2 The Importance of Water-Energy-Food Nexus in the Promotion of Sustainable Cities in the Perspective of the Sustainable Development Goals

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Abstract

The water-energy-food nexus is directly connected with the implementation of the 17 Sustainable Development Goals (SDGs) that make up the United Nations 2030 Agenda. Therefore, the water-energy-food nexus is directly related to the objective of building sustainable cities, to achieve the 17 SDGs. In this research, the nexus composed by the triad—water-energy-food—is evidenced, based on *the following*: SDG 2: zero hunger and sustainable agriculture; SDG 6: clean water and sanitation; SDG 7: clean and

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affordable energy; connected to SDG 11: sustainable cities and communities. As a result, water quality, access to clean and renewable energy, and food security play and exercise a central role in the cities' sustainability. Thus, to make more sustainable cities, they must adopt energy efficiency strategies and promote renewable and clean energy technologies. In this connection, this research aims to analyze the importance of the water, energy, and food nexus for the promotion of sustainable cities in the framework of the Sustainable Development Goals. To that effect, we used a methodology suggestion that considered the need for an integrative literature review, as well as an analysis of field practical data. Furthermore, a theoretical analysis was structured, thus proposing three levels of hypotheses described and discussed in the text. As a result, this article has a double aspect: it contributes to broadening the literature, and at the same time it points out mechanisms for managers and municipal policymakers to develop better policies and strategies that enable the achievement of the SDGs, especially those listed above, having as a consequence strategies to mitigate the impacts of climate change.

Keywords

Water-energy-food nexus · Sustainable cities · Sustainable Development Goals · Sustainable development

2.1 Introduction

The phenomenon of urbanization is undoubtedly an issue that, although not emerging from the contemporary catastrophic process, is a topic that has been discussed for some time, taking into account both the humanistic condition and the direction that will be given in the use of urban spaces and their resources (Lefebvre, 2016). With the process of industrialization and migration of populations from rural to urban spaces, several issues emerged, such as health crises, housing deficit, urban swelling, and environmental deterioration among others (Alfonsin, 2001).

In this perspective, themes focused on the issue of resources inserted in the framework of urban space show a latent gap and thus suggest studies and mechanisms for the present-future projection of these resources. To validate the perspectives of sustainable cities, it is important to consider the rational use of spaces, resources and their fair distribution.

Thus, the water, energy, and food nexus, or simply nexus, first presented at the Bonn Conference in 2011, is perhaps the UN's greatest contribution to postmodern society as a tool for building a world in which the needs of the largest number of inhabitants on our planet are met. The nexus provides resources for improving water, energy, and food security for the communities that use it. The logic of the nexus combines three strategic resources in an integrated way. It is through that logic that the developed and developing nations can be presented with an intelligent view capable of guiding technicians, scientists, managers, and society in general, in the optimization of solutions, improving governance in all sectors (Islam et al., 2020; Schlör et al., 2020).

The concept of sustainability has been introduced, considering the well-being of the planet with continued growth and human development. The definition offered by the World Commission on Environment and Development has been seen as the guiding principle for long-term global development and is based on economic development, social development, and environmental protection: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987).

In the last decades, many significant international events and commitments have impacted the evolution of sustainable development (Beynaghi et al., 2014; Lozano et al., 2014). In 2015, the 2030 Agenda for Sustainable Development was launched. This global development agenda includes 17 UN Sustainable Development Goals, or SDGs, and 169 milestones. The agenda addresses critical issues facing the world today, including the eradication of extreme poverty, tackling global inequality and climate change, promoting sustainable urbanization and industrial development, protecting natural ecosystems, and fostering the even growth of peaceful communities and governing institutions. A set of 232 indicators has also been developed to measure progress on SDG goals and targets, within and across countries (UN, 2018a). After 5 years, some progress is visible according to the last report of the UN (2020a): the share of children and youth out of school had fallen; the incidence of many communicable diseases was in decline; access to safely managed drinking water had improved; and women's representation in leadership roles was increasing. At the same time, the number of people suffering from food insecurity was on the rise, the natural environment continued to deteriorate at an alarming rate, and dramatic levels of inequality persisted in all regions.

The goals call for action "for people, planet, prosperity, peace, and partnership" to be implemented by "all countries and all stakeholders, acting in collaborative partnership."

With the adoption of the SDGs, countries and cities around the world are turning to the question of SDG implementation. How to make practicable these ambitious global goals? How can the national and local governments contribute? And why must cities and human settlements play a crucial role in their implementation (Kanuri et al., 2016)?

In this agenda, there is a specific goal with a focus on cities. The SDG 11 calls for "making cities and human settlements including, safe, resilient, and sustainable." That means creating opportunities for all, safe and affordable housing, better conditions in public transport, creating green spaces, improving urban planning, preparing cities with resilient societies and economies, and evenly increasing management with participatory ways.

Cities are critical to achieving the SDGs. As the world continues to urbanize, sustainable development depends increasingly on the successful management of urban growth for meeting the needs of the populations (UN, 2019). According to the United Nations' report, the world's population is expected to increase by 2 billion persons in the next 30 years, from 7.7 billion currently to 9.7 billion in 2050. That means that many cities and countries will face challenges including infrastructures such as housing, transportation, energy systems, and basic services such as education, health care, and food (UN, 2018b). Cities encompass some of the main issues to sustainable urban development, such as urban planning, transport systems, water, sanitation, waste management, disaster risk reduction, access to information, education, and capacity building (UN, 2020b).

The data shows that cities produce more than 50% of the world's greenhouse gas emissions (Hoornweg et al., 2011), are responsible for the use of 60% of the world's energy, and contribute to 70% of global waste (UN-Habitat, 2020). For this reason, cities are frequently considered the optimum strategic scale for action to mitigate climate change, in terms of land use, carbon control policies, and transitions toward a green economy.

In a scenery where climate change is accelerating, the world crisis is due to the scarcity of resources, and their poor distribution is becoming more worrying. One of the approaches is the water-energy-food nexus (Urbinatti, 2020). Toboso-Chavero et al. (2018) argue that cities are rapidly growing; they need to look for ways to optimize resource consumption, especially the food, energy, and water nexus.

Due to that, cities are increasingly paying attention to the sustainable development drivers. A sustainable city maximizes the benefits in economic and social dimensions under relevant constraints on environmental limitations (Mori & Yamashita, 2014). The authors emphasize the need for a balance between social and economic living standards and environmental sustainability.

Since 2016, the progress of the SDGs has been monitored globally, regionally, and subnationally. The SDSN (Sustainable Development Solutions Network) and Bertelsmann Stiftung annually publish the SDG Index and Dashboards (sdgindex.org).

In terms of the SDG 11 progress, the US Cities Sustainable Development Report (Lynch et al., 2019) provides an entry point into the United Nations' Sustainable Development Goals at the city level in the United States. The report shows that city performance isn't as closely tied to size, location, or goal; solutions and furthering progress require localized understanding and interventions. The last report published by SDSN discusses the impact of COVID-19 on SDG progress (Sachs et al., 2020). It is indisputable that COVID-19 will have severe negative impacts on most SDGs. In terms of sustainable cities and communities (SDG 11), the negative impact has been mixed or moderate; there is a rise in urban poverty and vulnerability; shut down of public transports, lower access to public/green spaces; movements of population that vary across countries; and sharp short-term reduction in pollution levels.

There is no doubt that there are still many challenges ahead for cities to be inclusive, productive, and environmentally friendly. New challenges have arisen due to COVID-19, an unprecedented crisis that is threatening lives and livelihoods, impacting health, the economy, and society in all countries (Leal Filho et al., 2020).

Thus, in the scope of sustainable urban spaces, a relevant aspect that even guided the theme selection, as well as the way to explore the bibliography, is about urban sustainability. The urban sustainability proposed by SDG 11 connected with the resources distributed and used in the urban setting, that is, water, energy, and food nexus, highlights the need to think and rethink policies that are more in line with the socio-environmental cities' outlook.

Given the aspects addressed, this article aims to analyze the importance of the water, energy, and food nexus for the promotion of sustainable cities in the context of the objectives of sustainable development.

2.2 Theoretical Framework

The literature review is divided into two themes: (1) the energy-water-food nexus as graphene for the SDGs and (2) the energy-water-food nexus in the context of sustainable cities.

2.2.1 The Energy-Water-Food Nexus as Graphene for the SDGs

Graphene is a derivative of carbon (one of its crystalline forms), as are the carbon nanotubes (diamond and graphite), and when added to other materials has remarkable thermal, mechanical, and electrical properties. Most applications in energy storage devices revolve around the application of graphene, as it can improve the performance, functionality, and durability of many applications. It is the strongest, lightest, and thinnest material that exists, being much more resistant than steel even though it is a two-dimensional material, that is, it has the thickness of an atom (Alam et al., 2019; Olabi et al., 2021).

And just like graphene, which comes from a simple, elementary, and necessary raw material for the formation of life, as we know it on Earth, the nexus is also a simple concept, whose very name clarifies its purpose and which establishes a relationship among three important resources for life on Earth (Hua et al., 2020). When investigating its potential, one can think of the nexus as a kind of graphene for the achievement of the Sustainable Development Goals (SDGs) and sustainability. Just as graphene has the potential to transform the world (Bandala & Berli, 2019; Makgabutlane et al., 2020), so does the nexus, which has incredible potential with much to be researched, being able to enhance the service of all SDGs.

The nexus is aligned not only with the concept of sustainability but also with the concept of industry 4.0. In this sense, we are already beginning to observe the emergence of concepts such as sustainability 4.0. If for some authors, industry 4.0 is seen more for its negative aspects, such as being responsible for the loss of countless jobs and for fostering the concentration of income; on the other hand, it can be an excellent ally of developed nations in meeting the SDGs and in the development of circular economy models (Dantas et al., 2020; Bai et al., 2020).

The techniques of automated irrigation and automation in planting are examples of how to optimize food production and also to reintroduce forests, thereby meeting various SDGs and avoiding diplomatic friction in the intervention in the natural wealth of other nations (USW, 2010; Goh et al., 2020). The automatic irrigation system allows the plants to receive water in the exact amount that the plant needs, and it is even possible to schedule irrigation. Thus, it eases the monitoring and irrigation time, which generally needs an extended working time, especially if the gardens have plants of different species, thus requiring irrigation in different quantities. This process is especially useful for greenhouses, including vertical gardens, thus allowing a large amount of food to be produced in a reduced space. For automated planting, specific equipment is used, which can use sensors for temperature and humidity of the air and soil and sensors for solar radiation.

It is observed the importance of interventions and support from governments in supporting research and incubators to address market failures so that the SDGs are achieved, remembering that sustainable development manages to meet the needs of the current generation without compromising the existence of future generations, at the same time that the best education is that which takes place through example (Surana et al., 2020).

Thus, it could be stated that if the concept of the nexus was already known and widely spread worldwide, it could have prevented the majority of developed countries from destroying their forests and from now being so concerned with forests and resources preserved by underdeveloped or developing countries. Even though Brazil has about 2/3 of its original forests preserved, the cleanest energy matrix in the world, passenger cars that do not use diesel, and is a pioneer in biofuels such as ethanol, it suffers from harsh environmental legislation that slows down the updating of its road and rail network, among other things, just like other developing countries. It is above all in the social dimension of sustainability that the ability to minimize conflicts is identified in the nexus, presenting evidence of becoming a central element in the development of a new era. Thus, while the SDGs can be seen as a set of guiding concepts for actions capable of developing the actions, the nexus contributes to the achievement of the SDGs by presenting concepts and strategic visions of resource management indispensable to human life, and in this sense the industry 4.0 also contributes to the achievement of several SDGs, highlighting two notable characteristics, the first is the potential to reforest large areas of deforested land and the automation associated with tools, software, irrigation systems, and machinery, which allow jumps in the volume of food production in the world, making it possible to feed the more than 7 billion human beings that currently live on our planet (Bai et al., 2020; Dantas et al., 2020).

For Islam et al. (2020), most studies related to the nexus were carried out by the United States, China, and Australia, representing 23%, 17%, and 15% of the total, respectively. Engineering thought from the perspective of the nexus is capable of turning professionals from the so-called hard sciences into social scientists, who, by performing engineering thinking with the logic of the nexus, sophisticate engineering projects and processes and thus meet important concepts and theories defended by social scientists, creating synergies and increasing efficiency (Proctor et al., 2020; Schlör et al., 2020).

Since the nexus relates three irreplaceable resources for human survival, at the same time that it guides managers in the efficient treatment of resources, the nexus also demonstrates their role as science and practice in international relations between countries and in their domestic markets. This art of orienting human relations in the face of strategic resources is what is identified in the nexus as an important instrument of diplomacy. Wars originate by obtaining resources, and then there are strategic management and governance tools that raise awareness and guide the importance of resources, the responsibility of all parties interested in these resources, and the encouragement of management tools capable of optimizing the use of resources prove to be diplomatic elements and, in essence, aligned with the UN objective, in creating the nexus in 2011 and the SDGs in 2015 (Salmoral et al., 2019; Hua et al., 2020; Schlör et al., 2020).

If, on the one hand, diplomacy can be understood as the art of preserving the rights and interests of the State in negotiation with foreign governments, on the other hand, through diplomatic relations, countries can bargain the resource of other countries, avoiding military wars and practicing wars of narratives and media in the defense of their interests. In this sense, international law recognizes the ability of States to exercise diplomatic protection over their national interests, and thus, again, the nexus is capable of structuring diplomatic deals on a rationalist basis capable of carrying out historical rescues (Hassan et al., 2017; Klimes et al., 2019; Proctor et al., 2020).

By drawing upon present and future scenarios of the planet while at the same time placing on the table, in numbers, what each country has done for the conservation of global nature throughout its history, reveals which countries have done little in this direction. Similarly, this points out which countries have advanced technology and how they plan to share these technologies so that the least developed countries reach the minimum acceptable Human Development Index (HDI) indicators that enable communities to optimize and reach the level of the most important SDGs. At the same time, we should avoid exacerbating the gap between the under-developed and developed countries, which mostly have advanced technology but have destroyed most of their forests. These are important challenges to be overcome in reaching the SDGs (Castillo et al., 2019; Santos, 2020).

The high potential for reforestation made possible by industry 4.0 is greater in the most technologically developed countries, which are precisely the countries that most polluted their waters and destroyed their original forests and which today charge countries that have preserved high percentages of their forests, to keep them untouchable. Industry 4.0 can help countries such as the United States, Canada, Russia, China, and the countries of the European Union to carry out reforestation of their original areas, avoiding diplomatic wear. And so it is clear that industry 4.0 can be an integrating element of countries, as can the nexus (Klimes et al., 2019).

Although cities can employ bioclimatic architecture solutions in their projects, aligned to the nexus, enabling water collection, treatment, and reuse, the use of energy efficiency and IoT concepts, along with renewable sources of energy generation, and also privilege the production of part of the food to be consumed in the urban environment, the fact is that large centers have become conflicting zones, as they do not support the demands and expectations of their inhabitants. Therefore, concepts such as those of sustainable cities and/or healthy people are more easily served in smaller cities, with a better population distribution from large centers to small centers, enabling direct service to important SDGs (del Río Castro et al., 2020; Liu et al., 2021).

2.2.2 The Energy-Water-Food Nexus in the Context of Sustainable Cities

Since the second half of the last century, discussions have been intensified about the urbanization process, which took place simultaneously in different parts of the world. In this connection, Lefebvre (2016) emphasized that this process occurred simultaneously with the advance of industrialization, which caused cities to spread into rural spaces and, consequently, led to the invasion of these spaces.

In this way, also according to Lefebvre (2016), that reckless urbanization driven by industrialization, whether from the perspective of rural-urban migration of people seeking jobs and economic improvement or from the perspective of enjoying the sociable spaces, resulted in the disorderly use of natural resources existing in the spaces that made up the cities.

As a result, the Industrial Revolution showed humanity how much the human being is capable of producing but also how much the human being is capable of consuming. Meadows (1972) projections impacted the world because they demonstrated that there is a limit to growth, imposed by nature itself. From this point on, many actions were taken to preserve the environment. However, where there are factories, there is employment. And a movement of people leaving the countryside searching for a better quality of life in cities could be seen all over the world.

New projections have been made; according to the UN (2019), 55% of the world's population lives in urban areas, and the population in urban areas is expected to be 70% of the world population by 2050. Therefore, cities need to prepare and transform themselves, becoming sustainable, healthy, intelligent, and resilient. Governments need to consider the goals for 2030 of the Sustainable Development Goals (SDGs) as a whole and contribute to solving so many problems that many cities still have.

Conceptualizing sustainable, healthy, intelligent, and resilient cities can be complex, as it requires urban transformation with economic and systemic changes. In general, it is a process that will make cities efficient, livable, inclusive, and environmentally friendly (Chehri & Mouftah, 2019). Much research is being carried out on urban sustainability to contribute and conceptualize urban sustainability.

A sustainable city can be defined as cities that develop responsibly in terms of social, environmental, and economic dimensions (Brito et al., 2019). These cities must reduce impact, waste, and emissions and expand recycling and encourage local businesses (El Ghorab & Shalaby, 2016), in addition to promoting environmental education. An active intervention aimed at improving the network of green spaces (Haase et al., 2017), the quality of human life (Li & Yi, 2020), and economic growth (Jing & Wang, 2020), is an essential driver to this aim.

We sought to define characteristics, indicators, and sub-indicators for sustainable, healthy, intelligent, and resilient cities. Anand et al. (2017) proposed a series of criteria and indicators; for this research, the following stand out: food security, use of renewable energy, and water quality/availability. Brito et al (2019) mentioned, among others, the following criteria: people, water, energy efficiency, and waste.

Deng et al. (2019), when proposing an evaluation method for urban sustainability, divided the evaluation points into primary dimensions, namely, building and installation, natural environment, people's satisfaction, and transportation system. Each primary dimension is made up of subdimensions. Regarding the subdimensions, the following stand out: energy efficiency, consumption efficiency, energetic environment, and health care.

Meerow (2020) cites the danger of rainwater. Su et al. (2019) present the indicators: energy consumption by gross domestic product (GDP) and water consumption by GDP. Langellier et al. (2019), with a view to a healthy city, present the indicators: changes in food preferences and nutritional literacy, among others. Based on this information, the importance of issues related to energy, water, and food is noticeable.

As highlighted by Sachs (2015) in the book *The Age for Sustainable Development*, the definition of sustainable cities is threefold, involving the three dimensions of sustainable development. Sustainable cities are economically productive, socially and politically inclusive, and environmentally sustainable. It means that cities must promote an inclusive and efficient economic activity and preserve the biodiversity, air, and water and physical health and safety of the citizens, especially in an age of increasing vulnerability to extreme climate catastrophes from climate change.

However, even though there are many sustainable city initiatives worldwide, there are also many difficulties and challenges.

The official road map for achieving the SDGs in urban environments, *Getting Started on the SDGs in Cities* was proposed by Kanuri et al. (2016) with collaboration from SDSN's Thematic Network on Sustainable Cities. The guide underly four steps: Step 1: Initiate an inclusive and participatory process of SDG localization. This includes raising awareness of the SDGs, engaging stakeholder collaboration, and potentializing political leadership. Step 2: Set the local SDG agenda: equipping the SDGs with ambitious but realistic local agendas, evidence-based decision-making, and public involvement. Step 3: Plan for SDG implementation: using goal-based planning, both long-term and multi-sectoral, and supporting it with financial resources and partnerships. Step 4: Monitor SDG progress: developing local monitoring and evaluation systems that are affordable, comprehensive, and effective in reliably capturing progress on local goals and targets.

In Brazil, the first connotation given to the idea of sustainable cities occurred through the normative scope of Federal Law 10.257 of 2001, also called the Statute of Cities. This law, in addition to establishing and regulating the Brazilian Urban Policy, aims to establish basic guidelines to govern the common use of urban spaces and also to establish mechanisms to conceptualize and seek the construction of apparatuses for urban sustainability (Brasil, 2001).

From this perspective, later in Brazil, the Sustainable Cities Program, an initiative of organized civil society in 2011, aims to contribute to the sustainability of cities through the involvement of the teams responsible in the city halls. The program proposes a process based on guidelines, indicators, and targets, organized into 12 thematic areas and linked to SDGs: (1) governance; (2) common natural resources; (3) equity, social justice, and a culture of peace; (4) local management for sustainability; (5) urban planning and design; (6) culture for sustainability; (7) dynamic, creative, and sustainable local economy; (8) education for sustainability and quality of life; (9) better mobility; (10) local action for health; (11) from local to global; and (120 responsible consumption and lifestyle options. The relevance of this program is that it is based on the engagement of local governments with goals for action during their management time (Programa Cidades Sustentáveis, 2017, 2020).

Although many collaborations between politics, research, business, and civil society have been developed in cities worldwide, Khair et al. (2020) emphasize the importance of local community active participation in promoting a city more sustainable, especially regarding their monitoring process.

Weymouth and Hartz (2018) also argue that to achieve the implementation of SDGs in cities, collaborative problem-solving and decision-making are required. According to them, the role of new partnerships in governance and the empowered participation of everyday people to develop public wisdom can help cities to integrate and implement SDGs and bring transformative change.

Dalla Fontana et al. (2020) researched the water-energy-food nexus in the Brazilian context. The authors mentioned that when implementing policies aimed at a specific sector, objectives in other areas may be impaired since the nexus requires an integrated approach. The research by Yuan et al. (2020) aims to measure the sustainability of the urban food-energy-water nexus in cities. The model used is composed of nine indicators, which are food production, malnutrition, agricultural area, energy consumption, electrical access, renewable energy, water consumption, access to water, and wastewater collection.

Bazzana et al. (2020) studied the impact of the water-energy-food nexus infrastructure on local well-being. According to the authors, the nexus proposes the use of natural resources in the social and economic context; however, the well-being of the population about investments in infrastructure is controversial.

When analyzing the effects of the construction of a specific hydroelectric plant, the results showed that there was a competition for land between rural communities and the water and energy sectors. In addition, the population's economic constraints can reduce access to new services (Bazzana et al., 2020).

However, thinking about the water-energy-food nexus in the context of sustainable cities proposes environmentally, economically, and socially viable policies but also intelligent, resilient, inclusive, and healthy. It is therefore important to assess whether the indicators contribute to the Sustainable Development Goals (SDGs). With that, we have the hypotheses of this research:

H1. There is an influence of sustainable city energy indicators in the SDGs.

H2. There is an influence of water indicators of sustainable cities in the SDGs.

H3. There is an influence of food indicators from sustainable cities in the SDGs.

2.3 Methodology

The theoretical-methodological structure proposed by this research followed two pathways: (1) selection of the methods used and (2) division of the steps and procedures used in the collection and treatment of data. For the first stage, the choice of methods and guidelines, their nature, way of obtaining data, and way of approach are highlighted.

Regarding its nature, it is proposed as applied research, since it aims to investigate and correlate data obtained directly, with the findings in the literature in the search for answers to the proposed hypotheses. To help with this type of research, there is the direct research method, which, through its mechanisms, seeks evidence in the delimited field for analysis and sampling (Martins & Theóphilo, 2018). On the other hand, regarding the approach, this research is based on a quantitative approach, since, from the perspective of Saunders et al. (2016), the quantitative approach allows the formulation of hypotheses, which can be tested (contributing to the development of the theory) or examined in future research.

About the steps of procedures used in this research, three major basic cores stand out, namely, (1) literature review, using systematic mechanisms for an integrative review; (2) procedures for preparing indicators and sub-indicators; and (3) structuring of data collection and analysis mechanisms and definition of the application area (Florianópolis).

Thus, in the first stage, for the integrative review, databases were not specifically defined, since the objective of integrative reviews is to obtain the main elements to support a given topic. However, in the searches, we used the main repositories/publishers such as Elsevier, Periódicos CAPES, Springer, and Google Scholar, searching keywords "water-energy-food nexus"; "sustainable cities"; "water-energy"; and "food nexus," defined to obtain more relevant and quoted results, compatible with the thematic proposal.

For the second stage, regarding the procedures for the development of indicators and sub-indicators, the literature review was essential, as it allowed the extraction of the most cited indicators. Subsequently, in the third stage, the data collection instrument was elaborated, using the questionnaires through the Google Forms tool, proposing a data collection instrument connected with the findings of the literature review.

In a subsidiary way, an analysis was carried out using descriptive statistics and the technique of modeling structural equations of partial least squares. For that, the real data were collected through direct research applying questionnaires. The dimensions listed in the present study were identified, translated, analyzed, and adapted from existing models in the literature mentioned in this work, aiming at maintaining compatibility with the theme and context of this research.

Regarding the procedures of the third stage, we highlight (1) the structuring of the research instrument and (2) data collection. Thus, the first version of the instrument had 72 questions on the 4 dimensions. On the other hand, about data collection, the period used was between June, 27 and August, 18, 2020, online, through the Google Forms tool with dissemination on social networks and email distribution.

Regarding data collection, initially, the completion and validation of the questionnaires received were verified. A total of 75 questionnaires were collected and validated. The criterion used was the selection of respondents living in the metropolitan region of the city of Florianópolis. The delimitation of this region followed the sampling method; despite the non-probabilistic sampling, this can be considered a homogeneous group, with at least one characteristic in common, residents of Florianópolis, as recommended by Flynn et al. (1990) and Hourneaux Jr et al. (2018).

And as the last procedure, the data collected were entered into Excel spreadsheets and analyzed using descriptive statistics and the modeling of the technique partial least squares structural equations (partial least squares), supported by the SmartPLS software, version 3. Subsequently, there was a compatibility comparison of the data obtained with the literature review, culminating in the discussion established in this research.

2.4 Presentation of Results

The sustainable city model is composed of 3 indicators, which are (1) energy, with 9 sub-indicators; (2) water, with 13 sub-indicators; and (3) food, with 3 sub-indicators.

Table 2.1 Strategic map of the energy indicator

1	Indicator	Energy indicator
Description		Actions aimed at energy efficiency
Authors		Bao and Toivonen (2014), Taecharungroj et al. (2018), Sokolov et al. (2019), Brito et al. (2019), Anand et al. (2017), Alyami (2019), Subadyo et al. (2019), Su et al. (2019), Li and Yi (2020), Ruan et al. (2020), Brilhante and Klaas (2018), Sokolov et al. (2019), Deng et al. (2019) and Vukovic et al. (2019)
1.1	**Sub-indicator**	Energy consumption by GDP
Description		Energy consumed for a population
Authors		Su et al. (2019), Li and Yi (2020), Ruan et al. (2020) and Brilhante and Klaas (2018)
1.2	**Sub-indicator**	Solar energy and energy from waste plants
Description		Clean energy sources
Authors		Subadyo et al. (2019) and Sokolov et al. (2019)
1.3	**Sub-indicator**	Wind force
Description		Wind power source
Authors		Subadyo et al. (2019)
1.4	**Sub-indicator**	Smart housing
Description		Residences with clean technologies
Authors		Anand et al. (2017) and Deng et al. (2019)
1.5	**Sub-indicator**	Hydroelectric plants
Description		Amount of energy generated in hydroelectric
Authors		Subadyo et al. (2019)
1.6	**Sub-indicator**	Energy measurement or sub-measurement
Description		Energy spent on a population
Authors		Alyami (2019)
1.7	**Sub-indicator**	Potential for renewable energy and passivity
Description		Amount of energy that can be generated
Authors		Bao and Toivonen (2014), Anand et al. (2017), Brilhante and Klaas (2018) and Alyami (2019)
1.8	**Sub-indicator**	Energy-efficient building systems
Description		Clean technologies for buildings
Authors		Bao and Toivonen (2014), Alyami (2019), Subadyo et al. (2019) and Vukovic et al. (2019)
1.9	**Sub-indicator**	Energy-efficient technologies
Description		Investment in clean technologies
Authors		Anand et al. (2017) and Sokolov et al. (2019)

Table 2.1 shows the strategic map of the energy indicator, including the description of the indicator and the sub-indicators, as well as the authors who supported the indicator and the sub-indicators.

Yuan et al. (2020) observed that renewable energy plays an essential role in the nexus and that future work should focus on the technological innovation associated with the nexus. State-of-the-art technology, which in recent years has become accessible on some scale to remote regions, enhanced the quality of life in the countryside, minimizing rural exodus and enabling reverse movement, especially after the COVID-19 world pandemic in which people have been forced to isolate at home to avoid crowds, which is uncommon in rural regions.

Table 2.2 shows the strategic map of the water indicator, including the description of the indicator and the sub-indicators, as well as the authors who supported the indicator and the sub-indicators.

The nexus also provides resources where there is a regional shortage, for example, through the so-called virtual water imports. Whether through

Table 2.2 Strategic map of the water indicator

2	**Indicator**	**Water indicator**
Description		Actions aimed at water efficiency
Authors		Bao and Toivonen (2014), Taecharungroj et al. (2018), Sokolov et al. (2019), Brito et al. (2019), Alyami (2019), Subadyo et al., (2019), Su et al. (2019), Meerow (2020), Brilhante and Klaas (2018), Giles-Corti et al. (2019), Steiniger et al. (2020), Jing and Wang (2020) and Li and Yi (2020)
2.1	**Sub-indicator**	Access to drinking water
Description		Access to drinking water in a population
Authors		Bao and Toivonen (2014), Brilhante and Klaas (2018), Alyami (2019), Giles-Corti et al. (2019) and Steiniger et al. (2020)
2.2	**Sub-indicator**	Wastewater capacity
Description		The capacity of wastewater in a city
Authors		Brilhante and Klaas (2018), Alyami (2019) and Jing and Wang (2020)
2.3	**Sub-indicator**	Water intake (rain, runoff)
Description		Investment in water intake
Authors		Alyami (2019) and Sokolov et al. (2019)
2.4	**Sub-indicator**	Per capita water consumption
Description		Water consumption of a population
Authors		Brilhante and Klaas (2018) and Su et al. (2019)
2.5	**Sub-indicator**	Industrial wastewater produced
Description		Quantity of wastewater produced from industries
Authors		Jing and Wang (2020) and Li and Yi (2020)
2.6	**Sub-indicator**	Renewable water source
Description		Investment in renewable water
Authors		Alyami (2019)
2.7	**Sub-indicator**	Quality of wastewater treatment service
Description		Water quality
Authors		Steiniger et al. (2020)
2.8	**Sub-indicator**	Water reuse (recycled)
Description		Investment in water recycling
Authors		Alyami (2019)
2.9	**Sub-indicator**	The leak detection system, meter system
Description		Monitoring of water leakage
Authors		Alyami (2019)
2.10	**Sub-indicator**	Drainage, sewage, and water systems
Description		Drainage, sewage, and water actions
Authors		Giles-Corti et al. (2019)
2.11	**Sub-indicator**	Water conservation technology and accessories
Description		Investment in clean water technologies
Authors		Alyami (2019)
2.12	**Sub-indicator**	Sewage and garbage treatment
Description		Actions aimed at the treatment of sewage and garbage
Authors		Bao and Toivonen (2014), Brilhante and Klaas (2018), Alyami (2019), Steiniger et al. (2020), Su et al. (2019) and Li and Yi (2020)
2.13	**Sub-indicator**	Surface runoff production
Description		Estimation of runoff production
Authors		Meerow (2020)

land degradation, water scarcity, or food crises, the main challenge under these various levels of restrictions is to reconcile long-term and global objectives, not limited to an immediate vision of economic benefits, privileging the guarantee of local livelihoods and nonnegotiable human rights to water and food, as well as energy, resources directly related to the HDI of nations (Xu, 2019; Islam et al., 2020; Liu et al., 2021).

Table 2.3 shows the strategic map of the food indicator, including the description of the indicator and the sub-indicators, as well as the authors who supported the indicator and the sub-indicators.

One of the issues that have become a concern with estimates of population growth is how to feed everyone. Today, malnutrition is still an unsolved

Table 2.3 Strategic map of the food indicator

3	Indicator	Food indicator
Description		Actions focused on food
Authors		Bao and Toivonen (2014), Langellier et al. (2019), Anand et al. (2017), Rosales (2011), Giles-Corti et al. (2019), He et al. (2020) and Steiniger et al. (2020)
3.1	Sub-indicator	Nutritional literacy
Description		Provision of nutrition professionals
Authors		Langellier et al. (2019)
3.2	Sub-indicator	Taxation of ultra-processed foods
Description		Control of ultra-processed foods
Authors		Langellier et al. (2019)
3.3	Sub-indicator	Access to food with sustainable and quality production
Description		Providing healthy food
Authors		Bao and Toivonen (2014), Langellier et al. (2019), Anand et al. (2017), Rosales (2011), Giles-Corti et al. (2019), He et al. (2020) and Steiniger et al. (2020)

problem, affecting 40% of the world's population. Another problem that often goes unnoticed is the deficiency of micronutrients, such as vitamins. There is also a third problem, obesity, common mainly in rich countries; about 15% of the world population are obese (Sachs, 2017).

Many people are not well informed about the nutrients they need to have a healthy life, so nutritional literacy and the availability of nutrition professionals are important. Many people do not have a varied menu; thus, they are deficient in nutrients.

2.4.1 PLS (Partial Least Squares) Analysis

In this subsection, the analysis of partial least squares will be carried out, through two steps: evaluation of the measurement model and analysis of the structural model, both of which are broken down in sequence.

2.4.2 Evaluation of the Model: Validity and Reliability

From the exportation of the collected primary data to the SmartPLS software, version 3, and its configurations having been made, the report of the preliminary data obtained was generated. The evaluation of the model started through its convergent validity, reliability, and discriminating validity, as recommended by Hair Junior et al. (2017).

It should be noted, however, that the sequence of analyses occurred by the recommendation of Bido et al. (2019), namely, (1) convergent validity; (2) discriminant validity (DV); (3) reliability; one of the assumptions for assessing reliability is that its convergent and discriminant validity are adequate. Thus, if any problem in the convergent or discriminant validity is diagnosed, it is suggested not to proceed to the reliability assessment.

Thus, it was found that the AVE of the latent variable (LV) values greater than 0.50 are acceptable, according to Ringle et al. (2014), and values greater than 0.40 may be acceptable in applied social sciences.

Once the convergent validity is assured, the next step was to assess the model's discriminant validity, which indicates whether the constructs or variables are independent of each other (Hair Junior et al., 2017). According to Ringle et al. (2014), there are two ways to ascertain this indicator: (a) by observing the cross loads, that is, indicators with higher factor loads in their respective LV than in the others, as recommended by Chin (1998) and (b) Fornell-Lacker criterion, in which the square roots of the AVE must be greater than the correlations between the constructs (Fornell & Larcker, 1981).

First, cross factorial loads were evaluated, according to the Chin criterion (1998), which proved to be adequate.

Subsequently, the RV was evaluated according to the Fornell-Larcker criteria, which according to Hair Junior et al. (2017) is considered more conservative. Table 2.4 shows the values of the

Table 2.4 Values of the correlations between LV and square roots of the AVE values on the main diagonal (highlighted)

	Energy	Food	SDG	Water
Energy	0.779			
Food	0.571	0.808		
SDG	0.632	0.661	0.791	
Water	0.762	0.672	0.716	0.842

Source: Made by the author, based on research data (SMARTPLS3®, 2020)

Table 2.5 Values related to the internal consistency of the model

Dimension	Cronbach's alpha	Composite reliability	AVE
Energy	**0.870**	**0.902**	**0.607**
Food	**0.695**	**0.840**	**0.653**
SDG	**0.956**	**0.961**	**0.625**
Water	**0.954**	**0.960**	**0.709**

Source: Made by the author, based on research data (SMARTPLS3®, 2020)

correlations between LV and square roots of the AVE values on the main diagonal (highlighted).

Through the analysis of Table 2.4, it appears that all the values of the correlations between the LV are less than the square roots of their AVE; therefore, the Fornell-Larcker criterion was met.

Finally, the values of internal consistency were evaluated using Cronbach's alpha and composite reliability. Table 2.5 shows the referred values, together with the values related to the AVE.

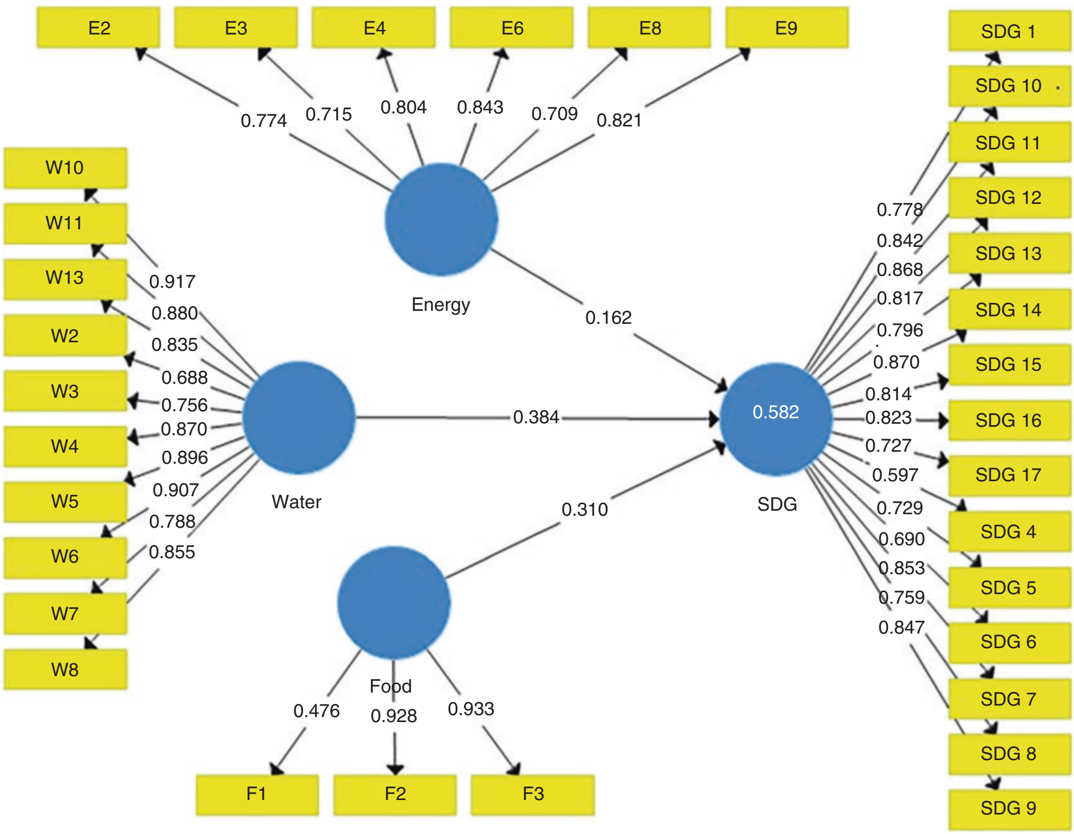
Table 2.5 shows that the Cronbach's alpha of the constructs is greater than 0.60. Also, the reliability criterion met was considered, through the composite reliability indexes, which were higher than the minimum limit of 0.7 (Hair Junior et al., 2017).

Therefore, by validating the measurement model, based on the criteria described above, the next subsection will be dedicated to the analysis of the structural model.

2.4.3 Evaluation of the Structural Model

The first evaluation carried out consisted of the analysis of collinearity, which is the inflation variation factor (IVF). According to Hair Junior et al. (2009), failure to comply with this assumption may make inferences based on the model that is erroneous or unreliable. It is emphasized that, in the context of PLS-SEM, IVF value equal to or greater than five indicates a potential collinearity problem (Hair Junior et al. 2011). However, according to Hair Junior et al. (2009), one should consider removing one of the corresponding indicators if the level of collinearity is very high, as indicated by an IVF value equal to or greater than ten.

As all values are less than ten, it was decided to keep all variables. Subsequently, Pearson's determination coefficients (R^2) were evaluated. According to Ringle et al. (2014, p. 67), R^2 "assesses the portion of the variance of endogenous



Source: SmartPLS3® (2020).

Fig. 2.1 Proposed model, R^2, and path coefficients. (Source: SmartPLS3® 2020)

variables, which is explained by the structural model." Fig. 2.1 shows the structure of the measurement model, with the values of R^2 and path coefficients.

According to Cohen (1988), for the area of social and behavioral sciences, the coefficient usually varies between 2% and 26%, with R^2 = 2% considered a small effect; R^2 = 13% medium effect; and R^2 = 26% large effect. Hair Junior et al. (2011) consider that R^2 results above 0.20 are considered high in disciplines such as consumer behavior.

It appears that the endogenous LV ODS has an R^2 of 0.582, above the percentage suggested as large/high; according to the classifications of Cohen (1988) and Hair Junior et al. (2011), all have a large effect on the model. The model explained a substantial part of the variation of endogenous variables, specifically, 58.20%.

To test the significance of the pointed relationships, the bootstrapping technique was used, which, according to Ringle et al. (2014), is a resampling technique used to assess the significance (p-value) of the correlations (measurement models) and the regressions (structural model). Thus, a bootstrapping resampling procedure and analysis were performed with 5000 bootstrap samples per group. As shown in Table 2.6, only in Hypothesis 1 is it above the reference value (1.96). In this case, H_0 was rejected, and it can be said that the correlations and regression coefficients are significant, providing support for this part of the proposed model.

Then, it is observed in the nexus that the interdisciplinarity and multidisciplinarity that this science possesses are capable of meeting the urgent need to improve water, energy, and food security for the poorest. And it is capable to guide the

Table 2.6 Hypothesis testing

Hypothesis	Path	T statistics	P values	Results
H1	Energy → SDG	1404	0.161	Not supported
H2	Food → SDG	2670	0.008	Supported
H3	Water → SDG	2362	0.019	Supported

Source: Made by the author (2020)

richest not to waste, managing responsibly and intelligently necessary and limited resources. This can be stated especially if indices and trends of population growth on the planet are noted (Proctor et al. 2020; Schlör et al., 2020).

Yuan et al. (2020) state that cities are the places where the consumption of food, energy, and water occurs and that consumption creates challenges that have a strong impact on natural sources. Just as the nexus can guide the design of engineering and architecture projects, it can also assist in the analysis of sustainable, smart, and healthy cities and their governance mechanisms.

2.5 Conclusion

With this study, we got the understanding that cities, in their most unique forms, are inextricably connected with the existing nexus in the triad: water-energy-food, resulting from the rapid urbanization process, which during the last decades has proved to be of extreme concern.

In this light, it appears that the main problems involving the topic of rapid urbanization; unregulated and unbridled use of natural resources; and their resulting social, economic, and environmental problems have resulted in a repetitive logic in different parts of the world.

Thus, as a result of this reflection and the research carried out between the literature and the practice, this article aimed to analyze the importance of the water-energy-food nexus for the promotion of sustainable cities in the context of sustainable development objectives.

As a result, we found the most cited indicators and sub-indicators in the literature, which make up a sustainable city model regarding the water-energy-food nexus. The model had a practical application with the population of a city, thus validating the relevant indicators and sub-indicators for this population.

Cities are the places where the consumption of food, energy, and water occurs, and this consumption creates challenges that have a strong impact on natural sources. Just as the nexus can guide the design of engineering and architecture projects, it can also assist in the analysis of sustainable, smart, and healthy cities and their governance mechanisms (Yuan et al., 2020).

However, given the positive aspects of industry 4.0, it is clear that it allows for an opposite movement, from cities to the countryside. This movement helps to reach the quality-of-life indicators, with the advantage that small cities have better indicators about urban violence, level of air and noise pollution. The consequences of these actions can be reflected in lower levels of stress, making it even easier to access land, which makes green development paths feasible, stimulating circular and family economy models (Dantas et al., 2020; Liu et al., 2021).

Supported by industry 4.0, the nexus establishes new engineering concepts and production standards, capable of guiding also the commercial relations that occur both between countries and in their domestic markets.

The results help municipal managers and policymakers to formulate policies and strategies that enable the SDGs to be met. Furthermore, the research contributes to the understanding of the interrelationships between the water-energy-food nexus and sustainable cities in the context of the Sustainable Development Goals and strategies to mitigate climate change.

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