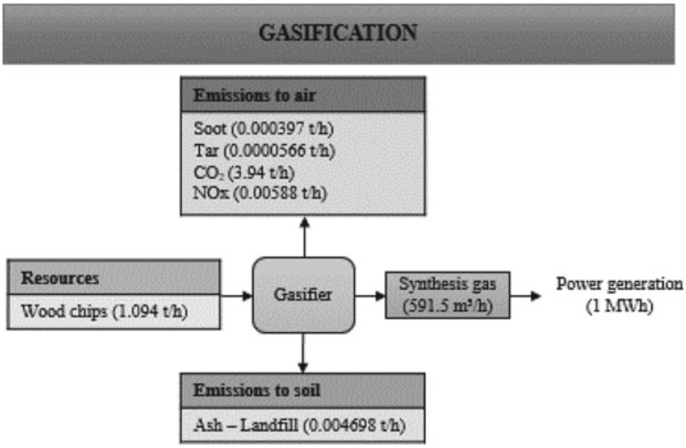

Fig. 20.4 Gasifier data for the functional unit (1 MWh)

Table 20.2 Boiler + ST ashes

Boiler + steam turbine (ashes)					
Ashes type	Withdrawal location	Percentage (%)	Volume (kg/h)	Volume (kg/day)	Volume (kg/year)
Heavy ashes	Readler	82.15	22.155	15952.021	194082.924
Soft ashes	Hopper	15.84	4.271	3075.587	37419.643
Humid ashes	Wet scrubber	0.59	0.161	116.257	1414.462
Thinnest ashes	Decanter	0.32	0.081	58.523	712.040
Calcinated ashes	Pre-heater	0.29	0.080	57.926	704.777
Incrustated ashes or emitted in the atmosphere	All system	0.81	0.219	157.889	1920.985

Source Henne (2018)

Table 20.3 presents the input and output products—biomass and synthesis gas—and evaluates the produced wastes which are ashes, tar, CO_2 and NOx, all in reference values converted into kg/h to perform the simulation in the LCA.

The functional unit (1MWh) equalizes the power performance by presenting the equivalent difference in input and output products, according to the maximum capability provided by the technology. Figure 20.3 shows that the ash volume, produced in the boiler and usually disposed in landfill, reached a level twice as high as that in the gasification process showed in Fig. 20.4. This occurs due to lower efficiency in the Rankine cycle.

Table 20.3 Gasification + ice input and output products

Gasification + internal combustion engine (ICE)				
Input product	*Volume (kg/h)*	*Volume (ton/h)*	*Volume (ton/month)*	*Volume (ton/year)*
Biomass	58,000	58	1392	508,880
Output product	*Reference value*	*Volume (m^3/h)*	*Volume (m^3/day)*	*Volume (m^3/year)*
Synthesis gas	31,351 m^3/h	752,424	22,572,720	6,591,234,240
Output wastes	*Reference value*	*Volume (kg/h)*	*Volume (kg/day)*	*Volume (ton/year)*
Total produced ashes	0.86% of mass production	249.4	5985.6	2,184,744
Tar	9 g/m^3 of syngas	3.07	73.68	26,893.2
Soot	0.39 g/kWh	21.041	505	184.32
Carbon dioxide (CO_2)	3601.04 kg/ton	208,860	5012,640	1829613.6
Nitrogen oxides (NO_x)	5.375 kg/ton	311.7	7480.8	2730.492

Source Liu et al. (2012), James et al. (2016), Ayyadurai et al. (2017), Ahmed et al. 2019

Solid waste in gasification (tar and ashes), as shown in Fig. 20.4, is considered to be disposed in landfill. The present study found that the two processes use the same disposal treatment. However, both ashes in the processes can be used as compost for agriculture.

For the constitution and inventory analysis, the authors applied datasets from the Ecoinvent database (version 3.5) with the Euro5 system.

The Life Cycle Impact Assessment stage consists of converting, according to predefined characterization factors, the inventoried data into potential impact categories. For this, the selected method was ReCiPe 2016, at midpoint level. Given that the possible implementation of gasifiers has the potential to contribute to technological changes in the Brazilian energy sector, the impact categories were selected in consideration of the potential environmental impacts of these changes.

Thus, the environmental impacts were subdivided into the following categories: (a) Land use, to assess the impacts of land use; (b) Terrestrial acidification, to assess indirect impacts on food production (since acidified soil has its productivity compromised); (c) Freshwater eco-toxicity, Freshwater eutrophication and Water consumption to assess impacts on water; and (d) Global warming, to analyze the impacts of greenhouse gas generation. The last step consists of the interpretations as described in the results and discussion section.

Results and Discussion

The results are presented in the following Figs. 20.5, 20.6, and 20.7, and the values with the reference unit obtained for each impact category are shown in Fig. 20.7. It was observed that the main factor responsible for environmental impact is the production of wood chips, due to the forest management, cultivation, fertilization and industrial processes to obtain this product. The boiler presents more influence on global warming than gasification, as observed in Fig. 20.5, due to the CH_4 and N_2O emissions.

The gasification impacts shown in Fig. 20.6 show that terrestrial acidification is the process category with the greatest impact. This technology presented a considerably larger value in relation to the boiler as presented in Fig. 20.7, and it occurs mainly

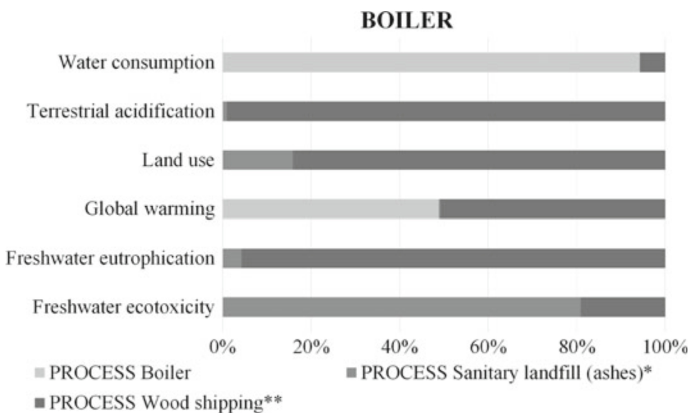

Fig. 20.5 Boiler process values in relation to different environmental impacts from LCA

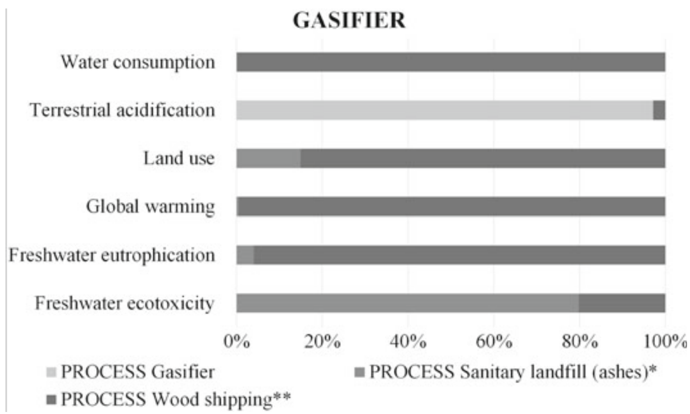

Fig. 20.6 Gasification process values in relation to different environmental impacts from LCA

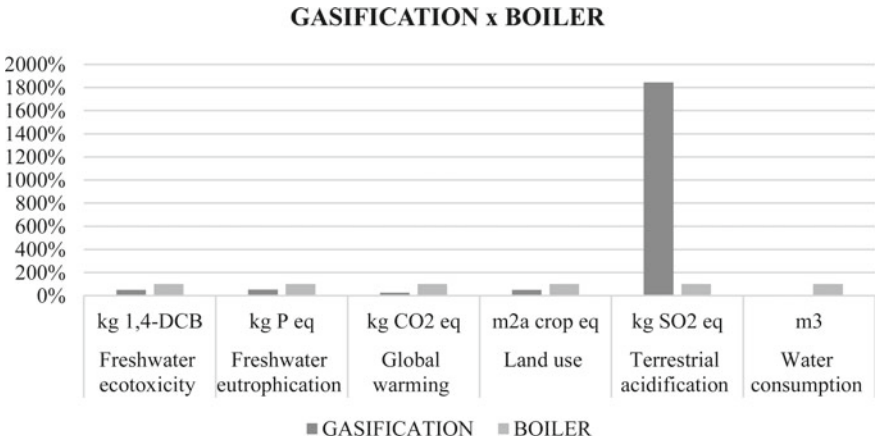

Fig. 20.7 Comparative analysis of boiler in relation to gasification process

due to higher NO*x* emission, which is affected by air-fuel ratios with lower oxygen concentration and the possible disposal of tar in the soil.

In Fig. 20.7, diagnosis evaluation determines that gasification guarantees better performance in almost all environmental impact categories, except for terrestrial acidification and ozone formation. This is mostly due to the fuel consumption (mainly wood chips) being nearly one half in comparison to the boiler process and to the higher optimization of energy from heat purposes.

In the global warming category, the lower carbon dioxide equivalent (CO_2eq) is because the gasification technology provides waste treatment in situ and has greater power efficiency. It also demonstrates that methane (CH_4) and nitrous oxide (N_2O) in the boiler emissions have greater global warming potential than carbon dioxide (CO_2) and nitrogen oxide (NO*x*) in gasification. The greater values in the water consumption and land use categories with the boiler are related to the process (Rankine Cycle) with high wood chips consumption to generate steam and lower efficiency; the consumption requires more forest supply and the centralization demands more area for electricity generation, when compared to the decentralized gasification process.

Figure 20.7 concludes that the environmental impacts on the large scale do not show significative differences in the two processes, only that the terrestrial acidification in gasification presents more impact. However, considering all the categories, the figure shows that the gasification process is the more sustainable process in comparison to the analyzed boiler.

According to the graphs and tables which show that the gasification consumption of wood chips is half the value of the boiler demand to generate the same electrical potential, it can be surmised that gasification has less impact in all the impact categories, mainly because wood chipping is an important factor of environmental pollution in the entire industrial chain. Nevertheless, it is necessary to evaluate gasification as a decentralized process with in situ waste treatment, thereby developing a smart grid market in distributed generation, which reduces wood shipping to a centralized power plant.

Conclusions

Boilers and gasifiers are important technologies of power generation with wood waste, and the mensuration of environmental performance and impacts as obtained from LCA methodology are crucial in the evaluation of choosing sustainable systems. This paper concluded that gasification presents advantages in most of the environmental impact categories, due to double the efficiency presented by the power generation of the boiler, consequently reducing by half the ash, tar and hazardous greenhouse gaseous emissions (CO_2, NOx) in relation to the functional unit (1MWh), thereby presenting higher eco-efficiency.

These two technologies present different global yields and costs, thus the evaluation and acquisition depend on the stakeholders. The present study contributes to the stakeholder's orientation, showing the interaction and benefits of each one and their application in the wood industry, a sector which has consumers with different demands and which can utilize both technologies, depending on the desired products to own, supply or commercialize in the energy market.

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Chapter 21
Impacts of Green Tire Technology: Case Study of Environmental and Customer Perspectives

Gustavo Fonseca Costa Rodrigues and Nathan Peixoto Oliveira

Abstract **Contextualization**: the scenario of natural resource degradation requires an urgent positioning of big companies. Government and social pressures are reflected in a company's responsibilities and products. **Research Problem**: Many of a company's required actions are focused on post-consumption, natural resource usage restrictions, and the search for alternatives to reduce the negative environmental effects. **Justification**: This work is concerned with improperly disposed tires, whose residues are difficult to eliminate in accordance with the National Environmental Council (CONAMA) legislation, and with the differentiation of green tires from low-cost and low-quality Chinese tires. **Objectives**: This research focused on the analysis of Michelin green tire technology in light of its efficiency and market views, comparing them to a common tire. **Methodology**: Using a case study, the cost, durability, market acceptance and associated usage benefits of both tires were studied. **Results**: Green tires increase fuel economy and cost slightly more than common tires. Regarding durability, the ordinary tires waste the equivalent of the value of two green tires in one life cycle. But despite the benefits in fuel economy, reduced CO_2 emission and mileage, these benefits are usually not perceived by lay consumers. **Conclusion**: Green tires are a new trend, and the tests results proved that it is possible to reduce the environmental impact while maintaining or even improving comfort, safety, fuel economy and performance.

Abstract **Contextualização**: o cenário de degradação dos recursos naturais requer um posicionamento urgente das grandes empresas. Ademais, pressões governamentais e sociais refletem nas suas responsabilidades e produtos. **Problema de pesquisa**: muitas das demandas estão no pós-consumo, nas restrições de uso de recursos e alternativas para reduzir o impacto ambiental. **Justificativa**: o trabalho se preocupa com pneus descartados inadequadamente, cujos resíduos são difíceis de eliminar

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de acordo com a legislação do Conselho Nacional de Meio Ambiente (CONAMA) e com a diferenciação de pneus chineses de baixo custo e baixa qualidade. **Objetivos**: analisar a tecnologia de pneus verdes da Michelin em eficiência e mercado comparado a um pneu comum. **Metodologia**: pelo estudo de caso, foi analisado o custo, durabilidade, aceitação no mercado e benefícios associados ao uso de ambos. **Resultados**: os pneus geram economia de combustível e custos próximos aos pneus comuns. Em durabilidade, o comum desperdiça mais dois pneus verdes em um ciclo de vida. Adjunto, apesar dos benefícios como economia de combustível, emissão de CO_2 e quilometragem, eles foram superiores as percepções de consumidores leigos. **Conclusão**: o pneu verde é uma tendência e os testes mostraram redução no impacto ambiental, mantendo ou melhorando conforto, segurança, economia de combustível e desempenho.

Introduction

Theme Presentation

The tire industry in Brazil is concentrated in large multinational companies, which are: Goodyear, Pirelli, Bridgestone/Firestone, Michelin and Continental. Together, the manufacturers have 12 plants in Brazil, mostly in the state of São Paulo.

The numbers of production and sales have been growing over the past few years. In 2005, they produced about 53 million tires, with a domestic sales volume of about 38 million units, including direct imports and exports of around 18 million units.

Sales are aimed at three different segments: the automakers (OEM), the aftermarket and the foreign market. Automakers account for 26% of sales, and the aftermarket, which is composed of tire dealers shops, is responsible for 42%. Exports account for 32% of sales, aimed at about a hundred countries, especially the United States (USA), France, Argentina and Mexico. Exports are mostly inter-company operations.

With prospects of profitability in these three types of market, manufacturers had been making a series of investments in the country during the period 2004–2007. The investments totalled approximately R$ 3 billion, which resulted in an increase of 30% of installed capacity in the country. These investments were motivated by three factors: increased domestic demand, a favorable scenario for exports and a change of production of the world's tire industry in low labor cost countries.

However, after planned investments reached maturity in 2004, the country scenario was no longer favorable. The exchange rate frustrated the expectations of exports, and the growing share of remold and Chinese tires in the aftermarket intensified competition in the internal market. The importation of used tires, used as raw material for remolding tires, became the center of a controversy between the various actors in the industry.

Another widely discussed issue concerns the environmental impact of abandoned or improperly disposed tires, whose residues are difficult to eliminate. In order to solve this problem, the National Environmental Council (CONAMA) has created a resolution that has rules on the matter, forcing manufacturers to provide for environmentally adequate disposal of the waste tires.

In an attempt to differentiate their tires from Chinese tires and other low-cost and low-quality tires, the biggest manufacturers have stepped up investment in some technologies. At first, this would add even more costs to its products that were already at a price level higher than the new entrants, but it was the only way to differentiate their tires and not turn the product into commodities.

Due to this reason and the environmental preservation issue, a technology called Green Tires entered the scene. These tires provide greater durability, and greater fuel economy, as a primary benefit, through its low rolling resistance coefficient.

Objective

The aim of this work is to present Green Tire technology, which is increasingly widespread due to the social and environmental pressures that have affected the tire industry, and the advantages and disadvantages of this new product.

In order to draw conclusions about the efficiency and market acceptation of this new technology, a comparison between a green tire and a common tire is proposed to analyze from a financial standpoint if the higher price of green tires is returned in worth through savings in fuel consumption.

Justification

The advancement of this type of product and the high technology employed aroused interest in understanding what stage the big companies of this segment are at, with respect to the current trend of sustainability.

Tires are created for every market share and consumer profile. A customer who opts for a conventional or performance-oriented tire wants better braking and grip performance. At the other extreme, a customer of a compact car is more focused on the economy and durability of the tire. There are still those concerned with environmental issues, and this public is the focus of this dissertation, as well as the real advantages and disadvantages in the purchase of this type of product.

Methodology

The methodology used for the qualitative research will be the case study approach, aiming to objectively and directly present a comparison of the costs involved during the acquisition of tires with different technology, taking into account their initial costs, durability and associated benefits during their use.

Theoretical Foundation

World Tire Market

The tire market experienced strong growth in the last three decades. The gross sales of the industries in the sector more than tripled over that time, starting from a level of about US $35 billion in 1985 to US $110 billion in 2015. During this period, the tire industry went through a process of concentration amongst the ten largest companies, subjecting them to mergers and acquisitions, which resulted in five groups (Table 21.1).

Over the past decade, Bridgestone and Michelin have alternated in sales leadership in the sector, while Goodyear ranks third in the market share. Together, the three largest companies held more than 50% of the world market. Table 21.2 illustrates the industry ranking.

Table 21.1 Enterprise mergers and acquisitions processes

1981	2005
Goodyear Dunlop	Goodyear
Firestone Bridgestone	Bridgestone
Michelin BF Goodrich Uniroyal	Michelin
Pirelli Armstrong	Pirelli
Continental General	Continental

Source Michelin—fact book (2005)

Table 21.2 2016 Tire manufacturers ranking

		2016		
Rank		Euro	Share tyres	
1. (1.)	Bridgestone	27,042.3	22,412.5	82,9
2. (2.)	Michelin	20,907.0	20,488.9	98,0 %
3. (3.)	Goodyear	14,380.0	14,380.0	100 %
4. (4.)	Continental The Future in Motion	40,549.5	10,717.4	26,4 %
5. (5.)	Pirelli	6,058.4	6,056.2	100 %
6. (7.)	Sumitomo	6,132.1	5,254.6	85,7 %
7. (6.)	Hankook driving emotion	5,216.8	5,216.8	100 %
8. (8.)	Yokohama	4,831.4	3,857.7	79,8 %
9. (9.)	Maxxis	3,436.7	3,436.7	100 %
10. (11.)	Cooper Tires	2,774.8	2,774.8	100 %

Source Adapted from Tyrepress (2018)

Brazil's Tire Market

The Brazilian industry had a starting point with the implementation of the General National Transportation Plan in 1934.

In 1936, the Brazilian Society of Rubber Artifacts was inaugurated. Also known as Tires Brazil, in its first year of operation it produced 29,000 tires.

The first companies to install plants in Brazil were Goodyear, Firestone and Pirelli, around 1940. Michelin started local production only in early 1990. With the opening of Continental's plant in 2006, the five largest world producers began to manufacture in Brazil. The country is the seventh largest producer of tires for cars and the fifth of tires for buses and trucks.

It is worth mentioning that the factories invest, on average, US $12 million annually in innovation, R $8.4 million in internal R&D. Among the innovations, we can mention green tires, tire labeling, the use of new raw materials (such as rice husk to produce silica) and the test fields specially designed for the different Brazilian land. Among the products specially designed for the country, we have as examples the specific tires for tractors and trucks that are used in sugar cane cultivation and special tires for small passenger cars.

The country's manufacturers strictly fulfill the environmental commitment and legal obligation to collect waste tires responsibly, according to the annual targets set by IBAMA. Reciclanip, an entity maintained by the industry has an annual cost of US$ 40 million associated with the 834 collection sites in 26 states and the Federal District which ensure the proper disposal of waste.

Not all importers comply with this legal obligation. IBAMA annually publishes the Tires Report, which has consolidated information provided by manufacturers and importers on intended volumes of waste tires. It is apparent that from 2009 to 2013, an environmental liability of approximately 150,000 tons of waste tires accumulated, which were the responsibility of importers who have not fulfilled the obligation (IBAMA 2018).

Tire Environment Impact

According to Wills (2008), we can cite the following as automotive emissions that impact the environment:

- Emissions of particles through the exhaust of the vehicle;
- Fuel evaporative emission (emitted into the atmosphere through evaporation of fuel hydrocarbons);
- Crankcase gas emissions (combustion byproducts that pass through the engine piston rings and lubricant vapors);
- Dust emissions from tire wear, brake and clutch;
- Re-suspension of soil dust particles;

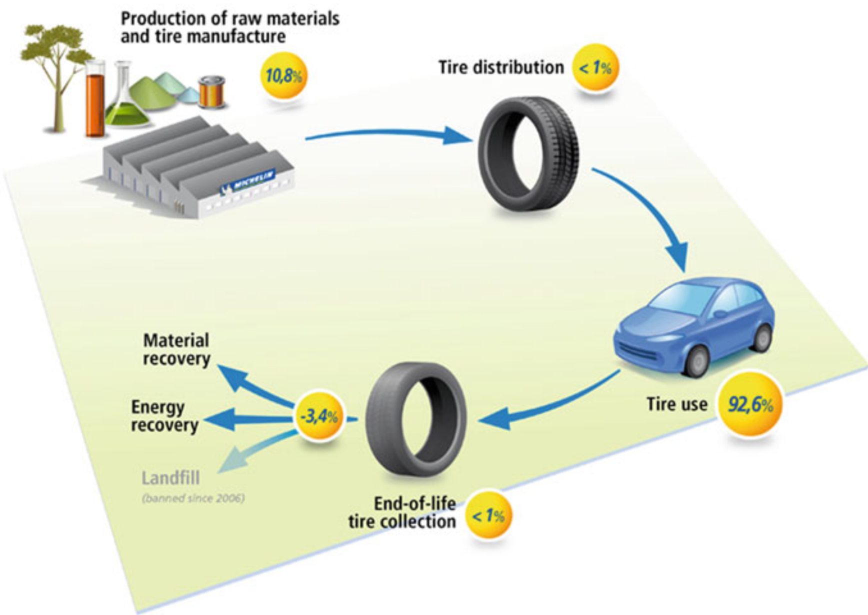

Fig. 21.1 Contribution of different tire stages to its impact on the environment. *Source* Adapted from Michelin (2009)

- Evaporative emissions of fuel in the fuel transfer operations (associated with the storage and refueling).

All these emissions are responsible for acid rain, cloud urban pollution, greenhouse gases (GHG), global warming and other environmental problems.

The presence of vehicle tire emissions in the atmosphere is due to the burning of fuel in the engine to overcome the rolling resistance. Figure 21.1 illustrates clearly what life cycle assessments of tires clearly show, that it is during its use that the impact of a tire on the environment is at its greatest: 92.6% for a car tire.

The tire becomes an unusable product after wear of the tread, because the worn tire puts the safety of vehicle occupants at risk in wet road conditions. Discarding tires generates disorder and their environmental impact can be quite high.

According to Lagarinhos (2011) and cited by Kovac (1973), tire wear is influenced by several factors, such as tire design, composition of the tread, enhancing tissue, soil conditions, the driver and the severity of usage.

Green Tires

One of the ways to reduce the environmental impact of a vehicle is to reduce its pollutant emissions into the atmosphere, ie, reduce your fuel consumption. One of the most effective ways to achieve this is by reducing the rolling resistance force that is linked directly to the type of tire of the vehicle.

Three factors should be considered for reducing rolling resistance: a decrease in the tire weight, a change in its structure and a change in its compounds. The challenge for companies is to balance the three fronts, because there is no point in creating an extremely light tire if it has short durability.

The green tire concept originated in 1983 by the manufacturer Pirelli and has evolved since then, making use of new technologies and new raw materials.

Figure 21.2 shows the challenge of the tire industry; because hysteresis improves rolling resistance, this reduces the vehicle braking capability. The role of new technologies is to improve the tire performance as a whole.

The substance responsible for hysteresis and lower rolling resistance (RR), and which achieves the best performances, is silica.

With the addition of silica, it was possible to develop rubber compounds which exhibit low hysteresis at low frequencies (the portion related to the rolling resistance) and high hysteresis at high frequencies (related to braking), as shown in Fig. 21.3.

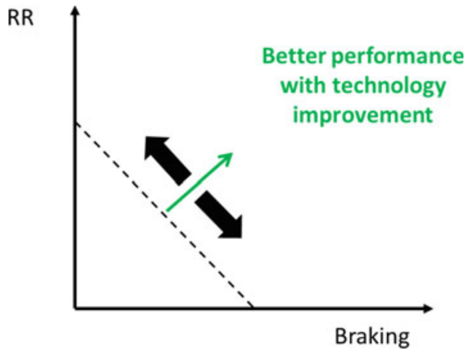

Fig. 21.2 Graph showing relationship between rolling resistance and braking of the vehicle. *Source* Adapted from Michelin (2009)

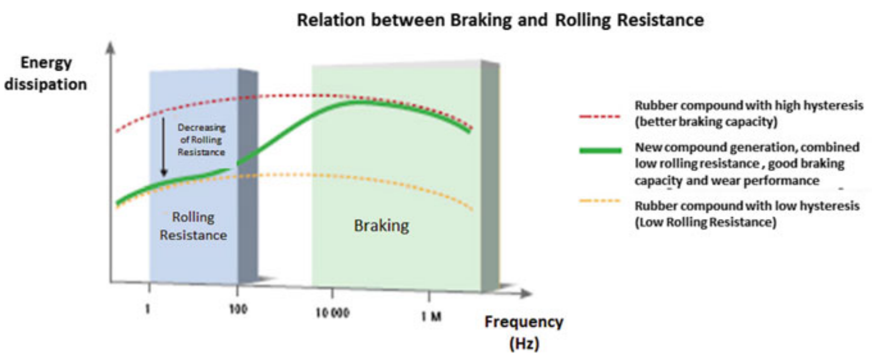

Fig. 21.3 Difference between highly hysteretic compound with little hysteresis and silica. *Source* Adapted from Michelin (2009)

In combination with the silica, it is important to use one or more rubbers that have a glass transition point at appropriate temperatures, because the hysteresis of the compound is low at normal operating temperatures.

With this change in the composition of tires, it was possible to reduce the rolling resistance by 20–30%, while other characteristics were maintained or even improved. To further the reductions in rolling resistance values and thus create ever more ecological tires that maintain safety, pneumatic industries should follow three precepts (Michelin 2009):

- Improve tire architecture, reducing efforts, strengths and unnecessary distortions, through which there is energy loss;
- To reduce the hysteresis losses at frequencies involving rolling resistance (results achieved using silica and binding of chemical elements forming a compound that, unlike the rubber compound with carbon black, have no long polymer chains. This entails a very hysteretic material in the high frequencies, improving friction, and low hysteresis at low frequencies, improving the RR);
- Reducing the weight of the rubber compound used in the tire through a new design or new materials, that is, designing tires which are lighter, thinner.

Case Study

A fact widely discussed regarding green tires is their higher price. By using different raw materials, the cost of a green tire can often be higher than the usual tires, but studies prove that this value is returned to the customer, thanks to fuel economy.

According to a study by the National Academies of Science, a 10% decrease in rolling resistance can result in a savings of 1–2% of fuel. As some green tires that are on the market today reach a 20% decrease in rolling resistance, the customer can save up to 4% in fuel consumption.

This case study aims to compare all the costs and benefits that a driver would have, using a common tire and using a tire with green tire technology.

Two brands of tires were chosen with great relevance to the Brazilian market: Michelin and Pirelli.

Michelin's recognition of product quality and investment in technology are the reasons the brand was chosen to represent the tire with green tire technology.

Pirelli, the leader in the Brazilian market, has a more popular appeal for the vast majority of its products. The fact that it does not have such a strong investment in technology means that its cost of manufacturing is lower, which ends up being reflected in the final price of the product.

Unfortunately, due to the maturity of the national market, the price aspect is decisive for the choice of product, leaving performances related to product safety and durability in the background.

The size of the tires chosen for this study is 205/55 R16. This dimension equips a circulating fleet of 1,940,000 vehicles in the national territory, resulting in the parking of 7.760.000 tires in soil. Table 21.3 shows the list of the main vehicles of

Table 21.3 Brazilian fleet equipped with 205/55R16

Brazilian main fleet equipped with 205/55 R16		
Honda Civic	Kia Soul	Citroen C4
Toyota corolla	Fiat Stilo	Volkswagen Beetle
Volkswagen Golf	Fiat Bravo	Nissan Sentra II
Chevrolet Vectra	Chevrolet Zafira	Fiat Linea
Chevrolet Astra	Ford Focus	Peugeot 308
Volkswagen Jetta	Renault Megane	Ford Focus II
Renault Sandero Stepway	Volkswagen Golf VII	JAC J6
Peugeot 307	Peugeot 408	Volkswagen Bora
Nissan Sentra	Chevrolet Sonic	Audi A3 Sedan

the Brazilian fleet that are equipped with this dimension of tires.

Both of the tires chosen for this test have a rather compelling business appeal, and this coupled with the maturity of a price-oriented market, means that the lay consumer is left without many alternatives for a smarter choice.

For this comparative study we will use some Brazil vehicle averages, such as the annual mileage, average fuel consumption, average vehicle weight, average fuel price and average vehicle autonomy with a single tank of gasoline. Table 21.4 shows the averages considered for the study.

After these premises, we needed to differentiate the tires in the performance that characterizes the "green tires" technology: the Rolling Resistance (RR).

The following values were identified for the two brands participating in the study:

(a) Pirelli Phantom: F on RR → 12,0 kg per Ton
(b) Michelin Primacy 3: C on RR → 7,8 kg per Ton

Table 21.5 expresses the gain in kg/Ton between the two tire brands studied and the price difference between them. For the moment, we will consider that the 2 tires have the same durability, even though we know that green tires have longer durability than normal tires.

Table 21.6 shows the economy generated by green tires through gasoline consumption. The difference between the green tire and the normal tire is 2.9% per year. This percentage may seem small, but it means a difference of 147 L throughout the life

Table 21.4 Assumptions

Background and assumptions		
Vehicle consumption	10.0	l/100 km
KMs traveled per year	15	km/year
Vehicle weight	900	kg
Fuel prices	1.16	€/L
Vehicle range	500	km

Table 21.5 RR coefficients

	Normal tires	Green tires	Gain
Rolling Resistance Coefficient	12,0 KG/T	7,8 KG/T	4,2 KG/T
Longevity	50.000 Km	50.000 Km	0 Km
Longevity per year	3,3 years	3,3 years	0,0 years
Purchase price for a tire	70€	86 €	-64 € / 4 tires

Table 21.6 Fuel saved

	Normal tires	Green tires	Gain
Cost of four tires per 1.000 km	5,60 €/1000 km	6,88 €/1000 km	-1,28 €/1000 km
Vehicle consumption (l / 100)	10 L/100	9,706 L/100	0,294 L/100
Fuel expense for 1000 KM	116,00 €/1000 km	112,59 €/1000 km	3,41 €/1000 km
Annual consumption of the vehicle (l)	1500,0 liters/year	1455,9 liters/year	44,1 liters/year

of the vehicle's tires. In order to have an idea of the impact of this on the national market, this economy is multiplied by the data of the tires parked only from the size of the aforementioned study.

Comparing the 2 previous tables, where one shows the extra initial cost of buying a green tire and the other shows the fuel economy that this tire provides, we have Table 21.7.

In spite of an annual investment of 19.20 € to buy 4 green tires, in that same year (that is the basis of the study) the vehicle owner saves 31.96 € in fuel due to the low coefficient of rolling resistance of these tires. This saved amount, following these same premises of consumption, allows the driver to drive an additional 441 km per year.

Extrapolating these calculations to the whole tire life cycle, estimated to be 3.3 years according to assumptions used in the calculation, the driver would have a savings of €107, or could drive another 1470 km.

Another point raised can be the durability of the product. Thanks to new raw materials, a green tire can last longer, which would offset the cost a bit more compared

Table 21.7 Gains on fuel and KM

	Normal tires	Green tires	Gain
Annual fuel cost	1.740,00 €/year	1.688,84 €/year	51,16 €/year
Annual tire cost	84,00 €/year	103,20 €/year	-19,20 €/year
Annual fuel and tire cost	1.824,00 €/year	1.792,04 €/year	31,96 €/year
Free km			441 Km/year

Table 21.8 Fuel and wear gains

	Normal tires	Green tires	Gain	Gains on whole life of the Green tires
Rolling Resistance Coefficient	12,0 KG/T	7,8 KG/T	4,2 KG/T	
Longevity	50.000 Km	57.000 Km	7.000 Km	7.000 Km
Longevity per year	3,3 years	3,8 years	0,5 years	
Purchase price for a tire	70€	86€	-64 € / 4 tires	
Cost of four tires per 1.000 km	5,60 €/1000 km	6,04 €/1000 km	-0,44 €/1000 km	
Vehicle consumption (l / 100)	10 L/100	9,706 L/100	0,294 L/100	
Fuel expense for 1000 KM	116,00 €/1000 km	112,59 €/1000 km	3,41 €/1000 km	
Annual consumption of the vehicle (l)	1500,0 liters/year	1455,9 liters/year	44,1 liters/year	167,58 liters
Annual fuel cost	1.740,00 €/year	1.688,84 €/year	51,16 €/year	194 €
Annual tire cost	84,00 €/year	90,53 €/year	-6,53 €/year	-25 €
Annual fuel and tire cost	1.824,00 €/year	1.779,37 €/year	44,63 €/year	170 €
Free km			441 Km/year	1.676 Km

to other tires. As green tires reduce hysteresis, they also reduce heat generation, thereby causing their degradation to slow down, because heat accelerates the chemical reactions that promote the aging of rubber compounds.

These calculations were quite conservative, especially since we did not consider green tire wear. Using all the previous premises (and taking into account that a green tire has a 14% longer life than the normal tire, corresponding to 57,000 km), at the end of the life of the 4 tires the fuel economy provides for the purchase of 2 new green tires. Table 21.8 shows this calculation.

Theme Discussion and Results

The technology of green tires has been gaining prominence in the national market, supported mainly by three factors.

The first of these factors is the product cost, combined with the performance gain. The development cost of the green technology for tire manufacturers has decreased over the years that the product is on the market, making the tire with this technology more affordable and with a cost close to "common" tires. The initial disbursement cost is still a decisive factor for the purchase of tires in the national market, even though it is clear that the green products have a longer durability, which provides a lower cost.

Associated with the factor of cost is the main benefit of the green tire, which is the fuel economy. Although little valued by consumers, as the case study shows, this benefit may be much higher than the lay consumer perceives. An example of this is the last simulation of the case study that shows that at the end of the life of 4 green

Table 21.9 Environmental impact

	Normal tires	Green tires	Gain
Vehicle range	**500 km**	**515 km**	**15 km**
Average CO2 emitted in g / km over the life of the tires	**250 g CO2/km**	**242,65 g CO2/km**	**7,35 g CO2/km**
CO2 emitted by the vehicle in tons per year on average over the life of the tire	**3,750 T/year**	**3,640 T/year**	**0,110 T/year**
Equivalent to the Carbon caught annually by	**150,0 trees**	**145,6 trees**	**4,4 trees**
Liters of air taken from the atmosphere each year	**13.899.000 liters/year**	**13.490.369 liters/year**	**408.631 liters/year**
Equivalence of oxygen necessary for a man respiration	**927 days**	**899 days**	**27 days**

tires, the savings on the same vehicle would be equivalent to the cost of 2 more green tires.

Usually the average driver does not know how to measure mileage or fuel economy, other than fleet or professional users, who need to closely monitor all the costs of their activities for their business. Proof of this is the higher percentage of lower quality tires in the passenger car market compared to the percentage of these tires in the light truck and truck market.

The other issue that has been supporting the growth of green tires is the environmental impact of these products compared to the common tire. This environmental impact can be ciphered economically through fuel economy, the focus of this study, but also through the amount of CO_2 emitted into the atmosphere and the amount of trees needed to absorb that amount of CO_2.

Extrapolating these calculations, we can predict this impact by comparing the liters of air taken from the atmosphere per year and the equivalence in days of oxygen necessary for man, as shown in Table 21.9.

With consumers becoming increasingly sensitive to evident environmental concerns, this type of analysis can be a decisive factor in the purchase of green tires.

Final Considerations

Reviews and Comments

This work noted the growing concern over the environment and fuel economy, which makes green tires a current trend.

It was found that each manufacturer chooses to approach the green segment in a different way, either with a decrease in tire weight, a new design on the tread, the use of new raw materials or a combination thereof in order to achieve the ideal results and always improve the final product characteristics. Regardless of approach, each of the major companies has green products, making it even clearer that this is a growing and promising market.

Looking at the products available today and the results obtained in the various tests, this paper proves that it is possible to reduce environmental impacts while maintaining or even improving other tire characteristics, such as comfort and safety. Even if the tire presents a higher price, this cost can be returned through fuel savings over the life of the tire.

Many innovations have been presented in the tire market, yielding increasingly promising results for the environment, such as the innovative materials presented in this paper.

Legislation can increasingly help to promote these new technologies that balance the environmental impacts, safety, economy and comfort by analyzing and exposing all aspects to the consumer.

It was observed that a possible way to boost both automakers and tire manufacturers is to increase the dissemination of energy efficiency results, making membership in government labeling programs mandatory for manufacturers. In this way, the end result is the reality seen in the market.

Future Works

The maturity of the national market means that environmental impact is a strong decision criterion for choosing products. Based on the studies of this work, the potential environmental gain that the green tires provide, in relation to the number of trees and CO_2 emission saved due to this technology, could be a very interesting line of study for future work.

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Chapter 22
Development of a Water Purifier Made from Green Coconut Fiber: Application of an Innovative Product

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Abstract The green coconut shell (endocarp) can cause damage to the environment if it is discarded incorrectly, mainly due to its weight and because it takes approximately eight years to decompose in nature. In Brazil, approximately 2.8 million tons of coconut are produced per year, of which 70% are improperly disposed as solid waste. The consequences of this are the release of methane gas, the proliferation of diseases and visual pollution, observed mainly on the Brazilian coast. On the other hand, in Brazil more than 35 million people live without treated water, with the aggravating fact that 7.5% of children and adolescents do not have access to drinking water. In this context, this article presents a study regarding the production of a high impact and low cost water purifier, which operates through the recycled use of coconut fiber. The study relied on extensive market research, including queries in the INPI (National Institute of Industrial Property) database, to certify the exclusivity of the product. Some product development tools such as Quality Function Deployment (QFD), financial viability analysis, and Product Life Cycle Evaluation were applied in the development process. A study of the effectiveness of the water filtration level was also applied.

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Introduction

Coconut palm cultivation has been growing considerably in recent decades, according to Martins and Jesus Júnior (2011), and Brazil is the fourth largest producer of coconut in the world, accounting for over 80% of the production among South American countries. In the face of so much production, there is a relevant concern regarding solid waste from coconut.

Coconut waste is difficult to degrade and generates considerable amounts of unused materials. Its decomposition time takes about eight years (Carrijo et al. 2002), and studies show that 6.7 million tons of bark per year are incorrectly discarded (Rosa 1998). Thus, the need for a large area for the proper disposal of these wastes is clear.

Brazil has a major problem regarding the correct disposal of solid waste and the reuse of this waste. In 2017, Brazil allocated 59% of municipal solid waste to sanitary landfills, 22.9% to controlled landfills, and 18% to uncontrolled landfills (ABRELPE 2017). It is possible to realize that all this waste is extremely harmful to the environment, because when exposed to the environment it can cause damage to the health of the population through the proliferation of diseases by vectors. In addition, according to Passos (2005), there is still the problem of the release of methane, one of the gases that most contributes to the greenhouse effect, thus contributing to global warming.

Faced with this alarming situation, it can be said that the disposal of coconut shell in landfills should be seen as potential renewable waste. More than 80% is treated as waste, being thus discarded, when it could be used in different ways. When processed, for example, it is possible to obtain coconut fiber, a byproduct with countless applications in several areas (Senhoras 2004).

In another scenario there is the reality of about 35 million Brazilians without access to treated water service in the country (TRATA BRASIL 2019). In addition, according to Instituto Trata Brasil, 7.5% of children and adolescents have water at home, but it is not filtered or from a safe source (TRATA BRASIL 2019).

Thereby, this research aims to reduce the environmental impacts caused by the improper disposal of coconut shell, through the creation of a water purifier using this material. The research also aims at recycling coconut and producing a practical, cheap, affordable high impact water purifier.

Theoretical Framework

Coconut Shell Reuse Possibilities

It is understood that the production and consumption of coconut leads to a high amount of waste, both in volume and weight, which may cause problems in the city's health management system (Senhoras 2004). In urban areas, the disposal of coconut in inappropriate places ends up polluting streams, public roads, clogging manholes, as well as creating visual pollution mainly perceived on the coastlines. Thus, the reuse of coconut shell has the potential to considerably reduce problems in its disposal in dumps and may benefit populations in this new production chain (Correia et al. 2003; Apaolaza et al. 2005).

As it is a material with low cost characteristics and wide availability, the possibilities of coconut reuse are many, and may have applicability in areas such as handicraft, construction, pharmaceutics, agriculture etc. By grinding the mesocarp, it is possible to take advantage of the waste, thereby adding value to it, with the aim of obtaining the coconut fiber and powder. According to Carrijo et al. (2002), both fiber and powder are excellent organic materials, since most of their content is composed of hydrogen (H) and carbon (C) (Silva et al. 2013).

Activated Charcoal (AC)

Jabit (2007) define activated charcoal (AC) as a predominantly amorphous solid (that is, without defined atomic structure) which has a high internal surface area and a porous structure. This material is characterized by being an adsorbent, thus ensuring the removal of various types of pollutants, such as metallic ions, (Huang and Su 2010), anions (Wang et al. 2010; Demiral and Gunduzoglu 2010) and dye (Vargas et al. 2011; Li et al. 2010), among others.

Carbonization and activation are the two basic steps for AC production (Girgis and El-Hendawy 2002). The first stage is characterized by the dehydration of raw materials and the carbonization itself. In the end, a porous structure is formed, with narrow and rudimentary pores (Mopoung 2008). However, the activation process can be divided into two groups: chemical and physical activation, both with the purpose of improving pore quality and increasing surface area.

When carbonized and chemically activated with phosphoric acid, coconut fiber has a high surface area (higher than 1000 $m^2\ g^{-1}$) and a high level of micropores (around 80% of total pore volume). Some studies show that the material is efficient in wastewater treatment (Phan et al. 2006).

Absorption

The adsorption process is one of the most common water treatment methods. This process is made possible by the ability of a solid to retain substances present in liquid or gaseous solutions, allowing the separation of the other components. By definition, the adsorbent is the solid where adsorption occurs, whereas the adsorbate is defined as the substance that will be deposited in the adsorbent (Bhatnagar and Sillanpaa 2010).

The use of activated charcoal for the adsorption process is a practical tool, especially with effluents with low dye concentrations (Feng et al. 2005). Adsorption depends on some important factors, namely: the origin of the adsorbent, the origin of the adsorbate and the adsorption conditions. Similarly, the adsorption quality of a material is defined by its specific surface area, pore size and distribution, ash content and density (Fernandes 2008).

Product Cost Analysis

According to Bacic et al. (2011), the costs are the expenses required to perform a service or to obtain a good. Silva and Lins (2010) define costs as the means used during the processing of a good or service to achieve benefits for the organization, and they must be calculated after sales of the product or service are closed.

Bhatnagar and Sillanpaa (2010) state that a good alternative for the development of adsorbents is through the use of agroindustrial residues, since these materials have high carbon content, low ash content and durability. Also in this context, it should be emphasized that these wastes are available in abundance at low costs. Thus, with the efficiency of the adsorption process through the removal of contaminants in industrial effluents and sewage deodorization, these wastes can be used in a low cost water treatment process, thus providing clean and clean water through a simple and environmentally friendly solution (Jain et al. 2009).

Design for Environment—DFE

According to Borchardt et al. (2009), the Design for Environment (DFE) concept emerged in the 1990s, at a time when US electronics factories aimed to lessen the damages of their activities on the environment. From that, this concept became more prominent, and the terms Design for Environment (DFE) and Ecodesign began to be part of environmental management programs.

Bitencourt (2001) states that the Design for Environment (DFE) concept involves the development of environmentally friendly products, while maintaining the economic and technical feasibility of these products, by addressing all stages of the lifecycle, from creation to final delivery. For Tingström and Karlsson (2006), it is important to highlight the multidisciplinarity of DFE, since developing a product is not a linear and repetitive process, but a complex process, where unexpected interactions between product and the environment can arise, and it is necessary to use nonlinear models for this kind of product development.

Ergonomic Analysis

According to Iida (2005), in the field of ergonomics, products in general—from the most elaborate to the simplest—aim to ensure consumer satisfaction; thus the products relate directly or indirectly to people. Again according to Iida (2005), for this relationship to be positive, it is necessary to analyze some primary requirements such as product format, user-friendliness and product quality.

According to Baxter (2000), in order to verify the product task analysis, we can cite two aspects: the relationship between products and human beings and the physical size of users (anthropometry). For Sabino Netto et al. (2004), one way to study ergonomic qualities and opportunities is through the prototype, working on a possible alternative to include ergonomic attributes to the product.

Methodology

According to Fleury and Vargas (1994), methodology should not be considered as a simple set of methods and techniques, but rather a discipline whose objective is to analyze the characteristics of the various methods available, as well as being considered a way of conducting research. Some methods were used in this research in order to collect information that would be pertinent to the execution of the project. The research was conducted in stages, as follows: market research, literature review, research at INPI (National Institute of Industrial Property), development of alternatives, ergonomic studies, studies on the manufacturing process and development of the marketing plan.

Several factors justify the development of the project, which was defined as a water purifier that uses coconut fiber as a filter. Through brainstorming to identify customer needs, together with recognizing the negative impact of coconut disposal, the need for proper disposal of coconut waste, and the environmental focus of the project, the idea of developing the product emerged. For this, some meetings were held with the group members in search of ideas for carrying out the project. With the idea defined, a survey was conducted at INPI to certify that there was not a similar product in its database. Then a market research was conducted to define the target audience of the product.

Through a literature review, it was possible to prove the effectiveness of activated charcoal made from the coconut shell, obtained through a vacuum combustion procedure that does not harm the environment. From this same charcoal a filter is made that acts as a dishwashing sponge, in which water passes through the pores and is filtered. In case the water has high levels of mineral salts, the filter retains this excess, and if there is a low amount of salts, the filter has the ability to add them.

In order to meet market needs, it is essential to obtain customer feedback. Thus, a questionnaire with questions regarding the product was designed to measure what the customer considers most important to the product. A cost analysis was performed to assess customer requirements and product specifications. Moreover, an ergonomic analysis was also used, aiming to analyze the usability of the product. A marketing plan was then defined, setting sales strategies, the disclosure strategy and communication channels.

Analyzing the results collected by the questionnaire, the application of the ergonomic study and the marketing plan, we were able to stipulate the best material to manufacture the product, besides choosing the most appropriate size and shape. Thereby, it was possible to design the coconut fiber water purifier in the best possible way, and in a way that could better meet the needs of customers.

Results

Definition of the Product

The purifier has a simple and practical design, and the product is divided into three parts. Internally it is formed by a small plastic reservoir in the form of a flat cylinder, where the AC is deposited. Externally it is composed of a shell of this container, which has the water outlet on the bottom surface and a small rubber cylinder on the top surface, which will be fitted directly to the tap spout. In addition, the purifier has a simple flow regulation system, so by rotating the bottom surface where the water outlet is, it is possible to control its pressure.

Function Analysis

The main purpose of the product is water purification, and this is possible due to the filtering characteristics of AC. In this way, the purifier ensures the removal of chlorine, parasites, contaminants, harmful heavy metal ions, bacteria, viruses, pollutants, unpleasant tastes of water and any kind of odor, providing proper water for use.

Market Research

Market research was done through a survey, structured based on questions raised through a brainstorming session. The aim of this survey was to identify customer needs, profiles, income and interests to align the product to market needs. Thus, it was identified that 87% of respondents believe that the filter/purifier can be improved in terms of water pressure, filter cleaning periodicity, and storage capacity. It was also stated that 80% would buy a sustainable and low cost purifier. Other identified needs were increased water flow, adaptability, practicality, low cost and product efficiency. Thereby, the most pertinent information obtained in the survey was taken into consideration in the development of the product. With this in mind, we sought to satisfy the customer and obtain a competing product in the market.

By analyzing competitors in the market, there are many types of purifying products that perform water filtration, using AC or candle filter. However, none of the products found in the market today perform this purification through the exclusive use of green coconut endocarp, which is a recycled and efficient fiber.

Materials Analysis

Definition of Materials

For the production of the purifier, besides the AC, Polypropylene and silicone rubber were also used. Such materials were mainly chosen for the best cost benefit and the lowest possible impact on the environment.

Polypropylene (PP) is a thermoplastic polymer used on a large scale, mainly because of its economic viability. Its main applications are in the manufacture of plastic containers. The material is characterized by being nontoxic, with high fracture resistance, as well as easy molding and recycling.

The choice of silicone rubber for the purifier was due to the demand for a material that had high strength, excellent suitability and plastic moldability.

Design for Environment—DFE

Table 22.1 states DFE strategies that are applied to the product.

Table 22.1 DFE strategies applied in the water purifier

Categories	Detailing
Materials	Avoid mixing of materials; Use of recyclable materials; Avoid use of raw material capable of generating hazardous waste; Avoid use of toxic substances
Product components	Reuse of components; All product components can be recycled
Product characteristics	Simple product; Reduce the use of raw materials; Easily dismountable product; Practical design

Source Prepared by the authors

Ergonomic Analysis

From the technical, aesthetic and ergonomic qualities, as well as a study of the main failures and weaknesses of the competitors, an analysis was performed to establish the product sizing, adaptability, weight, design and practicality. The practicality of the product was one of the main factors taken into consideration when defining its characteristics. Given this, the product was designed in the simplest and most adaptable way.

The purifier is 7.5 cm long, 6.5 cm in diameter, and due to its few components the product is characterized by lightness, weighing around 80 g. The size of the product was defined by the average sink depth, so that it should fit on the tap and not cause any difficulty when washing the dishes.

Thus, starting from the principle of the adaptability of the purifier to the faucet, extensive research was carried out in order to determine the diameter of the most commercialized faucets in the market. As a result, the vast majority of kitchen faucets had a diameter between 1.5 and 2 cm. For this reason, the top part of the product, a thick cylinder that attaches to the spout, will be made of silicone rubber, which gives the necessary grip.

Waste Generated

The product is based on DFE strategies, thus it aims to use the smallest possible variety of materials, as well as to avoid adhesives, glues, and mixed materials, always prioritizing the environment and recycling. Thus, the purifier is composed of only two different types of materials, which are polypropylene and silicone rubber, in addition to the mesocarp of green coconut that has already been recycled.

The polypropylene was chosen because of its recyclability, being a thermoplastic, when under high temperatures it becomes malleable and can be recycled. The recycling of the silicone rubber can be done through a technique where the material is depolymerized in silicone oil, in specific conditions of temperature and time, resulting in a product of similar consistency to virgin material.

Cost Analysis

Combining cleaner production and reduced costs during the production process, different agricultural materials can be used in the production of AC, including jute and coconut fiber (Senthilkumaar et al. 2005). Polypropylene (PP) was defined to be used in the product body. This choice was made based mainly on the cost-benefit, being an affordable and resistant material. The AC, obtained by the green coconut fiber, is the main raw material used in the product. Finally, silicone rubber was chosen for the part where it will be linked to the tap nozzle, precisely because of its adaptability and resistance.

Table 22.2 Costs of product materials

Material	Value (R$/Kg)
PP	4.00
Silicone rubber	14.90
Activated charcoal (AC)	18.50

Source Estimated based on Mercado Livre

Table 22.3 Product unit cost

Components	Value (R$)
PP	0.67
Silicone Rubber	0.26
Activated Charcoal (AC)	4.44
Total	5.37

Source Estimated based on Mercado Livre

Materials Cost Analysis

In order to establish the prices of each product component, the cost to produce the purifier is estimated, presented in Tables 22.2 and 22.3. The overall cost of the materials used is R$5,37, being a low value for the product. However, it is necessary to add to this value the other costs involved in production, which were not estimated. It was considered that production costs are lower than material costs, although it depends on the production volume.

The product is sold as a kit that lasts around six months, containing the body of the product in polypropylene and the silicone rubber. This silicone rubber may wear out and should be replaced after some years of use. Regarding the AC filter, the product is composed of a kit of three refills, with the objective of lasting at least six months of use.

Product Detailing

Through the application and analysis of quality tools, it was possible to identify relevant functions, requirements and priorities for customers that should be prioritized in the product. This is justified by the fact that is increases the selling points, as well as being an innovative idea and a non-existent product in the market.

It was found that the purifier containing a coupled pressure setting would be the most viable option to invest in, as it was a product feature of major relevance to customers. In addition, it would not significantly change the cost of the product.

The product will be coated at the base with a shell of the same material, containing a set of holes, where the water will pass. The system flow will be controlled by the rotation of the shell that covers the base of the product. By rotating it the holes

Fig. 22.1 Product body. *Source* Prepared by the authors

Fig. 22.2 Purifying container. *Source* Prepared by the authors

that were previously open will be covered by the surface of the shell, increasing the pressure in the central cavity of the purifier.

The product model is presented in Figs. 22.1 and 22.2.

In the inner part of the reservoir there is a cartridge where all the activated carbon of the coconut fiber will be deposited. It is in this container that the filtration process will take place. From the moment water enters the purifier, it will pass through the activated charcoal through the small cavities, exiting through a porous film.

Conclusion

Given the current scenario, where there is a large negative impact of coconut disposal on the Brazilian coast, it was possible to realize the efficiency and the importance of the product. It can contribute to solving problems of coconut waste disposal in Brazil, as well as being a low cost and affordable product. Therefore, the product is characterized as being sustainable, as it aims to remedy a serious deficiency in water treatment throughout the national territory, in line with the inadequate disposal of coconut, which currently causes pollution of coastal cities.

Thus, it is important to highlight that through the use of product development tools, together with market research, it is possible to identify the preferences and needs of the potential consumers, enabling the development of a prototype that can meet such requirements.

As a result, it is easy to see that the use of methods such as those employed in the project allow for the translation of customer requirements into product characteristics, making the final product more attractive and functional for the target audience.

For further work it is necessary to develop a marketing plan, describing how the purifier would be introduced to the market. In addition, it is also necessary to register the product patent with INPI, in order to certify the exclusivity of production.

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Chapter 23
The Anthropocene: Conceptual Analysis with Global Climate Change, Planetary Boundaries and Gaia 2.0

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Abstract Anthropogenic actions have generated disturbing global environmental changes and have caused the Earth to reach its planetary boundaries by destabilizing the Earth's self-regulating equilibrium system (the Gaia hypothesis). By means of a bibliometric study of the most relevant articles published in the journals of Science Direct and Scopus in the last 5 years, the present article analyzes the Anthropocene through a dialogue amongst the three spheres: global environmental changes, planetary limits and Gaia 2.0. It is concluded that the mitigation or adaptation of the consequences of the self-regulation of the Earth will require a global degree of effort and individual cognitive awareness and change to achieve a new reality of Gaia 2.0 self-regulation.

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Introduction

The geological era of the Holocene lasted around twelve thousand years, characterized as a period in which the natural ecosystem of the Earth was relatively stable and autoregulatory (the Gaia hypothesis), which allowed for conditions to sustain life on the planet. However, humanity has reached a new geological period: the Anthropocene. This term describes the current period in which human action has come to be responsible for the global changes in the planetary system, which is verified by such climatic changes as global warming and the reaching of planetary boundaries (Pincetl 2017).

In that context, the Anthropocene recognizes the impact and consequences of anthropogenic actions on the environment and the need to limit climate change and global warming, investing in paths towards climatic resilience. For Sterk et al. (2017), a comprehensive view of resilience measures the ability of social-ecological systems to adapt to change at the same time that it propels development. Within this realm of resilience, it is critical to promote adaptative and mitigatory practices to deal with negative climatic effects, such as the manner in which sustainable development and autoregulation in Gaia is achieved (IPCC 2018).

In the face of these primary considerations, this article highlights the following research question: What connections do anthropogenic actions have with global climate change, planetary boundaries and Gaia 2.0?

As such, the general subject of the present article is to analyze the Anthropocene by means of a dialogue amongst the following three fields: global environmental change, planetary boundaries and Gaia 2.0. As specific objectives, a conceptual analysis will be conducted of global climate change, planetary boundaries, and Gaia 2.0, in light of the Anthropocene. The methodology is based on bibliographic survey and systematic revision of literature in the Scopus, Science Direct and Google Scholar databases, with the most recently published articles within the past five years holding the greatest relevance.

To address this proposed objective, this study is organized in 6 sections, in addition to the introduction. In Sect. 2, a conceptual analysis of global environmental change and planetary boundaries with the Anthropocene serves as the theoretical reference. In Sect. 3, the methodological procedures of the study are discussed. In Sect. 4, an analysis of the theory of Gaia and the Anthropocene are presented, while in Sect. 5, a discussion of Gaia and Gaia 2.0 is presented. Finally, in Sect. 6, the article ends with final considerations.

Theoretical Reference

Anthropocene and a Conceptual Analysis with Global Climate Change

Rapid population growth, currently estimated at 7 billion (ONU 2019), coupled with the massive accumulation of human activity, has affected the entire planet, its landscapes and its resources. It is possible to notice the impact of these transformations of the planet on a global scale beginning in the middle of the twentieth century, where the Holocene era ends and the Anthropocene begins (Pasimeni et al. 2019).

The term Anthropocene was first used by the biologist Eugene Stoerner in publications during the 1980s, and it was widely popularized in the twenty-first century by the winning chemist of the Nobel Prize in 1995, Paul Crutzen (D'Souza 2019). Both proposed that human activity would profoundly alter the planet to such a point that it would begin a new geological era: the Anthropocene (Biermann et al. 2016).

According to Rohan D'Souza (2019), environmental interferences accelerated by human action (such as the loss of biodiversity, alteration of the atmospheric composition, rise in the average temperature of the oceans, and perceivable rise of sea level) indicate that the terrestrial system is no longer within the equilibrium of its previous period, the Holocene (which refers to the last 11,700 years), and that the Anthropocenic era is imminently approaching an eco-catastrophe.

The Anthropocene recognizes that human actions directly impact the global environment and the importance of realizing the responsibilities that humans possess within this setting for reducing global warming and investing in perspectives of climatic resilience and sustainable development, which includes developing adaptations to face climatic alterations and promoting political actions as a form of mitigating social inequality (IPCC 2018).

Within all anthropogenic pulses that generate global environmental imbalance, the most urgent for attention is climate change and the subsequent global warming. The UN Framework Convention on Global Warming and the Paris Accord recognize that human action is capable of affecting geophysical processes of the Earth (IPCC 2018).

Furlani and Ninfo (2015) highlight in the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) that it is extremely likely that more than half of the observed increases in the average global temperature of the surface from 1951 to 2010 have been caused by the anthropogenic rise in greenhouse gases. The report indicates that the causes of the climatic alterations are the high rate of global emission of greenhouse gases and the high global atmospheric concentrations of carbon dioxide, methane and nitrogen, being reflections of human activities (IPCC 2007).

The IPCC suggests the adoption of mitigation and adaptation strategies: mitigation in the sense of reducing gases that cause global warming, and adaptation in the sense of adjusting natural and/or human systems in response to the actual or expected climate (Pasimeni et al. 2019).

The Paris Accord established the objective of limiting global warming to 1.5 °C. That goal translates into the urgent need for societal transformation, which includes developing changes in politics in existing cultures and the use of technology for adaptation and mitigation of the effects of global warming (UNFCCC 2019).

In that context, Bai et al (2016) reveal that it is critical to think about the meaning of the Anthropocene, such as where it can be used to define attitudes, choices and actions, with the objective of reducing human impacts in the terrestrial system. It is necessary to understand and approach the causes of the vulnerability taking place because of climate change in order to develop strategies as a form of adaptation for this, considering it is a process in which short-term actions produce long-term effects (Adamson et al. 2018).

As such, human beings are the principle cause for global climate changes, directly impacting geochemical cycles, such as the methane and carbon dioxide cycles according to Grindsted (2018). In the vision of an ethical environmental awareness, it is critical that human beings have real knowledge about the consequences of climate changes on the planet as a whole, as well as understanding the concept of the new geological era known as the Anthropocene, so that they can maintain the safety of global ecosystems (Hirsch 2015).

Anthropocene and Its Conceptual Analysis with Planetary Boundaries

According to Saunders (2015), the concept of planetary boundaries represents a series of environmental pressures driven by man that affect the planet negatively. The planetary boundaries or limits arose as a form of organization, so that scientists and scholars could assess and articulate the extent of environmental data, thus creating a force to face businesses, governmental politics and international directives (Ryberg et al. 2018).

For Castree (2014), the concept of planetary boundaries was accompanied in recent years by the idea of the Anthropocene, which since then has been debated. In other words, the concept of planetary boundaries is a particular version of the concept of the Anthropocene in all contexts and independent of names, considering both provoke a reflection about the continual alterations to the Earth.

As such, environmental planetary boundaries mark a zone of safe operation for human activity (Child et al. 2018). Although there were discussions about when it started, it is generally accepted that we are currently living in the Anthropocene era, which is a period characterized by rapid and unpredictable environmental changes. In this new geological era, we are in danger of surpassing our planetary limits, including the lack of potable water, biodiversity, climate change, and nitrogen pollution (Bridgewater and Aricò 2016).

It is important to point out, according to Butler (2016), that the planetary transformation, including the atmosphere, climate, ecosystems and biodiversity, has enormous implications for human health, many of which are profoundly disturbing, especially in low-income environments. Some consequences for the health of the Anthropocene were partially recognized, even in environmental epidemiology, but the long-term consequences remain poorly understood and highly underestimated.

According to Corlett (2015), the planetary boundaries in the Anthropocene are seen as limits which are not safe to surpass in variable global environments together, considering they delineate a safe operational space, as if it were an acting territory for humanity. In a way, they can also be seen as an attempt to maintain the Holocene as Earth's system, because this is the only state where there is autoregulation.

As such, the planetary boundaries are environmental changes caused by man on a global scale. They are limits that were planned to define a "safe operational space for humanity," as a type of pre-condition for sustainable development. According to Rockstrom et al (2009), the planetary boundaries are classified into 9 characteristics of nature and are directly linked to impacts caused by the evolution of humanity. Table 23.1 below presents the 9 planetary boundaries and the impacts of their effects.

The implications of the concept and the proposal of planetary boundaries are still emerging and involve empirical, scientific, ethical and political dimensions. However, it is worrisome to know that, of the nine planetary boundaries, humanity has already surpassed three: the boundary (1) climate change due to CO_2 concentrated in the atmosphere; the boundary (4) changes in the biogeochemical cycle of nitrogen with consequences on the greenhouse effect that is essential to maintain the temperature of the planet in ideal conditions for the survival of human beings; and the boundary (7) rate of loss of biodiversity, which triggers the melting of glaciers and the rising

Table 23.1 Planetary boundaries × impacts and effects

	Planetary boundaries	Impacts/effects
1	Climate change	CO_2 concentration in atmosphere/increased temperatures
2	Acidification of the oceans	Extinction of coral species/extinction of all marine life
3	Stratospheric ozone	Pollution caused by cars and industry/Ozone loses protective layer and turns into a pollutant
4	Biogeochemical cycle of nitrogen	Greenhouse effect/global warming
5	Phosphorus cycle	Loss of biodiversity/extinction of species
6	Global use of fresh water	Lack of potable water/survival of all living organisms
7	Rate of loss of biodiversity	Melting of glaciers/rising of sea level
8	Chemical pollution	Rise of the use of fossil fuels/industrialized agriculture
9	Atmospheric accumulation of aerosol	Pollution of the air /respiratory diseases

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of sea level. With that, it is understood that there will be terrible consequences for humans if they do not respect the limits of natural processes (Saunders 2015).

As such, the structure of the nine planetary boundaries still needs to be totally incorporated into the model of the global view of energy, considering the emphasis has recently been almost exclusively on the mitigation of emissions of CO_2 (Child et al. 2018).

Methodology

Systematic review of the literature consisted of the most relevant articles published in the past 5 years (2014–2019), collected from the databases Science Direct and Scopus, between the months of March, April and May of 2019. With regards to the Anthropocene and global climate change, 39 articles were collected, of which 11 were relevant for the study. With regards to the Anthropocene and planetary boundaries, 22 articles were collected, of which 15 were relevant for the study. The bibliography of Rockstrom 2009 was necessary, considering that all the research beginning in that year reference the article "Planetary Boundaries: Exploring the Safe Operating Space for Humanity. Ecology and Society." And finally, for the Anthropocene and Gaia, 37 articles were collected and 10 used for the present study. The reports of the IPCC from the years 2007, 2014 and 2018 and other articles outside of the pre-established period collected from the database Google Scholar were judged necessary to complement the research.

Analysis

From Gaia to Gaia 2.0

In the era of the so-called Anthropocene, the admission that human actions have influenced and accelerated a global environmental climatic crisis is feasible. The autoregulation of the Earth as a biotic system and a superorganism is in imbalance. As such, the Gaia theory states that the need is growing to develop short and long-term actions that mitigate change and adapt the planet to reestablish equilibrium. Thus, the Gaia system (hypothesis/theory of Gaia) arises from the cooperation between biotic and abiotic elements, living and non-living (Clarke 2017).

The Gaia theory arose at the end of the 1970s, when the chemist James Lovelock cited a speculation about "a cybernetic biological system capable of generating homeostasis on the planet for a time." The biologist Lynn Margulis made another profound contribution to the theory, when she combined her knowledge of microbial ecology and the expertise of Lovelock in geology, physiology and cybernetics (Clarke 2017). In accordance with the Gaia theory of Lovelock and Margulis, living beings make up an autoregulatory system that has maintained habitable conditions until the beginning of the Anthropocene (Lenton and Latour 2018).

Like all new theories, it took decades for the Gaia hypothesis to be partially accepted, considering it was necessary to await the validation of facts by other scientific methods so that it would be possible to confirm or deny it. It is known for a fact that the Earth regulates itself. According to Lanton et al. (2018), the Gaia hypothesis postulates that a system of life consists of the Earth, and its abiotic environment regulates itself in a habitable state. However, it was discovered too late that this regulation is flawed, that the system of Earth is quickly approaching its critical state, and that all life is at risk (Lovelock 2007).

According to Clarke (2017), by means of a cognitive experiment based on homeostasis, the Gaia hypothesis arises from a basic model of first order autoregulation that uses negative feedback to correct deviations from a desired operating state. With analogies taken from cybernetic engineering, this hypothesis proposes biosphere feedback that maintains certain atmospheric conditions, like the global temperature throughout geological time.

The Gaia hypothesis alleges that the entirety of living organisms that comprises the biosphere acts as a single entity capable of regulating chemical compositions, the pH of the surface and occasionally the climate. The Gaia hypothesis is the understanding that the biosphere functions as an active system of adaptative control sufficient to maintain life on Earth. In other words, it is understood that the theory combines the evolutionary interests of its constituent parts (organisms or species) as selective units in a more inclusive entity or of a higher order, to whose evolutionary interests the two constituents are at least partially subordinated (Doolittle 2017).

In that sense, the Gaia hypothesis understands that the maintenance of life on the planet is only possible because there is an autoregulatory system of the planetary scale, which possesses stabilizing properties that keep the planet in habitable conditions (Nicholson et al. 2018). According to Lanton et al. (2018), the surface of the Earth is a materially closed system, in that the fluctuations in the exchange of materials between the solid surface of the Earth, atmosphere or outer space are generally scarce.

However, according to Lenton and Latour (2018), the natural existing autoregulation in Gaia is no longer sufficient to maintain the balance of the terrestrial system, considering that anthropogenic actions have come to be integrated into the natural system of the planet. Humans and non-humans should be seen as inter-related subjects of the Earth (Robert 2018).

For Lenton (2016), the information of the past and present of the planet can influence the current and future state in a cause and effect relationship, like a cycle of closed feedback that profoundly affects its behavior positively and negatively. The negative feedback tends to maintain the status quo and the positive feedback tends to drive change.

In that sense, the transition from Gaia to Gaia 2.0 happens in the moment that we enter the new geological era, the Anthropocene, where it is necessary to adapt and learn with the Gaia system in order to facilitate global sustainability (Lenton and Latour 2018). Thus, the destabilizing feedbacks can easily arise in an ever more complicated manner (Doolittle 2017).

Nonetheless, beyond adopting such practices, it is critical to learn from the Gaia theory, in order to reach the stage of Gaia 2.0, that the Gaia hypothesis can be taken as an affirmation that all (or most of) the biota of the Earth is, in the long term, indirectly interdependent and consists of a unit on a higher level than that of the species. Considering the species are like this, having adaptations to the biotic (as well as the abiotic) environment around them, they are, in various degrees, co-evolving with all others (Doolittle 2017).

In that sense, it is necessary for humans to have a greater awareness that their actions must impact less on the global environmental system in order to reach a natural level of autoregulation that occurred in Gaia, with the intention of attaining a greater global sustainability in Gaia 2.0 (IPCC 2014; Lenton and Latour 2018).

Discussion

Uncertainty: Anthropogenic Changes in Society

From the origins of history, humans have sought to improve the quality of their lives by means of technological innovation, developing scientific and social organization. This progress has accelerated immensely following the Industrial Revolution. As discussed in the theoretical reference, despite the positive advancements of such progress, it has also stimulated a series of extreme changes in environmental conditions, such as loss of biodiversity and rise in sea level (D'Souza 2019). As a result, the Anthropocene is defined by a globally measurable impact of human activity on Earth's system (Mooij et al. 2019).

Amidst such rapid progression and advancement of society, the growth in the demand of food threatens to continually exacerbate current environmental concerns. Conijn et al (2018) explain that as a result of the rise in food consumption for the coming years, the following improvements are suggested for 2050: reduction of waste, less consumption of products of animal origin, greater efficiency of food conversion, greater harvests and pastures, reduction in the loss of nitrogen and phosphorus from agricultural lands and reduction in the volatilization of ammonia (NH3). With the inclusion of these methods, the results are more far-reaching in the food system, highlighting the importance of this interaction.

Beyond the environmental concerns themselves, the rapid advancement and changes that are characteristic of the Anthropocene have widened global gaps in resources, technology and information, presenting yet another challenge for current and future generations of humanity. Casarejos and Rocha (2019) highlight that all poverty and social inequality should be imperatively eradicated, and that wealth should flow from places of excess to circumstances of need. Such transitions require changes in a compartmentalized world and cities profoundly concerned with sustainability. It is up to everyone to promote the increased awareness and commitment to sustainability, generating a cluster of transformative solutions aligned on a planetary scale.

Discovery: Understanding the New Terrestrial System

Such drastic changes witnessed from the Holocene to the Anthropocene signal uncertainty and unpredictability in Earth's social-ecological system, indicating a shift from the Gaia system to Gaia 2.0. As such implications for human well-being have become more evident, multilevel and multiscale responses have begun to occur in order to better understand this new system. These vary from social activism to decisions in political and governmental arenas, and even to very necessary business and innovation transitions in the use of materials, commerce and waste management. An example is the rising political awareness of plastic pollution in the ocean, and its inclusion in the new planetary frontier can help mobilize the action that today is urgent and necessary in all of these fronts (Villarrubia-Gómez et al. 2018).

With such social justice concerns, the principle of resilience—one which is based on the ability of systems to independently progress in the face of change—is critical in a better understanding of how social-ecological systems can promote sustainability. For instance, Mavrommati et al. (2016) suggest that decision-making be based on contributions from both scientists and economists in order to represent a wider spectrum of interests in global well-being.

For Sterk et al (2017), there exist seven fields of social learning resources that underscore the need for a resilient approach, given that the current trajectory of Earth's system is unsustainable. The seven foregoing principles, for Sterk et al (2017) are: (1) social learning, (2) social networks, (3) adaptation, (4) implementation, (5) reform of governance, (6) responsibility and (7) resilient perspective, as shown in Table 23.2. The intention of these orientations is to drive participation and responsibility at several levels of society, transforming the solution from singular improvement to a systematic reform. The change should not necessarily be seen as negative, but as an opportunity for betterment through an example of innovation.

Implementation: Operationalizing Planetary Boundaries

Häyhä et al (2016) understand that to operationalize the concept of planetary boundaries, the limits need to be translated and aligned with the relevant targets in those decision scales. They then propose the development of a structure that tackles biophysical, socio-economic and ethical dimensions of the connection amidst different levels, to supply a consistently applicable approach to translating the planetary boundaries in compartments on a national level for the safe operational space

Table 23.2 principles of resilient systems

	Principles	Explanation
1	Social learning	New information, skills or understanding can be attained through partnerships with those individuals concurrently working on the development of sustainable systems
2	Social networks	Following changes, this type of connectivity can allow for an expedited flow of information and cohesive unity of the collective
3	Adaptation	Complex adaptive systems (CAS) thinking allows for the development of systems built to handle failure and uncertainty through dynamic learning
4	Implementation	It is central to encourage the participation of the entire community of stakeholders in executing these changes in order to create more autonomous systems
5	Reform of governance	Government structures that are polycentric foster a resilient environment in that they facilitate the proliferation of the other principles
6	Responsibility	For each element within the system, it is critical that each is able to compensate for each other as each one has a unique response to changes
7	Resilient perspective	Focusing on slower variables and feedbacks enables the construction of systems that will not be bogged down by these feedbacks

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of the Earth. In this sense, we link the structure of the planetary boundaries with operational and political concepts widely applied to more robust decision-making for sustainability.

Starting from this same understanding that Häyhä et al. (2016) has about operationalizing planetary boundaries in scales, Villarrubia-Gómez et al. (2018) understand that multilevel and multiscale responses are starting to occur. Thereby, having defined which are the planetary boundaries that should be covered, each acting area can create mitigating actions. For example, the ministry of agriculture of a country can create actions on how to harvest food using less water, stimulating also the creation of new action for innovation, thoughts, and culture, bringing a view of responsibility about it all for the whole community.

Mavrommati et al (2016), upon discerning the critical points indicating uncertainty about the needs and preferences of future generations, suggest criteria that require the conservation of environmental conditions. In other words, the integration of biological and ecological thresholds is proposed in decision making, such as planetary boundaries.

Dao et al (2018) propose that current and future populations on Earth have similar rights to natural resources. In invoking such a discussion concerned with rights, the question then becomes a political one, in which each government assumes the responsibility to protect those rights of future populations. In this sense, the authors evaluate the environmental implications of the consumption of countries as compared with the national limits of each one. As such, an approach was developed to better characterize the planetary boundaries and understand which limits can be effectively quantified.

Both environments that Dao et al. (2018) and Mavrommati et al. (2016) present are an understanding of the extreme importance that governmental support with socioeconomic methods can contribute to analyzing resources and quantifying demand to then prospect a milder environment for future generations. However, as it was explained in the introduction, the planetary boundaries have been surpassed in three of the limits and its impacts are catastrophic. In addition to the governmental support for analysis and quantification of the facts, the actions should be emergencies that increase awareness and call for responsibility in all communities in general, independent of location, social class or gender.

In light of this situation, types of mitigation can be adopted, such as public investment in sustainable transportation and the production of renewable energy (clean energy and energetic efficiency). Furthermore, types of adaptations to climate change can be developed, such as the creation of public policies for better infrastructure planning, allowing for greater control and protection from natural disasters (IPCC 2004).

According to Shaw and Nerlich (2015), the mitigating policies will only be successful if justified by a cost-benefit analysis. As such, the discourse about climate change policy was based on historical constructions of environmental values that assume two opposite biases: that of environmental equilibrium versus economic development (Shaw and Nerlich 2015). Once again, this view underscores the multi-faceted approach suggested in the resilient model proposed by Sterk et al (2017).

All in all, adaptative and mitigating behaviors can be developed together as a way to enhance the positive effects by making rationale use of water, creating new systems of energy generation, developing local agriculture, disseminating environmental education and creating greener urban spaces (IPCC 2014).

Conclusion

In order to answer the research question, a conceptual map must be drawn between the concepts of global environmental changes, planetary boundaries and Gaia 2.0 as they relate to global trends in human action. Humans have propelled the planet into the new Anthropocene era, as marked by the innumerous changes in the terrestrial ecological system. Gaia 2.0 suggests that, within this new system in which autoregulation is not sufficient to maintain livable conditions, humans must deal with the uncertainty of environmental conditions. In order to do so, scientists and others in the realm of sustainability have proposed planetary boundaries which delineate a safe zone of conditions in which humans can operate. Thus, this article contends that Gaia 2.0 alleviates the uncertainty presented by current global environmental changes by stressing the need to abide by the planetary boundaries, and in this way, it ensures sustainability in a non-homeostatic terrestrial system.

In the face of the preceding discussion, it is evident that the actions of the Anthropocene era impact the autoregulatory system of the Earth (the Gaia hypothesis), by interfering in global climate and by surpassing three of the nine planetary boundaries. Therefore, for the Earth to regulate itself in order to reach the equilibrium conditions of GAIA 2.0, the resilient approach to climate is necessary, which includes adaptation and mitigation practices. Such methods are seen as strategies to maintain the impacts of climate change in a moderate situation, instead of extreme and catastrophic situations; however, they are constituted of a long and continual process of raising awareness of sustainable practices for humanity (IPCC 2014).

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