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ORIGINAL ARTICLE

Co-creating sustainability indicators for the local water–energy–food nexus

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Abstract
Sustainability indicators have become essential tools to deal with compartmentalized resources planning and management in cities. The development of water, energy, and food nexus (WEF nexus) indicators is a prominent goal of current research, but the focus is mainly on economic issues and material flows. Attention to the local scale and context, social aspects, and the inclusion of non-academic actors is mostly lacking. To address these gaps, this paper reports and reflects on the co-creation of sustainability indicators related to the WEF nexus in the city of São Paulo, Brazil. With a transdisciplinary approach, non-academic actors were included in the different stages of the process using the Urban Living Lab methodology, to improve the usability of the produced indicators' set. The case of São Paulo concerned on-going actions in the peri-urban and rural areas of the city which seek to improve environmental protection by stimulating more sustainable forms of agriculture. Thirty-four indicators were developed through a sequence of interactive activities, such as workshops, meetings, and field trips. The presented process aims to strongly enhance usability by actively involving users from the start, connecting the nexus approach to previous knowledge and familiar frameworks, paying attention to the local scale and context, and to social aspects, and by anticipating future use in various ways.

Keywords Sustainability indicators · Water–energy–food nexus · Transdisciplinarity · Usability

Introduction

The Water–Energy–Food nexus (WEF nexus) has been widely discussed, both in the scientific literature and policy arena, due to the growing global demand for water, energy, and food, and the pressure of climate change on these resources. Shifting the focus from the single sectors to the complex interactions between them is considered to be extremely important for the sustainability and security of human societies. Cities, more specifically, demand a significant set of goods and natural resources to ensure water, energy and food supply, which may result in a substantial production of GHG emissions, solid waste, and pollutants (Rosenzweig et al. 2018; World Climate Research Programme 2019). Therefore, promoting actions addressing water, energy, and food issues would be of great benefit for the sustainability of cities (EC 2006; Yuan et al. 2021). Initiatives (e.g., a public policy) focused on only one of these sectors could bring losses and unexpected impacts, or can limit the efforts made in other areas (Bizikova et al. 2013; Howells et al. 2013). The nexus concept was conceived as an attempt to address the complex interrelationships between water, energy, and food at different scales, strengthening synergies between sectors and minimizing trade-offs to ensure more efficient, equitable and fair use of natural resources (Hoff 2011; Bazilian et al. 2011).

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In the initial propositions presented by Hoff (2011) at the Nexus Bonn 2011 Conference, the nexus emerged as a way of addressing issues of efficiency and economy (e.g., green economy), and actions aimed at social (e.g., impacts of urbanization, access to resources, and poverty) and environmental issues (e.g., investments for ecosystems preservation and combating climate change). The nexus is directly connected to the priorities of sustainable development policies, and the concept aspires to reconcile economic viability, environmental protection, and social well-being (Brundtland Commission 1987; Emas 2015).

To support cross-sectoral planning and management of water, energy, and food resources, and to assess synergies and trade-offs between economic, environmental, and social impacts, sustainability indicators are considered essential tools (Nhamo et al. 2018, 2020; Feng et al. 2020). Indicator-based assessments of the nexus can serve to: (i) provide a comprehensive view of current and future resource access and availability, especially for developing countries experiencing resource scarcity (Cansino-Loeza et al. 2020; Feng et al. 2020); (ii) monitor the anthropogenic and natural pressures on natural resources; (iii) synthesize data to support decision-making in favor of sustainability of natural and social systems at different scales; (iv) communicate relevant information and provide guidance for policy-making in a concise, transparent, and effective way (Giupponi and Gain 2017; Yuan and Lo 2020).

Nexus indicators, mainly developed by scholars, are becoming more prominent in the literature and tend to focus on economic issues and material flows (Cansino-Loeza et al. 2020; Yi et al. 2020). Additionally, there is limited consideration of the social and political dimensions of resource availability, accessibility, and sustainability, while the indicators consider the elements of the nexus mostly at larger geographical scales (Cairns and Krzywoszynska 2016; Artioli et al. 2017; Arthur et al. 2019; Dalla Fontana et al. 2020).

More specifically, there is a lack of studies on WEF nexus indicators that consider: (i) the local scale and context in which resource management essentially takes place (Williams et al. 2014; Giupponi and Gain 2017; Saladini et al. 2018; Feng et al. 2020); (ii) issues beyond flows and metabolism, especially social issues such as impacts of urbanization, access to resources and poverty (Hoff 2011), integrating the pillars of sustainable development (economic, environmental, and social dimensions) (Cairns and Krzywoszynska 2016; Dalla Fontana et al. 2020; Das et al. 2020; Wahl et al. 2021); and (iii) the usability of the information, producing actionable knowledge for policy makers, by involving non-academic actors and considering their needs (Dilling and Lemos 2011; Urbinatti et al. 2020; van Gevelt 2020; Wahl et al. 2021).

Although the scientific literature calls for collaborative and transdisciplinary approaches (Tress et al. 2005; Howarth and Monasterolo 2017), these are still in an early stage in nexus research (Albrecht et al. 2018; Wahl et al. 2021). Despite that many nexus research articles claim policy relevance, outcomes and impacts on policy are rarely assessed or even considered (Urbinatti et al. 2020). Therefore, there is an urgent need for studies that involve actors beyond scientists (practitioners and/or other stakeholders) to co-develop nexus initiatives (Cairns and Krzywoszynska 2016; Hoff and Kasparek 2016), as this would enhance the credibility, salience, and legitimacy of the produced information when assessing sustainability issues at the nexus (Cash et al. 2003; Bréthaut et al. 2019; Norström et al. 2020; Wahl et al. 2021). This approach is also important to guarantee that social and local aspects of sustainability are taken into consideration, while giving the participants opportunity for self-reflection (Giatti 2019; Dalla Fontana et al. 2020).

Such a collaborative approach can be organized as a short-term process, with activities such as interactive stakeholder workshops (Treemore-Spears et al. 2016; Culwick et al. 2019), but it can also be organized as a longer term process, utilizing methodologies like the Urban Living Lab (ULL) (Bulkeley et al. 2016; Schäpke et al. 2018; Culwick et al. 2019; Wahl et al. 2021). An ULL provides an interactive platform for researchers and non-academic actors to jointly identify key issues affecting the locality, assess knowledge gaps, and to co-design, co-produce, and co-disseminate sustainable solutions (Mauser et al. 2013; Bulkeley et al. 2016). In addition to being locally embedded, the co-creation approach in ULLs is also characterized by involvement of end-users and real-life testing, and a focus on learning from the co-creation process (Voytenko et al. 2016; Scholl et al. 2017).

This paper presents and discusses the process of co-creation of sustainability indicators related to the water, energy, and food nexus, in the city of São Paulo, Brazil, following a transdisciplinary ULL approach, integrating academic and non-academic actors. Despite being part of the largest urban conglomeration in South America, the São Paulo Metropolitan Region, with 39 municipalities and over 20 million people (SEADE 2018), and having the largest GDP of the country (US$ 142 billion), 15% of the city's population lives in precarious settlements and about 25,000 people are homeless (SMADS 2019). Moreover, the city faces many environmental problems, which are likely to be aggravated by climate change (Assad and Magalhães 2014; Margulis 2017). In this sense, the complexity of the megacity of São Paulo offers fertile ground for developing urban sustainability experiments and to introduce the concept of the nexus in a transdisciplinary collaboration with local practitioners.

We thereby aim to contribute to nexus research presenting an integrative approach that considers aspects that are still underrepresented in nexus indicators, namely: (i) the local scale and context, (ii) social aspects, and (iii) the usability of the information, generating actionable knowledge for policy makers. The goal of this study is not to establish the ultimate roadmap for future nexus indicators research, but rather to promote the discussion and further research on how collaboration between academic and non-academic actors can enhance the usability of the information produced by nexus research.

Methodology

The WEF nexus in São Paulo and the case study "Connect the Dots"

São Paulo is largely dependent on an external supply of water, energy, and food, and there are multiple issues associated with these resources. The urban growth process, for instance, has led to intensive and irregular occupation of areas where major water sources are located, resulting in an increase of floods, lower water quality, and a reduction of the water storage capacity of local reservoirs (Franco et al. 2015; Sepe and Pereira 2015). While these local reservoirs, in the south zone of the city, were originally designed to generate hydroelectric power, they now serve multiple uses including the supply of drinking water. However, the development of residential areas (both legal and informal) on the reservoirs' surroundings contributes to the pollution of the waterbodies that feed the reservoirs. As a strategy to maintain the water quality, the water flow directed to the reservoirs has been reduced, resulting in a decrease of their power generation capacity (São Paulo 2009). The urban growth also leads to environmental degradation of natural areas, and increases the pressure on local farmers who, in addition to other challenges such as aging and insufficient livelihoods, decide to sell their land for the construction of new residential areas rather than continuing to farm. Combined, all these aspects have negative effects on the local food production (Duarte et al. 2015; Amato-Lourenço et al. 2016). Furthermore, local communities suffer from poor access to water, energy, and food due to low income, housing conditions, schooling, gender, age, and family structure (São Paulo 2016).

To address some of these issues, the city of São Paulo has initiated a series of actions motivated by its Local Agenda 21 and, more recently, by its Master Plan (São Paulo 2014). For instance, actions are taking place in the southern peri-urban and rural region of the municipality (Fig. 1) in the districts of Parelheiros and Marsilac, home to more than 500 agricultural units, producing both conventional and organic food (Ligue os Pontos 2020).

Among these activities, the project "*Ligue os Pontos*" (LoP—or "Connect the Dots") has gained particular local and international attention due to its innovative approach for

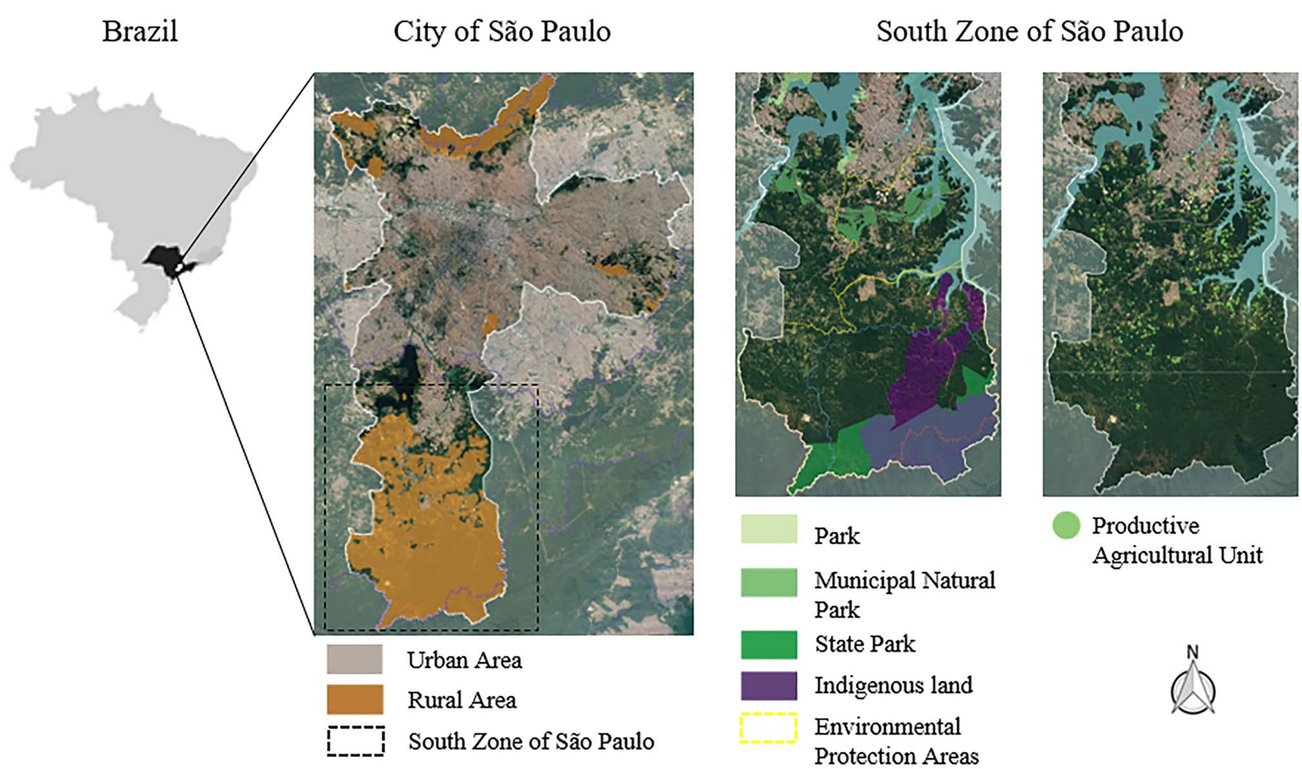

Fig. 1 Location of the city of São Paulo and the main characteristics of the south zone of the city. Source: Ligue os Pontos (2020)

sustainable development (https://ligueospontos.prefeitura.sp.gov.br/). Municipal practitioners involved in our study were also involved in LoP, potentially making collaboration easier and more fruitful. Conceived and coordinated by the city of São Paulo, through the Municipal Secretariat for Urbanism and Licensing, the project received the 2016 Mayors Challenge Latin America and The Caribbean Award established and supported by the Bloomberg Philanthropies, and was active until 2021. The main goals of the LoP were to: (i) contain urban sprawl in the south zone of São Paulo by maintaining the farmers in the area, (ii) promote sustainable resource use and agriculture, and (iii) preserve natural ecosystems. The project operated mainly on three fronts: (1) 'Data and Evidence', collecting data and information about the farmers and agricultural properties in the region through a census and mapping, to encourage and establish data-based decision-making in rural development policies; (2) 'Strengthening Agriculture', offering technical assistance to farmers to promote the transition to organic and agroecological agriculture and improve traditional techniques; and (3) 'Value chain', seeking to improve market access for farmers and the logistics of food production and distribution.

As critical results from the LoP, an extensive census was done in the territory in 2019 and technical assistance has been provided to farmers. There were also specific actions to promote local entrepreneurship, connect the farmers with other markets and expand the access of the peripheral population to organic food directly from the producers. In addition, virtual platforms were created to improve accessibility to information and to support public policies, such as: "Sampa + Rural" (https://sampamaisrural.prefeitura.sp.gov.br/), a platform that brings together information on local agriculture, tourism, and healthy eating initiatives; and "Sisrural" (https://sisrural.prefeitura.sp.gov.br/), or System of Technical Assistance and Rural and Environmental Extension, which is a tool for consulting and collecting data in the field, application of forms and monitoring of action plans by authorized technicians. Also, georeferenced information about the rural area was generated and added to the "Geosampa" (http://geosampa.prefeitura.sp.gov.br/), a municipal system that gathers georeferenced data on more than 350 layers relevant to the city (Ligue os Pontos 2020).

Indicators co-creation process

The Urban Living Lab approach was employed in this study and it brought together several actors from science and the public sector, including representatives of the Municipal Secretariat for Urbanism and Licensing; the House of Ecological Agriculture of the district of Parelheiros; the Environmental Protection Areas in the south zone of the city; and the LoP project. Cooperation in previous projects between the researchers and one representative of the municipality was essential to initiate the process and to invite other participants, who then invited others. This representative is a Geologist from the Municipal Secretariat of Urban Development, part of the LoP project, with experience in the area of Urban Environment and Urban and Regional Planning, while the other participants have diverse backgrounds, such as biology, engineering, social sciences, international relations, architecture, and geography.

One of the activities of the ULL was the development of sustainability indicators that can capture the impacts of existing actions on the interface of water, energy, and food in the territory. Particularly, the request for developing sustainability indicators came from practitioners from the LoP, who showed interest to have more data to assess their project's impacts on the territory, which was not foreseen in their project proposal. The ULL approach was thus operationalized in our case by embedding the co-creation of sustainability indicators from a nexus perspective locally in the LoP project, directly involving the end-users of the indicators from the municipality in the process, real-life testing of usability by including repeated reality-checks (e.g., on data availability), and explicit attention for learning from the co-creation process. Learning by the municipal practitioners focused on the added value of the nexus perspective, whereas learning of the researchers concentrated on how to enhance the usability of the indicator set.

The indicators were developed through a number of activities (Fig. 2), which took place between 2018 and 2021. This approach consisted of 22 steps organized in four phases: design, identification, organization, and dissemination, which were inspired by the process of knowledge co-creation developed by Mauser et al. (2013). It should be noted that the process has not followed a fully linear path, but has been characterized by feedback loops made of feedback-discussion-adjustments between different steps. This implies that the interaction between participants did not have the same intensity throughout the entire process, and academic and non-academic participants played a more or less active role at different stages of the project. Furthermore, the flexibility of the ULL allowed some actors to leave due to administrative changes, health and personal problems, while other participants were included later, invited by current participants.

The four participatory workshops (steps 6, 7, 8 and 14, in Fig. 2) represent the main moments of active interaction between participants and were central in the co-creation of the indicators. The most important issues that were raised during the discussions were noted. Individual interviews with five of the most active non-academic participants were held to identify what they considered the main insights and challenges of the process. Three non-academic participants from the LoP, who were engaged in most of the activities along the process, actively

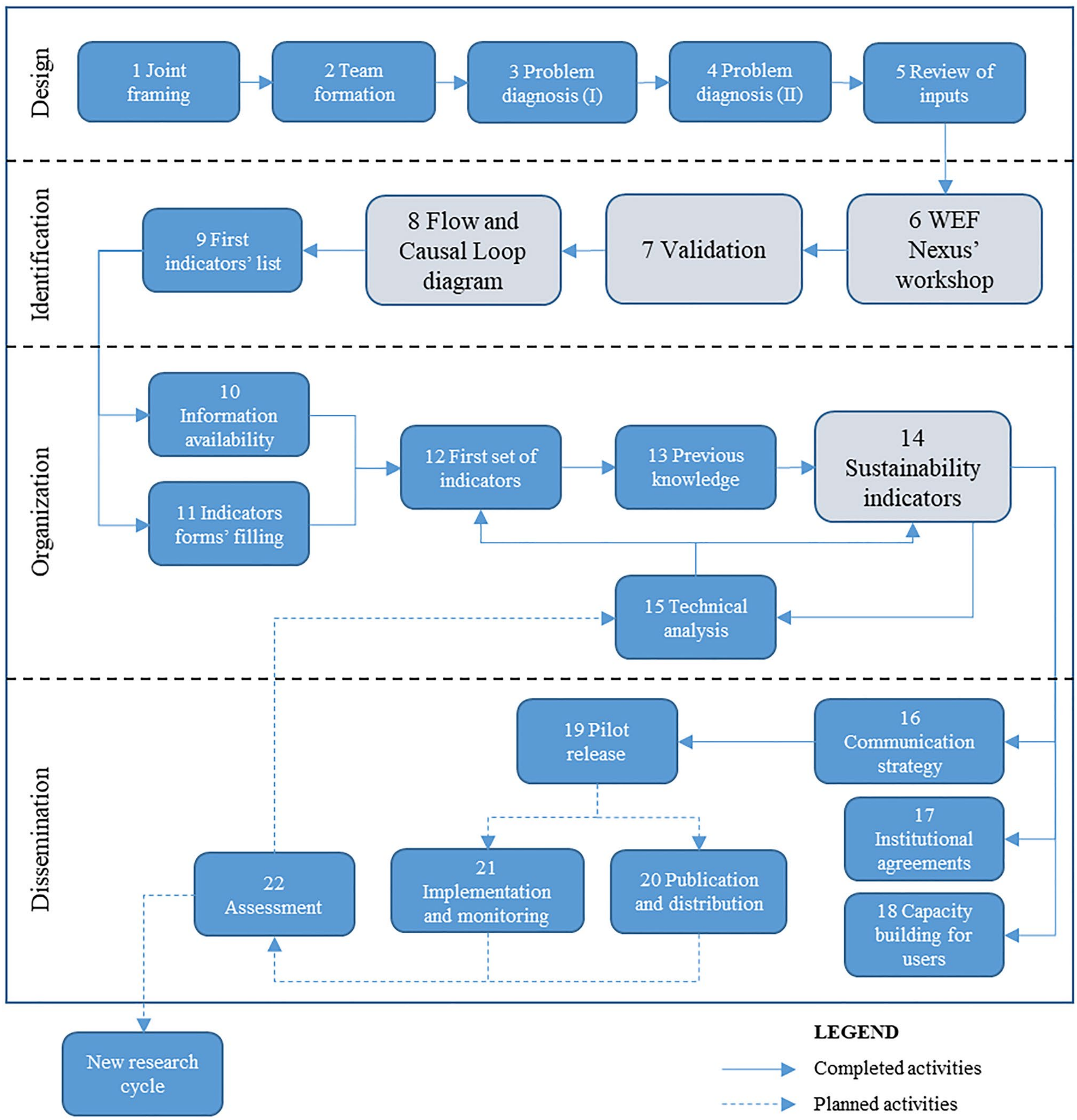

Fig. 2 Roadmap of the co-creation process. Source: Elaborated by the authors

participated in the writing of this paper, as a direct output of the participatory process and proving their commitment.

Design phase

The design phase began with the joint framing of the project (step 1). The main goals were established in a participatory way, building on existing relationships between scientists and local practitioners. After defining the development of sustainability indicators as the desired outcome of the ULL, the participants of a first working group were identified (2). Several meetings with this group were held to mobilize participants and to reach a common understanding of key concepts, such as “WEF nexus”, “ULL” and “transition to sustainability". To make a diagnosis of the local problem context and the main actors and conflicts in the south zone of São Paulo, the researchers participated as observers in several municipal councils (of the Environment, Sustainable Development and Culture of Peace; Sustainable and Solidary Rural Development; Environmental Protection Areas) and LoP meetings during 2019 (3), and made field visits to the territory (4). A critical review of inputs (5) was then performed based on (international) expertise of the group, secondary data collection, end users' demands, technical approach, and institutional and political context.

Identification phase

The aim of the identification phase was to compile a preliminary set of indicators. The first WEF nexus workshop (6) was held to apply the WEF nexus concept to the study area and included 15 participants (6 academics and 9 non-academics). After a brief recap of the nexus concept (a more detailed explanation was already delivered in the previous meetings), participants identified, through a series of activities, the opportunities and challenges with regard to water, energy, and food in the study area, and discussed whether there were any missing issues and whether they agreed with the lists of elements.

A second workshop (7), including 18 participants (7 academics and 11 non-academics), was held to categorize and review the collected information. The participants critically thought about new aspects to add, excluded duplications, and analyzed and validated the entire set of information.

The third workshop (8), including 11 participants (5 academics and 6 non-academics), was held with the goal of identifying and discussing specific interactions between the previously identified aspects and, more broadly, other environmental and social aspects. To do so, a combination of flow and causal loop diagrams was used (Halbe et al. 2015; Terrapon-Pfaff et al. 2018). This information was then at the core of a preliminary list of sustainability indicators (9).

Organization phase

In the following steps, researchers looked for data availability for the identified indicators (10) and provided forms to be filled in with specific information for each of the indicators (11). Data availability was checked in the literature, in the municipality website, and in other documents from the municipality, such as the census made by the LoP project, which provided a robust set of data. Quality criteria were applied to exclude some of the indicators (see INTARESE 2020). The indicator forms included information about name, description, objective, measure, minimum periodicity, data availability, limitations, source, formula, and territorial unit.

The application of the quality criteria and filling in of the forms was done by a subgroup of the ULL participants (consisting of four researchers and three practitioners from the municipality involved in the LoP project), and led to the exclusion of a number of indicators that had no data available. This resulted in an initial list of indicators (12), which was further discussed within this subgroup through exchange of e-mails and short video calls. From these interactions, it has been clear the need of integrating the new set of indicators with the existing expertise of the participants, in particular with respect to familiar sustainability frameworks (13). The indicators and the chosen framework were presented in the fourth workshop (14), including 18 participants (7 academics and 11 non-academics), allowing them to discuss if there were missing or overlapping indicators. The aim was to reduce the number of indicators to facilitate comprehension, acquisition of data, and communication. A technical analysis (15) of the content was done by the academics to review the indicators and users' demands, by applying once again the quality criteria, filling in the forms, excluding overlapping indicators and changing names of indicators.

Dissemination phase

To improve the usability of the information and promote actual use of the indicator set, the group made preparations for the dissemination of the final products and the evaluation of their usefulness. This was done in steps 16, 17, and 18, which concerned the development of a communication strategy, making institutional agreements, and building capacity for users, respectively. These steps considered administrative rules for the agreement, the possibility to include material in existing municipality online databases, and the distribution of responsibilities for managing, updating and monitoring the indicators.

The remaining steps (19–22) still have to be implemented, due to the different timing between the research process and the administrative process for the non-academic actors. These actions are planned for 2022. It should be noted that these steps need a greater involvement of the non-academic actors, since they are the ones who are in the position to add the produced indicators to the city's existing online databases. The pilot release (19) will be followed by the publication and distribution of the indicator set to a wider audience (20) and by the implementation and monitoring of the indicators (21). The evaluation (22) will be of utmost importance, to determine in the longer term whether implementation of the indicators has led to a broader application of the WEF nexus concept in policy-making and to observe the impacts of the LoP and other actions that are currently on-going in the study area. The partners should also reflect on the process and data produced and, if necessary, should return to step 15, technical analysis, and modify the indicator set and framework.

The evaluation of the process, the implementation of the indicator set and the impacts of the LoP project with the entire group, may result in new research questions, which can be jointly framed, initiating a new transdisciplinary knowledge co-creation cycle.

Results

In this section, we present the results from the four interactive workshops (steps 6, 7, 8, and 14) and the dissemination phase, including observations on the co-creation process itself.

WEF nexus elements (workshops 1 and 2)

In the first workshop, 57 elements were identified by all the participants present. After the workshop, the researchers worked through the list, following an inductive approach to organize the identified elements in different categories, which are closely aligned with the local context. The elements were clustered in tables for water, energy, and food. The tables were presented to the group and discussed in the second workshop to improve the quality of the information. The group worked together, as part of a reflection and validation process, to exclude duplications, add elements that were missing and adjust the terminology, resulting in a list composed of 55 elements (Table 1). The signs (+), (−), and (=) in Table 1 represent the positive (opportunities), negative (challenges), or neutral elements, respectively, in the study area.

Concerning water, most of the identified elements belong to the sociopolitical and natural resources categories. Even though many barriers to better use of water in the territory were found, the group also identified several opportunities, connecting water with actions for the preservation of natural resources, for the well-being of the population and for more efficient water consumption in the residences and agriculture. Actions to create a closer relationship with water (cultural, sports, leisure, etc.) and inadequate land use of floodplain areas are examples of how the participants included social aspects.

Identifying the connections of energy with water and food was challenging. The current actions in the region are not directly targeting energy consumption or production, and the ULL participants were not very familiar with energy issues, since these are usually approached in a sectoral manner and are governed by federal policies. Even so, the group found some important energy-related opportunities that could be applied in the study area, in many of the categories. The possibility of integration between producers and communities and the clandestine power connections in the area are examples related to the access to resources and social aspects identified by the participants.

Concerning food, the identified elements were mostly clustered in the sociopolitical, logistics, and production categories. The participants found many opportunities for the local population to improve agricultural practices and to promote organic production, but there were also challenges identified, often related to the supply chain and the particularities of food production. Participants included social and environmental aspects, such as the high labor cost and lack of skilled labor in the territory, and the importance of maintaining the rural landscape through food production.

It is important to note that not all the identified elements were used in the next steps. The lack of data that can be used to measure whether or not that indicator is being met, for instance, which is often an issue for the development of indicators (Cansino-Loeza et al. 2020), has proven to be a problem in our case as well. Although many of the data were found in the municipality and LoP database, there was a lack of information for a few indicators. It was therefore necessary to turn to literature, which is not ideal. In fact, data that are found in the literature must be avoided if possible since they are usually not context-specific and do not account for local specificities.

In addition, non-academic participants, who were not familiar with the concept of the nexus, began to better understand it, including its potential to undertake more integrated action:

> "Talking about energy and also remembering water, for example, was very strategic and brought a gain to the point where we took a deeper look at some public policies that were being built in the secretariat and programs, such as the LoP and other plans" (participant of the municipality).

Flow and causal loop diagram (workshop 3)

The third workshop was held to work on the flow and causal loop diagram, with the intention of integrating the elements previously identified in workshops 1 and 2, and adding other relevant elements. A first version of the diagram was developed by the researchers in two parts: (i) the flow diagram, before and after the LoP project; and (ii) the causal loop diagram, before and after the LoP project. Both scenarios were made, so the participants could better comprehend the connections between the elements and the impacts of the LoP. Then, a diagram contemplating both flow and causal loop components with the LoP actions was presented to the group. Participants analyzed each of the interactions one by one, identified errors, clarified misunderstandings, added

Table 1 Water, energy, and food elements identified in the WEF nexus workshops

Water	
Socio-political	1. Create a closer relationship with water (cultural, sports, leisure, etc.) (+); 2. Water is not valorized in the territory (−); 3. Irrigation and licensing (−); 4. Payment for environmental services (+)
Infra-structure	5. Lack of sanitation (−); 6. Sanitation technologies (low cost): cisterns, banana cycle, septic tank (=); 7. Need for new technologies (lack of opportunities) (=)
Uses	8. Waste (−); 9. Low use and consumption (+)
Source	10. Rainwater harvesting for irrigation (+); 11. Water reuse (+)
Natural resources	12. Inadequate land use of floodplain areas (−); 13. Intervention in the Environmental Protection Areas: diversion of water sources, dams, grounding, etc. (−); 14. Water production for cities (+); 15. High availability of water sources (+); 16. Preserved vegetation (+); 17. Pollution (by pesticides, water pits, etc.) (−)
Production	18. Soil conservation (good practices, etc.) (−)
Energy	
Socio-political	19. Little political interest in rural sustainability (−); 20. Non-subsidized energy (−); 21. Possibility of integration between producers and communities (+)
Infra-structure	22. Low technical production (irrigation-water machines and implements) (−); 23. Inefficient irrigation systems (−); 24. Waste of energy due to lack of structure (−); 25. Clandestine power connections (−); 26. Low cost irrigation systems (+); 27. Water wheel—gravity irrigation (+)
Logistics	28. Diesel use and impacts related to production and runoff (−)
Uses	29. Low demand, lower costs: favor alternative systems (+); 30. Misuse of energy (−)
Source	31. Solar energy and irrigation (+); 32. Wind, solar biogas for supply (+)
Natural resources	33. Optimize existing natural resources in the production unit (+)
Production	34. Organic fertilizers to avoid spending on chemical fertilizers from outside the production units (+)
Food	
Socio-political	35. Increasing visibility of local food production/consumption (+); 36. Producers connected with the territory feel they belong (+); 37. High labor cost and lack of skilled labor (−); 38. Dissemination of healthy and sustainable food production (+); 39. Organic production has government support (=)
Economic	40. Organic niche market (=); 41. Low added value of products (vegetables) (−); 42. Competition with the production of other municipalities (−)
Uses	43. Uncontrolled use of water on the food production (-)
Logistics	44. Proximity to the largest consumer market in the country (Metropolitan Region of São Paulo) (+); 45. The chain of services/products/inputs for producers remains to be structured (−); 46. Lack of consolidation of the organization in production and trade (−); 47. Proximity to the consumer market (+); 48. Lack of local warehouse (−); 49. Logistics = 60% of the final price (−)
Natural resources	50. Maintaining the rural landscape through food production (+)
Production	51. Food production is good land use (+); 52. Ways of soil conservation (=); 53. Lacks adequate inputs for production (−); 54. Unsuccessful food production cycles and migration to flowers production (−); 55. Production method (technique and use of agrochemicals) (=)

or excluded information and modified names of variables, resulting in the final version of the diagram (Fig. 3).

External funding acquisition (bottom right of the diagram) is an important aspect to be considered, since it allowed the municipality to implement the LoP. The LoP project has three main work fronts, "data and evidence", "strengthening agriculture", and "value chain". Those work fronts comprise different actions that have positive or negative impacts on different elements of the diagram. "Natural resources preservation" and "water quality" are central components of the diagram, as they both are connected with many other components. This is due to the fact that the main goal of the LoP project is to protect the natural areas and improve the water quality in the region, by maintaining the farmers in the area, which in turn helps to avoid urban sprawl in the south zone.

Socioeconomic and urbanization aspects were decisive in considering the actions in the region, and are closely connected to the relations established between the nexus elements. In this sense, participants considered some critical aspects such as: the implementation of public policies (payment for environmental services); the relevance of technical assistance to improve traditional methods of food production; issues related to farmers' and irregular housing and its implications for water quality and natural resources preservation; and aspects of training and education, which result in new business models and have an impact on local markets and the labor force. Beyond-local impacts were also considered in the diagram to visualize

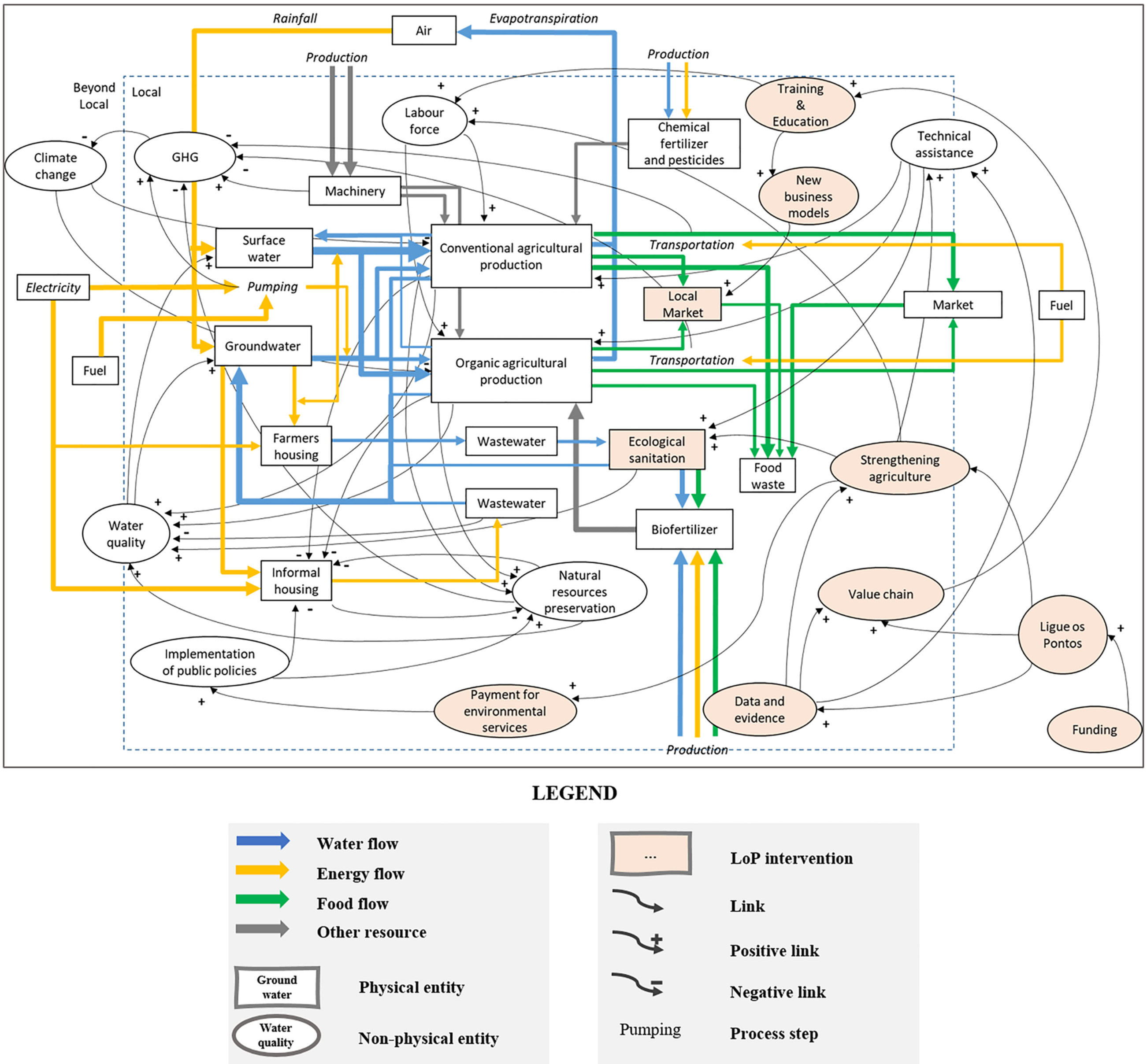

Fig. 3 Flow and causal loop diagram after the implementation of the LoP project in the south zone of São Paulo. Source: Elaborated by the authors

possible broader impacts of the local actions. Possible impacts on GHG emissions and absorption, for instance, were identified in the system, which could ultimately have an impact on climate change. This could help the practitioners to identify opportunities to improve the local GHG absorption or reduce GHG emissions (e.g., transportation; water pumping).

Another result was the fact that participants left this workshop with a better understanding of the nexus concept and how their actions have broader and systemic impacts. Being able to visualize these interactions while working on the diagram was fundamental to this process of learning and understanding:

> "With the discussions in the workshop, everything became clearer, the diagrams and flows workshop was good, because you end up aligning your own way of thinking. It's good, because it is necessary for people to understand what is being said, good visuals help in schematic logic" (participant of the municipality).

Sustainability indicators and PSIR framework (workshop 4)

The fourth workshop was held to work on the sustainability indicators' framework identified by the ULL participants, the Pressure-State-Impact-Response (PSIR). Such a framework had already been applied in a previous municipality action with Environmental and Urban Management Indicators (Sepe and Gomes 2008), so it was considered positive by the group to take advantage of practitioners' previous knowledge and, by that, improve the usability of the indicators. The first list of indicators, produced by the group in the previous steps, was then adapted to an empty PSIR framework, making it possible to identify new elements that were not identified previously (Fig. 4). The PSIR framework encapsulates the answers to four guiding questions, namely: What is happening? What can be done? What is being done about it? And, what will happen if there is no immediate action? (UNEP 2002). The PSIR framework was then presented and discussed with the participants in the workshop. The first columns were added with symbols of water, energy, and food, respectively, to remind the participants the connections of the indicators with the nexus elements.

There are 34 indicators in this framework that cover the content of the flow and causal loop diagram, with a few additions that arose in the discussion during the fourth workshop

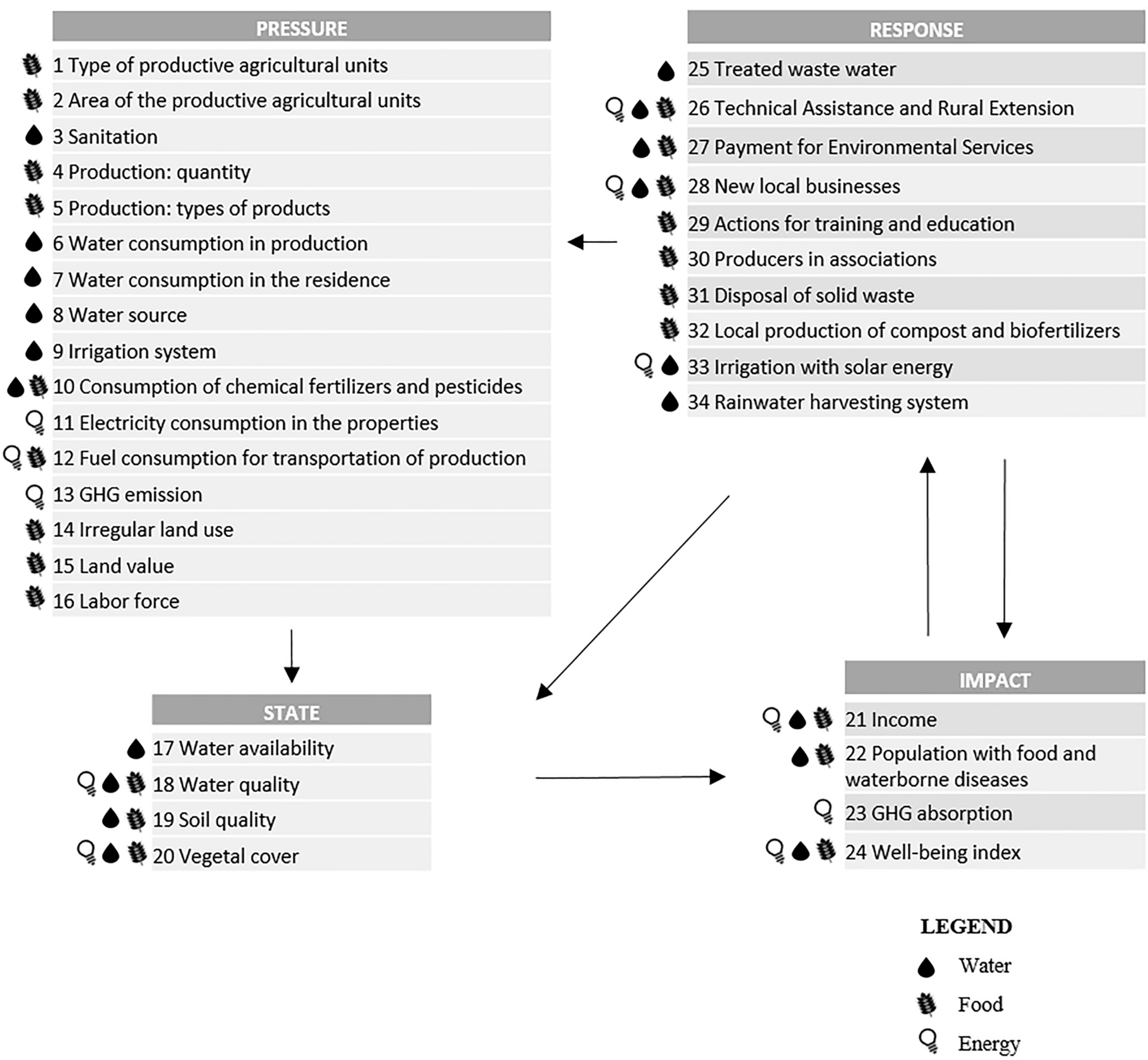

Fig. 4 Sustainability indicators in the PSIR framework. Source: Elaborated by the authors

(e.g., population with food and waterborne diseases). The reflection and discussions between the ULL members were helpful to improve the indicator set in the areas that were not covered by the flow and causal loop diagram. The inclusion of the Response and Impacts categories made it possible to consider broader components that were not necessarily considered previously, such as income, diseases, well-being, and the number of farmers in associations. These aspects are normally not considered in nexus indicators studies, as these usually focus on the material and flow components of the nexus (Arthur et al. 2019; Dalla Fontana et al. 2020), considered mainly in the Pressure and State categories.

While the use of indicators for the planning and management of public policies is a consolidated activity in several secretariats in the city of São Paulo, working with sustainability indicators from a nexus perspective was perceived as innovative and motivating. The ULL participants' expectation was that the nexus approach could encourage a more integrated view of the complex relationships between human action and the natural environment. On a higher level, working in an ULL was seen as an unprecedented opportunity to establish a different form of partnership between academia and local government, with an effective and active participation of municipal practitioners.

Another important result of this workshop was the recognition by the participants that the process of working together to find a better format to present the indicators resulted in a more usable final product:

> "It is very important to identify and consider the prior knowledge of institutional actors, as what was built in the past must be valued and what is being built in the present for the future must have applicability" (participant of the municipality).

Beyond the scope of the fourth workshop, we also found that the entire co-production process was very much appreciated by the non-academic actors participating in the ULL, who did not regard themselves as mere receivers of the information, but as active co-creators, which is likely to have resulted in more credibility and legitimacy of the produced knowledge:

> "It is very important from the beginning to feel part of the project and not just as a data provider" (participant from the LoP project).

Moreover, participants revealed that the interaction within the ULL allowed a better interaction among different Secretariats of the municipality, which improved in comparison to the communication they had before:

> "Among us (municipality) there is also a distant relationship, so the ULL was cool because it made us closer to the activities and actions with the LoP. Thus, this was advantageous so that we could strengthen our relationships, with a maturation between the parties" (participant of the municipality).

Dissemination of the results

Several actions were taken in the ULL to improve the usability of the co-created indicators' list to support the actions in the municipality. A cooperation agreement was signed between the researchers' university and the Municipal Secretariat of Urban Development and Licensing, at the beginning of the project. This agreement was revised several times due to changes in the municipality administration that occurred throughout the project, which affected the access to data, the relations with the actors, and the dissemination of the outcomes.

The next step is linking the indicators and the PSIR framework to an existing municipal online database, the Observatory of Indicators of the City of São Paulo, the "ObservaSampa" (https://observasampa.prefeitura.sp.gov.br/), which is a virtual system that aggregates several types of indicators about the city to support the municipal practitioners in the elaboration of new policies. While the members of the Municipal Secretariat of Urban Development and Licensing are committed to add this information to the system and are responsible for the monitoring of the content, changes in the administration and local government in 2021 impacted directly on the positions of the practitioners involved in the ULL and their partners in different Secretariats. This has jeopardized the possibility to include some indicators in the city's observatory in the short-term, as previously planned.

Discussion

There is a tendency in the use of nexus indicators to at most quantify the flows between the elements (Cansino-Loeza et al. 2020; Yi et al. 2020). However, this brings along the risk of overlooking local characteristics and specific needs, such as typical production and consumption patterns and possible related environmental impacts (Arthur et al. 2019). Our research showed how local characteristics and specific needs can be taken into account through active collaboration with local stakeholders and, in doing so, enhance the saliency and legitimacy of the knowledge produced (Dalla Fontana et al. 2021).

The focus on a local case and constant interaction and feedback between academics and non-academics fostered a critical reflection on the importance of including social aspects when discussing the nexus, which were considered as relevant aspects in the nexus research by Hoff (2011). This distinguishes our work from others that mainly focus on efficiency and material flows (Saladini et al. 2018; Feng et al. 2020). The necessity to go beyond the mere interactions between water, energy, and food was clear since the first workshop and was agreed upon by all participants. Inclusion of issues such as the importance of maintaining the rural landscape through food production, avoiding urban sprawl, the implications of irregular housing for water quality and natural resources preservation, and aspects of training and education were identified only through interaction with the local practitioners.

The flow and causal loop diagram was recognized as an important step for the ULL participants, since it provided a visual exercise to look for the main connections between the identified elements, which helped them to better comprehend the nexus concept, and to identify other components, especially those related to socioeconomic and urbanization aspects, which are still underrepresented in nexus research (Arthur et al. 2019; Dalla Fontana et al. 2020). Participatory, qualitative systems modeling also provides space for learning, which helps to increase legitimacy and agency between the different actors, producing new knowledge, awareness and skills (Bréthaut et al. 2019).

The use of the PSIR framework, in this specific study, had the advantage that it prompted academics and non-academics to reflect on the inclusion of indicators that were not identified from the flows and causal loop diagram (Cansino-Loeza et al. 2020; Yi et al. 2020). Components of well-being, health, and farmers' associations were identified during the inclusion of the indicators in this broader sustainability framework, especially in the Impact and Response categories. By adopting this broader framework, actions to support the local food system were considered for their contribution in improving the socioeconomic condition, health, and general well-being of the local farmers, and encouraging the coexistence of agricultural land use and preservation of natural areas rather than leaving room for urban sprawl and irregular settlements. The use of a framework already familiar to the local practitioners facilitated the process.

Thus, we argue that: (i) prior knowledge and expertise of local practitioners are something to be valued and built upon, improving the credibility, salience, and legitimacy of the generated information (Cash et al. 2003; Norström et al. 2020; Wahl et al. 2021); and (ii) linking nexus indicators to more systemic sustainability frameworks can be beneficial, since it provides new insights into how WEF interactions are interrelated with broader social issues, improving the relevance and usability of the new knowledge generated (Dilling and Lemos 2011; Urbinatti et al. 2020; van Gevelt 2020).

We recognize the importance of the nexus indicators being produced in many projects internationally (Cansino-Loeza et al. 2020; Yi et al. 2020). However, we think that adjusting those indicators to fit into a framework more familiar to the users, in our case the PSIR framework, may be key to increase the understanding and facilitate prompt use of the produced knowledge. Even with the possibility of losing the novelty of the nexus framework by going back to a more standard framework like PSIR, we believe that we gained in usability of the produced information. Although the inclusion of specific local characteristics and needs will probably reduce the transferability of the set of indicators produced, it increases the chances of the indicators being locally of use and used (Williams et al. 2014; Giupponi and Gain 2017; Saladini et al. 2018; Feng et al. 2020). The main outcome of this study that can be utilized in other contexts therefore concerns the lessons learnt from the process of co-creating the indicators, and not the indicators themselves, that are very context-specific. The inclusion of different actors from different backgrounds would have brought different results for the project, which underlines the need for transdisciplinary approaches to carefully select relevant actors to enhance the usability of the nexus information produced and ensure that innovative sustainable actions are taken (Howarth and Monasterolo 2017; Wahl et al. 2021).

We also argue that the local orientation and bottom–up process that we followed increased the legitimacy and salience of the indicator set, since it was not the result of a top–down imposition, but rather a result of a more organic process that revealed real local needs (Cairns and Krzywoszynska 2016; Hoff and Kasparek 2016). Researchers took a greater role in many of the activities of the ULL; however, this fact does not mean that the non-academic actors were mere receivers of information. Instead, they were involved since the beginning, jointly identifying the need for new indicators to assess the sustainability of current actions in the city. The intention was not to have an equal level of participation of all actors involved throughout the process. Academics, for instance, were more active in the organization of the information from the workshops and filling the indicators' forms, while non-academics had a more prominent role in the dissemination phase. The constant feedback and interactions between academic and non-academic actors were decisive, allowing the group to self-reflect (Giatti 2019; Dalla Fontana et al. 2020), and to explore the information gathered by the LoP project, which provided a robust set of data that could be used for the indicators, along with information already present in the municipal online database.

The process of engagement was mainly between academics and practitioners. However, we recognize that a greater involvement of local communities (Dalla Fontana et al. 2021), and in particular of local farmers in our case, would have been valuable to bring different insights. This was also reported as one of the flaws of this project by the representatives of the municipality and the LoP project. In fact, a few farmers participated in some meetings and activities, and workshops were planned to be held in 2020 exclusively dedicated to the engagement of local farmers. However, due to the COVID-19 crisis, further contact with farmers and other local actors was hampered, both by the need for social distancing and the lack of Internet access in the region to engage in online meetings.

The dissemination phase is also challenging. Usually, studies that develop nexus indicators generate a large amount of information and knowledge, and emphasize how the information generated is relevant for decision-making (Wahl et al. 2021). Nonetheless, most of these studies fall short in evaluating how the generated knowledge is actually used and whether and how it influenced the decision-making processes (Urbinatti et al. 2020). This type of evaluation can only be conducted a few years after these measures are taken. In our case, this step should be taken in the following years after the end of the LoP, to assess its long-term impacts. However, this may be difficult if the ULL is no longer running or the participants do not have the opportunity to work together, and changes in the municipal administration can impact on the relations between the ULL participants. To anticipate this, we paid attention to dissemination and monitoring of indicators already from the start of the process in the design phase (Mauser et al. 2013), to ensure regular updating of the indicator information and to promote its use by the practitioners. Moreover, maintaining good relations and communication throughout the process and preparing a dissemination plan might facilitate an active uptake of the indicator set and continued collaboration to update or revise it.

Conclusions

We have given great attention to the local context by focusing on the activities of the LoP project to promote sustainable agricultural practices and natural resources preservation in the rural south zone of São Paulo. As a result, the developed indicators are usable to the local government (Dalla Fontana et al. 2021) and can support current and future sustainability projects in alignment with local needs and priorities, rather than aspiring to abstract and decontextualized sustainability standards (Urbinatti et al. 2020). Practitioners from the municipality expect that the set of indicators can help to assess whether the LoP actions will consolidate as long-term public policies contributing to economic development, social inclusion, and environmental preservation. Furthermore, while the indicators have been developed around the elements of the nexus, they capture other environmental and socioeconomic issues as well, which are still underrepresented in most of nexus research (Cansino-Loeza et al. 2020; Yi et al. 2020). Thus, the co-creation process, the use of a broader sustainability indicators framework, and the inclusion of social aspects increase the information's relevance and usability, and help to broaden the discussion regarding the nexus and to incorporate the concept into current policies and actions (Cash et al. 2003; Norström et al. 2020; Wahl et al. 2021).

The use of the integrative nexus approach helped, on one hand, to reveal interactions and issues that are normally not on the radar of a local administration. In this sense, adopting the nexus approach is something innovative that brings a new and different perspective. On the other hand, it is also important to build on existing knowledge and instruments that are already familiar to practitioners and users, to facilitate the comprehension and improve the usability of the information (Wahl et al. 2021). Also, practitioners have only a certain capacity of managing data, so to consider and use previous experiences and knowledge may be advantageous for the decision-making process (Dalla Fontana et al. 2021).

The ULL setting was advantageous for the involved local practitioners who gave us positive feedback, and revealed the importance of working together with academics to co-create salient information, taking into consideration local expertise. We argue that the main lessons taken from this interactive experience can help future nexus research to bring concrete benefits to the cities, and avoid producing more data that end-users may not use.

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References

Albrecht TR, Crootof A, Scott CA (2018) The water–energy–food nexus: a systematic review of methods for nexus assessment. Environ Res Lett 13(4):043002

Amato-Lourenço LF, Moreira TCL, Arantes BLD, Silva Filho DFD, Mauad T (2016) Metrópoles, cobertura vegetal, áreas verdes e saúde. Estudos Avançados 30(86):113–130

Arthur M, Liu G, Hao Y, Zhang L, Liang S, Asamoah EF, Lombardi GV (2019) Urban food–energy–water nexus indicators: a review. Resour Conserv Recycl 151:104481

Artioli F, Acuto M, Mcarthur J (2017) The water–energy–food nexus: an integration agenda and implications for urban governance. Polit Geogr 61:215–223

Assad ED, Magalhães AR (2014) Impactos, vulnerabilidades e adaptação às mudanças climáticas. Painel Brasileiro de Mudanças Climáticas (PBMC), Rio de Janeiro

Bazilian M, Rogner H, Howells M, Yumkella KK (2011) Considering the energy, water and food nexus: towards an integrated modelling approach. Energy Policy 39(12):7896–7906

Bizikova L, Roy D, Swanson D, Venema HD, McCandless M (2013) The water–energy–food security nexus: towards a practical planning and decision-support framework for landscape investment and risk management. International Development Research Centre (IDRC) Report

Bréthaut C, Gallagher L, Dalton J, Allouche J (2019) Power dynamics and integration in the water–energy–food nexus: learning lessons for transdisciplinary research in Cambodia. Environ Sci Policy 94:153–162
Brundtland Commission (1987) Our common future; Report of the world commission on environment and development (WCED). Oxford University Press, Oxford and New York, p 300
Bulkeley H, Coenen L, Frantzeskaki N, Hartmann C, Kronsell A, Mai L et al (2016) Urban living labs: governing urban sustainability transitions. Curr Opin Environ Sustain 22:13–17
Cairns R, Krzywoszynska A (2016) Anatomy of a buzzword: the emergence of 'the water–energy–food nexus' in UK natural resource debates. Environ Sci Policy 64:164–170
Cansino-Loeza B, Sánchez-Zarco XG, Mora-Jacobo EG, Saggiante-Mauro FE, González-Bravo R, Mahlknecht J, Ponce-Ortega JM (2020) systematic approach for assessing the water–energy–food nexus for sustainable development in regions with resource scarcities. ACS Sustain Chem Eng 8(36):13734–13748
Cash DW, Clark WC, Alcock F, Dickson NM, Eckley N, Guston DH et al (2003) Knowledge systems for sustainable development. P Natl Acad Sci 100:8086–8091
Culwick C, Washbourne CL, Anderson PM, Cartwright A, Patel Z, Smit W (2019) CityLab reflections and evolutions: nurturing knowledge and learning for urban sustainability through co-production experimentation. Curr Opin Environ Sustain 39:9–16
Dalla Fontana M, Moreira FA, Di Giulio GM, Malheiros TF (2020) The water–energy–food nexus research in the Brazilian context: what are we missing? Environ Sci Policy 112:172–180
Dalla Fontana M, Wahl D, Moreira FA, Offermans A, Ness B, Malheiros TF, Di Giulio GM (2021) The five Ws of the water-energy-food nexus: a reflexive approach to enable the production of actionable knowledge. Front Water 3:729722
Das A, Sahoo B, Panda SN (2020) Evaluation of nexus-sustainability and conventional approaches for optimal water-energy-land-crop planning in an irrigated canal command. Water Resour Manag 34:2329–2351
Dilling L, Lemos MC (2011) Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. Glob Environ Chang 21(2):680–689
Duarte DH, Shinzato P, dos Santos GC, Alves CA (2015) The impact of vegetation on urban microclimate to counterbalance built density in a subtropical changing climate. Urban Clim 14:224–239
EC (European Commission) (2006) targeted summary of the European sustainable cities report for local authorities
Emas R (2015) The concept of sustainable development: definition and defining principles. Brief for GSDR 2015
Feng Y, Zhong F, Huang C, Gu J, Ge Y, Song X (2020) Spatiotemporal distribution and the driving force of the food–energy–water nexus index in Zhangye, Northwest China. Sustainability 12(6):2309
Franco FDM, Almeida CHD, Abreu GKM (2015) A macroárea de estruturação metropolitana de São Paulo: o projeto urbano como instrumento de transformação do território. Revista Iberoamericana De Urbanismo 12:53–74
Giatti LL (2019) Participatory research in the post-normal age: unsustainability and uncertainties to Rethink Paulo Freire's Pedagogy of the Oppressed. Springer, New York
Giupponi C, Gain AK (2017) Integrated spatial assessment of the water, energy and food dimensions of the sustainable development goals. Reg Environ Change 17(7):1881–1893
Halbe J, Pahl-Wostl C, Lange MA, Velonis C (2015) Governance of transitions towards sustainable development—the water–energy–food nexus in Cyprus. Water Int 40(5–6):877–894
Hoff H, Kasparek M (2016) The water–energy–food security nexus. German Technical Cooperation: analysis of the Project Portfolio and Assessment of Opportunities for Nexus Mainstreaming. Report of the GIZ Project "International Water Policy" (PN: 2014.2264.1)
Hoff H (2011) Understanding the nexus background paper for the Bonn 2011 conference. The Water, Energy and Food Security Nexus, Stockholm
Howarth C, Monasterolo I (2017) Opportunities for knowledge co-production across the energy-food-water nexus: making interdisciplinary approaches work for better climate decision making. Environ Sci Policy 75:103–110
Howells M, Hermann S, Welsch M, Bazilian M, Segerström R, Alfstad T et al (2013) Integrated analysis of climate change, land-use, energy and water strategies. Nat Clim Change 3(7):621
INTARESE (Integrated Environmental Health Impact Assessment System) (2020) Indicator selection: a protocol. http://www.integrated-assessment.eu. Accessed 30 Mar 2021
Ligue os Pontos (2020) Quem são os produtores agrícolas da Zona Sul de São Paulo. Informes Urbanos, Prefeitura Municipal de São Paulo, nº45, May 2020. https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/desenvolvimento_urbano/arquivos/45_IU_PRODUTORES-AGRICOLAS_2020_final.pdf. Accessed 30 Mar 2021
Margulis S (2017) Guia De Adaptação Às Mudanças Do Clima Para Entes Federativos. Brasília
Mauser W, Klepper G, Rice M, Schmalzbauer BS, Hackmann H, Leemans R, Moore H (2013) Transdisciplinary global change research: the co-creation of knowledge for sustainability. Curr Opin Environ Sustain 5(3–4):420–431
Nhamo L, Ndlela B, Nhemachena C, Mabhaudhi T, Mpandeli S, Matchaya G (2018) The water–energy–food nexus: climate risks and opportunities in southern Africa. Water 10(5):567
Nhamo L, Mabhaudhi T, Mpandeli S, Dickens C, Nhemachena C, Senzanje A et al (2020) An integrative analytical model for the water–energy–food nexus: South Africa case study. Environ Sci Policy 109:15–24
Norström AV, Cvitanovic C, Löf MF, West S, Wyborn C, Balvanera P et al (2020) Principles for knowledge co-production in sustainability research. Nat Sustain 3(3):182–190
São Paulo (2009) Guia das águas. Available at: https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/guia_aguas_1253304123.pdf (Accessed 30 March 2021)
São Paulo (2014) Lei nº 16.050, de 31 de julho de 2014. PDE - Plano Diretor Estratégico do Município de São Paulo, 2014.
São Paulo (2016) 1º Plano municipal de segurança alimentar e nutricional. Câmara Intersecretarial de Segurança Alimentar e Nutricional de São Paulo – CAISAN-Municipal. https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/trabalho/PLAMSANVERSAOFINALcompleta.pdf. Accessed 30 Mar 2021
Rosenzweig C, Solecki WD, Romero-Lankao P, Mehrotra S, Dhakal S, Ibrahim SA (eds) (2018) Climate change and cities: second assessment report of the urban climate change research network. Cambridge University Press, Cambridge
Saladini F, Betti G, Ferragina E, Bouraoui F, Cupertino S, Canitano G et al (2018) Linking the water–energy–food nexus and sustainable development indicators for the Mediterranean region. Ecol Ind 91:689–697
Schäpke N, Stelzer F, Caniglia G, Bergmann M, Wanner M, Singer-Brodowski M et al (2018) Jointly experimenting for transformation? Shaping real-world laboratories by comparing them. GAIA Ecol Perspect Sci Soc 27(1):85–96
Scholl C, Eriksen MA, Baerten N, Clark E, Drage T, Essebo M et al (2017) Guidelines for urban labs. JPI Urban Europe, Vienna. https://www.maastrichtuniversity.nl/research/msi/research-output/guidelines-urban-labs. Accessed 30 Nov 2021
SEADE (Fundação Sistema Estadual de Análise de Dados) (2018) Perfil dos Municípios Paulistas. http://www.perfil.seade.gov.br/. Accessed 15 Mar 2021

Sepe PM, Gomes S (2008) Indicadores ambientais e gestão urbana: desafios para a construção da sustentabilidade na cidade de São Paulo. Secretaria Municipal do Verde e do Meio ambiente: Centro de Estudos da Metrópole, São Paulo

Sepe PM, Pereira HMSB (2015) O conceito de Serviços Ambientais e o Novo Plano Diretor de São Paulo: Uma nova abordagem para a gestão ambiental urbana? Anais do XVI ENANPUR: Espaço, planejamento & insurgências. Belo Horizonte, MG

SMADS (Secretaria de Assistência e Desenvolvimento Social) (2019) Pesquisa censitária da população em situação de rua, caracterização socioeconômica da população em situação de rua e relatório temático de identificação das necessidades desta população na cidade de São Paulo. https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/Produtos/Produto%209_SMADS_SP.pdf. Accessed 8 June 2021

Terrapon-Pfaff J, Ortiz W, Dienst C, Gröne MC (2018) Energising the WEF nexus to enhance sustainable development at local level. J Environ Manag 223:409–416

Treemore-Spears LJ, Grove JM, Harris CK, Lemke LD, Miller CJ, Pothukuchi K et al (2016) A workshop on transitioning cities at the food–energy–water nexus. J Environ Stud Sci 6(1):90–103

Tress G, Tress B, Fry G (2005) Clarifying integrative research concepts in landscape ecology. Landsc Ecol 20(4):479–493

UNEP (United Nations Environment Programme) (2002) Geo Cidades: Relatório Ambiental Urbano Integrado - Informe Geo. Rio de Janeiro

Urbinatti AM, Dalla Fontana M, Stirling A, Giatti LL (2020) 'Opening up' the governance of water–energy–food nexus: towards a science-policy-society interface based on hybridity and humility. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2020.140945

van Gevelt T (2020) The water–energy–food nexus: bridging the science–policy divide. Curr Opin Environ Sci Health 13:6–10

Voytenko Y, McCormick K, Evans J, Schliwa G (2016) Urban living labs for sustainability and low carbon cities in Europe: towards a research agenda. J Clean Prod 123:45–54

Wahl D, Ness B, Wamsler C (2021) Implementing the urban food–water–energy nexus through urban laboratories: a systematic literature review. Sustain Sci 16:663–676

Williams J, Bouzarovski S, Swyngedouw E (2014) Politicising the nexus: nexus technologies, urban circulation, and the coproduction of water-energy. Nexus network think piece series, Paper 001

World Climate Research Programme (2019) Global Research and Action Agenda on Cities and Climate Change Science - Full Version. 31 pp. WCRP Publication No. 13/2019. Available at: https://www.wcrp-climate.org/WCRP-publications/2019/GRAA-Cities-and-Climate-Change-Science-Full.pdf (Accessed 26 March 2021).

Yi J, Guo J, Ou M, Pueppke SG, Ou W, Tao Y, Qi J (2020) Sustainability assessment of the water–energy–food nexus in Jiangsu Province, China. Habitat Int 95:102094

Yuan MH, Lo SL (2020) Developing indicators for the monitoring of the sustainability of food, energy, and water. Renew Sustain Energy Rev 119:109565

Yuan MH, Chiueh PT, Lo SL (2021) Measuring urban food–energy–water nexus sustainability: finding solutions for cities. Sci Total Environ 752:141954