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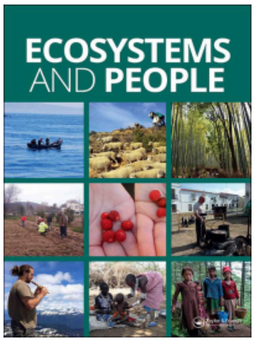

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REVIEW

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Biodiversity and ecosystem services dashboards to inform landscape and urban planning: a systematic analysis of current practices

Maria Riffat [a,c], Blal Adem Esmail[a], Jingxia Wang[b] and Christian Albert [a,c]

[a]Institute of Geography, Ruhr University Bochum, Bochum, Germany; [b]Department of Urban Studies and Planning, The University of Sheffield, Sheffield, UK; [c]Institute for Environmental Planning, Leibniz University Hannover, Hannover, Germany

ABSTRACT

Guiding the transformation of cities and regions towards more sustainable pathways requires a deep understanding of the complexities of socio-ecological systems. This entails gaining insights into the status and trends of biodiversity, ecosystems and their services (BES), as well as navigating complex governance and power structures, particularly in contested spaces. Digital dashboards, understood as visual representations of key information, could effectively communicate complex BES information to decision makers and planners in landscape and urban planning, enabling more informed decisions. While dashboards are increasingly being used in spatial-related applications, the lack of scientific understanding regarding the emerging applications of BES information in dashboards underscores the pressing need for research and review in this area. This study aims to identify and analyze contemporary case studies of BES dashboard applications to explore their potential role, which can effectively support decision-making in landscape and urban planning. We develop a conceptual framework of interlinkages between BES dashboards and landscape planning processes and apply this framework to analyze 12 state-of-the-art BES dashboard applications from Asia, Australia, Europe, North and South America. Our results reflect emerging practices of dashboards visualizing BES information, which varied in purposes, content, functionalities, visual design, and output features. The dashboards represented/covered a total of 66 BES indicators, including tree health, forest status and functionality, green and blue spaces connectivity, and specific components of biodiversity. Further research on user demands and real-world impacts is necessary to enhance the effectiveness of BES dashboards in informing landscape and urban planning for people and nature.

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KEY POLICY HIGHLIGHTS

- **Dashboards for reporting BES information**: Dashboards can facilitate the communication of biodiversity, ecosystems and their services (BES) information, providing policy makers with useful information for decision-making.
- **Framework for analysis**: Our conceptual framework developed for assessing BES dashboards in landscape and urban planning contexts enables practitioners to understand BES dashboard applications and opportunities.
- **Insights into worldwide BES dashboards**: Our analysis of 12 state-of-the-art of BES dashboards applications worldwide highlights the global reach of this tool. Decision-makers can gain valuable insights from various regions for addressing local biodiversity and ecosystem challenges.
- **Diverse range of indicators and customizations**: BES dashboards take diverse forms, including a wide range of indicators to customize BES information for local contexts and priorities.
- **Future BES dashboards research**: Future research and innovation should enhance BES dashboards' integration with planning systems, align with user demands, and impact real-world decision-making.

1 Introduction

Decision making in landscape planning is a complex process involving multiple disciplines and stakeholders with diverse interests, values, and knowledge (Martinez-Harms et al. 2015; Raadschelders and Whetsell 2018). It is compounded by the complexity and uncertainty of natural and social systems (García-Llorente et al. 2015). To promote sustainable development, interdisciplinary landscape planning approaches with appropriate methods of knowledge synthesis (Pullin et al. 2016) and stakeholder engagement (e.g. Etxano et al. 2015) are essential.

Integrating knowledge about biodiversity and ecosystems into planning and decision-making is fundamental to promoting sustainable development (Grêt-Regamey et al. 2015, 2017b; Ruckelshaus et al. 2015; Qiu et al.

CONTACT Maria Riffat maria.riffat@rub.de @MsRiffat
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2022). Biodiversity loss and fragmentation of ecosystems threaten the achievement of 80% of the Sustainable Development Goals (UNEP 2021). In landscape and urban planning, in particular, increasing efforts are being made to systematically integrate information on biodiversity, ecosystems and their services (BES) (Longato et al. 2021; Adem Esmail et al. 2022). It is argued that this integration can help address various societal challenges including air pollution, climate change, freshwater use and biodiversity loss (Díaz-Reviriego et al. 2019; Almenar et al. 2021). Ultimately, this could lead to better outcomes for people and nature (Wang et al. 2021; McPhearson et al. 2022). Due to the increasing awareness of the benefits of ecosystems for human well-being, the interest in BES information is growing in science, policy, and practice in both the public and private sectors (Geneletti et al. 2020b). The demand is to have information in a simpler, user-friendly, and understandable way to support planning and decision-making (Ruckelshaus et al. 2015; Qiu et al. 2022).

Numerous tools and approaches have been proposed to integrate BES information into landscape and urban planning (Thiele et al. 2019; Geneletti et al. 2020a). For example, tools for mapping and visualization of ecosystem services in land management systems (PALM, Grêt-Regamey et al. 2017a), and in river landscapes (RESI, Podschun et al. 2018), as well as for interactive knowledge transfer on ecosystem services (ESP-VT, Drakou et al. 2015). They arguably help make BES concepts operational and link them to planning and decision-making (Grêt-Regamey et al. 2017b). However, their practical applicability is still limited and effective integration of BES knowledge into planning is quite challenging (Longato et al. 2021; Adem Esmail et al. 2022). In practice, BES knowledge is often overlooked due to its complexity, time, and data requirements (Albert et al. 2014; Mascarenhas et al. 2014).

Against this background, digital dashboards are potentially useful tools for communicating and visualizing complex information, and they can interactively present complex information to decision-makers and actors involved in the planning process (Abd-Elfattah et al. 2014; Bartlett and Tkacz 2017; Payne et al. 2020). They are understood as a visual display of the most important information needed to achieve one or more objectives, consolidated and arranged on a single screen so that it can be monitored at a glance (Few 2006). In this research, we define 'BES dashboards' as online interfaces that assess and/or display spatially explicit information about the state or trends of biodiversity, ecosystems and their services in order to facilitate understanding and support planning, management, and decision-making at city or regional levels. The development of BES dashboards can draw on recent successful applications in many fields, including tracking smart city development (Young et al. 2017, 2020), providing COVID-19 information for preventive measures at national or global levels (Suri et al. 2022) and monitoring of management processes (Nadj et al. 2020).

The growing number of BES dashboards raises important questions about their key requirements and effectiveness in supporting planning and decision making. To our knowledge, however, few studies have addressed this topic with a focus on BES dashboards. Han et al. (2014) provide biodiversity indicators dashboard for tracking and monitoring purposes and Fegraus et al. (2012) present an ecosystem services dashboard to track and monitor agricultural systems. Notably, Braunschweig et al. (2022) highlight biodiversity risks by developing a risk matrix dashboard to bridge the gap between science and practice, but without explicitly acknowledging its embedding in a planning process. In general, there is limited information on the design principles, key features and selection of key indicators and metrics for BES dashboards (O'Donnell and David 2000; Velcu-Laitinen and Yigitbasioglu 2012; Matheus et al. 2020). Furthermore, there are few textbooks and articles that provide basic guidance on the features and requirements of generic dashboards (Few 2006; Pauwels et al. 2009).

BES dashboards developed by practitioners are on the rise, but insufficient conceptual knowledge and understanding of these dashboards in the planning process contribute to the existing research gap. A systematic framework to reveal the information on potential usage of BES dashboards to support planning processes is often lacking. Despite the available literature and the wide application of dashboards in different fields, a comprehensive theoretical basis is still missing to fully leverage their potential in planning processes. Given the usefulness of dashboards in communicating BES information during planning process, it is crucial to gain a deeper conceptual understanding of their potential. This is particularly important considering the current lack of theoretical constructs in the limited existing literature. Therefore, the study aims to systematically identify and analyze contemporary case studies of BES dashboard applications, in order to explore the potential role of these dashboards as interactive digital visualization tools that can effectively support landscape and urban planning. Within the scope of this research, we address three research questions:

RQ1. In what contexts are BES dashboards implemented, considering the level of decision-making, targeted planning stages and purpose?

RQ2. What are key design and process characteristics of the BES dashboards?

RQ3. What outputs are delivered by the BES dashboards, and what outcomes were expected?

By investigating these questions and analyzing selected case studies, we aim to improve scientific understanding of the implementation, design, and outcomes of BES dashboards. Ultimately, this research will contribute to gain empirical insights into state-of-the-art of dashboard applications as valuable tools in supporting landscape and urban planning processes.

2 BES dashboards in landscape and urban planning

Our understanding of the role of BES dashboards in planning can be usefully described as a conceptual framework (Figure 1), i.e. a concise summary, in words or pictures, of the relationships between dashboard elements and the planning context (adapted from Tomich et al. 2010). To develop the conceptual framework, we synthesized insights from existing review papers of dashboards on other topics (such as, Rahman et al. 2017; Velcu-Laitinen and Yigitbasioglu 2012; Mannaro et al. 2018; Lock et al. 2020; Young and Kitchin 2020; Wiedbusch et al. 2021) and combined it with insights from literature on BES decision support and digital visualization tools in planning (e.g. Klein et al. 2015; Billger et al. 2017; Stahre Wästberg et al. 2020; Hoffmann et al. 2021).

In our conceptual framework (Figure 1) we conceive BES dashboards as characterized by the specific context for which they are developed and applied. The context is provided by the level of decision-making (Schakel 2020) that the dashboard is intended to address, the targeted planning stages (Martinez-Harms et al. 2015) and the purpose of the application.

Similar to the planning process, BES dashboards are characterized here in terms of their design, process, and outputs (see Figure 1). Their design concerns the targeted users according to Geneletti et al. (2020b) and Billger et al. (2017), which data are used (Drakou et al. 2015), what temporal focus is chosen, and what type of BES concepts (e.g. TEEB 2010; OECD 2019) are applied. BES dashboard processes refer to the methods applied for acquiring or assessing BES information, the level of participation according to Geneletti et al. (2020b) and the types of actors involved (Billger et al. 2017; Stahre Wästberg et al. 2020) during design and development process of dashboards. Dashboard outputs consider their visual features, interaction opportunities, and if and how data from dashboards can be exported for further analysis. The outputs of BES dashboards such as interactive maps, charts, diagrams, and others can be easily transferred and communicated (Velcu-Laitinen and Yigitbasioglu 2012; Farmanbar and Rong 2020). In addition to providing an information basis for planning and decision-making, these outputs can serve to improve the understanding of the specific socio-ecological system.

For applications in planning, BES dashboards can take up issues of the respective planning context and support the ongoing planning process by providing relevant outputs in terms of information on BES states, trends, and impacts of planning scenarios (Han et al. 2021). This information can support the planning process itself but can also be applied effectively in the subsequent decision-making and governance processes. Successful implementation of evidence-based environmental governance requires researchers and authorities to effectively disseminate and communicate scientific information on biodiversity and ecosystems to decision-makers, ensuring that their requirements are fulfilled (Geneletti et al. 2020b).

Taken together, we argue that using BES dashboards could lead to improved knowledge uptake of complex BES information during planning, decision-

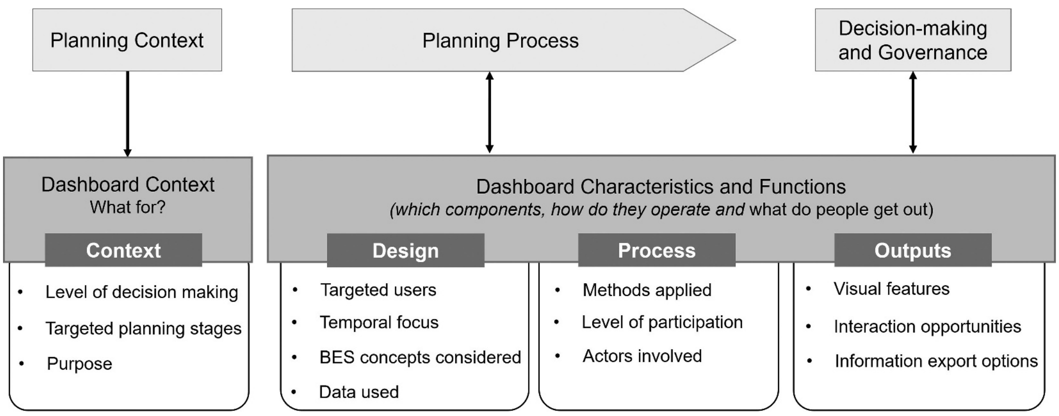


Figure 1. Conceptual framework of the interlinkages between BES dashboards and planning process, here the arrowhead symbolizes the streamlined horizontal progression of the planning process, depicting the transition from the planning context to decision making and governance. Each step in the cycle is vertically aligned to emphasize its direct linkages with the overarching context, design and development process of the dashboards.

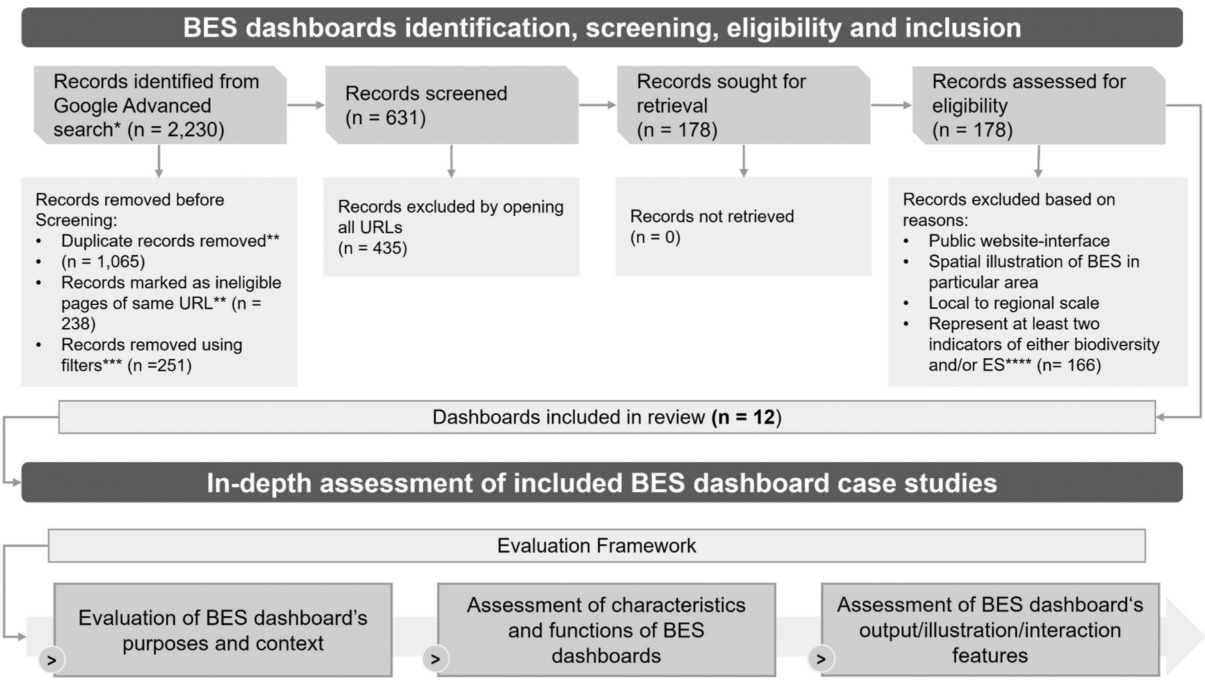
making, and governance processes. Additionally, the conceptual framework developed in this study for analyzing BES dashboards can serve as a valuable tool for diverse stakeholders i.e. governmental agencies, political, professional, disciplinary and non-governmental groups, and citizens, ultimately improving the utility of the dashboards.

3 Materials and methods

This study employs a two-step methodology, consisting of a systematic approach to identify contemporary BES dashboard case studies, and an in-depth analysis and interpretation of selected cases using our conceptual framework as the second step (see Figure 2).

3.1 Systematic approach to identify contemporary BES dashboard case studies

Relevant contemporary BES dashboard case studies were identified using an adapted PRISMA approach (Page et al. 2021). We searched using the Google Advanced search engine with a specific query to systematically identify contemporary BES dashboard case studies. Through this novel web scraping method, the search keywords used include dashboards, visualization platforms, web platform, presentation format, display format; and biodiversity, diverse ecosystems and ecosystem services (Figure 2). The search was conducted in May, July, and August 2021. To export the results from the Google search window to a CSV file, the Linkclump tool was used (Kikpiller and Siibak 2021). The final search returned a total of 2,230 dashboard URLs, from which duplicates, non-working URLs, and unsatisfactory URLs were removed, leaving 631 cases (Figure 2). After the initial screening, 178 BES dashboard URLs were then evaluated in detail against our inclusion criteria. We have focused on case studies that meet four specific criteria: (i) they are publicly available (Fürstenau et al. 2021); (ii) represent information spatially (Burkhard and Maes 2017) to potentially support planning process in general; (iii) are at the local to regional level where landscape and urban planning operates (e.g. Grêt-Regamey et al. 2017a; Fürst et al. 2017); and (iv) represent at least two indicators of either biodiversity (OECD 2019) and/or ecosystem services (e.g. TEEB 2010; Crossman et al. 2013). Operationally, we first verified that the identified URLs conformed to the definition of a generic dashboard. Subsequently, we ensured that the BES dashboard had a public website interface, presented a spatial representation of BES information at a local or regional level and contained at least two BES indicators from common categorization systems. These inclusion criteria were a crucial factor in significantly reducing the number of selected case studies for further analysis. Hence, a total of 166 dashboards were excluded based on our strict



Identified with google advanced search using query ("Dashboard" OR "visualization*" OR "visualization platform" OR "web platform" OR "presentation format*" OR "display format," "graphs," AND "ecosystem service*" OR "natural capital" OR "city" OR "cities" OR "region" OR "environment*" OR "sustainability" "provisioning service*" OR "food" OR "raw material" OR "fresh water" OR "medicinal resources" OR "regulating service*" OR "local climate" OR "food" OR "carbon sequestration" OR "carbon storage" OR "water purification" OR "biological control" OR "extreme event*" OR "recreation*" OR "tourism" OR "agriculture" OR "supporting service*" OR "habitat service*" OR "cultural service*"OR "waste water" OR "water treatment" OR "river" OR "soil*" OR "soil fertility" OR "biodiversity" OR "air quality" OR "green infrastructure" OR "nature-based solution*" OR "climate regulation" OR "habitat quality" OR "specie*" OR "drought regulation" OR "erosion prevention" OR "pollination" OR "urban ecology" OR "mental health" OR "physical health" OR "sense of place" OR "aesthetic*").

**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

***Filters = news /nachrischten, blogs, articles, translate, youtube, google books, researchgate, wikipedia, springer, dw, covid-19, mdpi, brochure, .pdf, .doc, .ps, .ppt, .xls, .kmz, .kml, .dwf

**** At least two indicators of either biodiversity and/or ES (ecosystem services) from common categorization systems such as TEEB-The Economics of Ecosystems and Biodiversity (TEEB 2010) and CBD-Convention on Biological Diversity (OECD 2019)

Figure 2. Steps for identification and in-depth assessment of BES dashboard case studies.

inclusion criteria (Figure 2). For instance, the dashboard of Sustainable City Government Portland, Oregon was excluded as it is not publicly available. Similarly, the dashboards of Dryden Municipality, Brampton City, and London City were excluded due to lack of spatial representation of the indicators (criterion ii), and they did not incorporate at least 2 BES indicators (criterion iv). As a result, 12 BES dashboard case studies with explicit representation of BES information were selected for in-depth analysis.

3.2 In-depth analysis of selected BES dashboard case studies

The sample of 12 selected BES dashboards was systematically analyzed using the review framework in Table 1. This review framework is based on the categories and subsequent sub-categories identified in Section 2 and detailed hereafter. The information extracted included the context, design, process, and outputs of the dashboards. Of note, the italicized text within the framework indicates categories that cannot be comprehensively understood solely through the dashboard tool itself. To gain a deeper understanding of these categories, additional investigation through external sources such as online news articles and reports, especially if provided by the developers as supporting data, is necessary. All other categories are possible to either directly identify or interpret into our review framework classifications from the dashboard interface itself. Accordingly, this study focuses mainly on the results of these categories (see Table 1). A more detailed description of the subcategories of our review framework and the corresponding literature is available in the Appendix.

Table 1. Review framework (categories in italics indicate that their anaylsis usually requires additional information beyond those available in the dashboard itself).

Categories	Guiding Questions
Dashboards context	
Level of decision making	• At what level of decision making does the dashboard support?
Target planning stages	• To which target planning stages does the dashboard contribute?
Purpose	• What is the purpose of the dashboard?
Dashboard design	
Target group	• Who are the intended users of the dashboard?
Type of BES information	• What type of BES information is considered?
Assessment theory	• Which DPSIR components are used and how are they evaluated?
Indicators	• Which specific indicators are used?
Data Used	• What data is used?
Dashboard process	
Levels of participation	• *What is the level of participation in different stages of dashboard design and implementation?*
Participatory methods	• *Which public participation methods were used?*
Dashboard designers	• *Who is involved in dashboard design?*
Dashboard managers	• Who is involved in dashboard management?
Methods applied	• Which methods are used for developing indicators and metrics for BES dashboards?
Evaluation approach	• Which evaluation approach is used for BES indicators?
Dashboard outputs	
Visual features	
Style	• Is the dashboard stand-alone for BES information or embedded into the general city/region's dashboard? • Is the dashboard single-page or multipage?
Visualization type	• How is the information visualized on the dashboard?
Visualization way	• What is the way of information visualization of the dashboard?
Colors used	• What type of color-code is used.
Interaction opportunities	
Format type	• Which format for interaction are used?
Tools for interaction	• Which tools for interaction are employed?
Level of interaction	• What level of interaction is enabled for each feature?
Output data and exportability	
Output data type	• What type of output data is offered?
Actuality of data	• What is the age of the data used?
Data update status	• What is the frequency of data updates?
Open data source	• If the data used is from an open source?
Exportability of data	• Is it possible to export the BES information?
Exportability format	• If yes, what format can information is exported in?

The dashboard context, in alignment with the planning context, here refers to the embedding of the socio-ecological context. It is characterized by the type of governance system, the level of decision-making, the targeted planning stages, and the purpose of the dashboard. The level of decision-making is categorized into supra-regional, regional, local and neighborhood scales. This study primarily focuses on regional and local scales (Grêt-Regamey et al. 2017a; Fürst et al. 2017; Longato et al. 2021). Indeed, various models for landscape planning exist recognizing different planning stages (e.g. Von Haaren and Reich 2006; Steiner 2012). In this study, we consider four main planning stages adopted from Steiner (2012) namely i) context definition and status quo analysis, ii) exploration of alternatives and definition of actions, iii) development of solutions and strategies and iv) implementation and monitoring. The hybrid class is also included to account for BES dashboards that provide support to multiple targeted planning stages. In understanding this information, the purpose statements of the dashboards often prove to be valuable resources. For example, the Perth City Dashboard was categorized as hybrid as it provides information relevant to planning stages (i) and (iv) of the review framework (Table 1). Finally, in terms of purpose, dashboards are classified as strategic, tactical/analytical, operational, or informational (Few 2006; Pappas and Whitman 2011; Dobraja and Kraak 2020). According to Rahman et al. (2017), Abd-Elfattah et al. (2014) and Eckerson (2010) strategic dashboards are used to help executives/decision-makers monitor the implementation of strategic objectives, communicate strategies and review performance. The tactical/analytical dashboard provides a more detailed level of information useful to monitor and manage the performance of management institutions (Abd-Elfattah et al. 2014; Nadj et al. 2020). The operational dashboards allow stakeholders to view up-to-date information used to manage and control operational processes (Eckerson 2010). All considered BES dashboards have an informational purpose as per their definition and in case of multiple purposes, they are classified as hybrid. Classification into one of the categories is based on the stated purpose, as reported in the case study of the BES dashboard, including its supporting documentation. In the absence of an explicitly stated purpose, the classification was made by the authors on the basis of purposes of the similar case studies. For instance, we interpret the Surrey Sustainability Dashboard as a hybrid because its 'stated purpose' relates to strategic elements (such as performance indicators), tactical elements (including historical trends data), informational features (raising awareness), and educating components (providing openly accessible information to the public).

Dashboard design features consist of targeted users, temporal focus, BES concepts considered, and data used. The categorization of the type of targeted users in the dashboard design process is based on the categories of actors presented in Geneletti et al. (2020b), which are divided into i) policy and decision makers, ii) experts and consultants, iii) academics and researchers, iv) representatives of business sectors, v) representatives of civil society and vi) individual citizens. We are aware that identifying the targeted users for certain dashboards can be challenging based solely on the dashboard tool itself. However, supporting documents accompanying the dashboards play a crucial role in providing insights into the intended users. In cases where these documents are unavailable, the developers of the dashboard and the funding parties involved provide indications of the targeted users. For instance, we interpreted the target users of the Eco-Paris Dashboard as academics and economic sector representatives, given that the dashboard was part of a project on economic issues. The temporal focus of the data used is categorized into current status, historical trends and projections (or forecasts). The driver-pressure-state-impact-response (DPSIR) model is used to identify the BES concepts following a similar approach proposed by Han et al. (2014). For a few BES dashboards the information is provided by the dashboards themselves such as Singapore Biodiversity Dashboard, however, for others this assessment is carried out based on the represented data and indicators on each dashboard.

Many actors and decision-makers are involved in the planning process (Billger et al. 2017; Geneletti et al. 2020b). Similarly, the dashboard design/development process also involves multiple actors such as designers and managers (sub-categories in Appendix) to achieve higher applicability, reliability, and advancement for better support in the context of planning, decision making and governance. In certain cases, the information regarding the actors involved in the design of the dashboard was not clearly stated, posing challenges for interpretation. Thus, the category is italicized in the framework. On the other hand, the information about dashboard managers is typically readily accessible through the dashboard tools, allowing for easier identification. As a basis for planning, participation levels and tools are analyzed to characterize public participation during the dashboard development stages. This information is also interpreted based on the data collection techniques, available supporting documents, and news articles. For example, in Jersey City Tree Canopy and Eco-Paris Dashboards, the participation methods used are categorized into citizen science and workshops, based on student's engagement for data collection or filling protocols and workshops to inform citizens. In Table 1, participation level and participation methods categories are denoted in italicized text representing that these categories cannot be assessed through dashboards solely.

Finally, dashboard outputs refer to the delivery of information through easily digestible visualization, using interactive ways to present complex BES information in the planning process as well as for governance and management purposes. The information on content visualization, display style, visualization format and colors used are evaluated in detail in relation to the output features. This information is comprehended and analyzed solely by means of dashboard interfaces. The expected planning outcomes of these dashboards were derived from either the dashboard websites themselves or inferred from their purpose statements. Analyses of real-world impact of these BES dashboards could have provided further insights but were beyond the scope of this paper.

4 Results

This research includes 12 contemporary BES dashboards case studies, which were systematically identified through a novel Google scraping method and selected based on an adapted Prisma approach (Figure 3). Three of the selected BES dashboards are located in the United States and two are located in Australia. The remaining seven BES dashboards are located in Canada, France, Italy, China, Singapore, Peru, and Indonesia. None have been found from Africa, confirming that most dashboards exist in the Global North.

In terms of content, most BES dashboards represent specific ecosystems in different metropolitan areas, including parklands, ecologically significant areas, green space networks, tree canopy cover (Surrey Sustainability, Perth City Tree Canopy, Jersey City Tree Canopy and City of Salinas Green Infrastructure Dashboard) and associated ecosystem services such as nutrient retention, groundwater recharge, cooling, and pollination (EcoParis Dashboard).

A second set of dashboards presents mainly biodiversity-related indicators such as habitat building species, species occurrence, biodiversity index (Singapore Biodiversity Dashboard), bioclimatic ecosystem resilience index and species count (Alto Mayo Watershed Dashboard).

The third remaining group of dashboards presents environmental data in general, such as air quality, water quality, and waste information (Arizona Region Dashboard and Hong Kong City Dashboard), fire alerts (Forest Conservation Dashboard Indonesia), and pollination and air quality (Florence City Dashboard). Of note, the dashboards of this type are often embedded in a city dashboard. Table 2 provides general information about the name, country, extent of dashboard coverage, scale, standalone meaning the dashboard is not embedded in a city or region's dashboard and URLs of selected BES dashboards.

4.1 *In-depth analysis of BES dashboard case studies*

4.1.1 *BES dashboards context aligned to decision making and planning processes to address socio-ecological challenges*

The case studies varied in context, including level of decision-making, targeted planning stages, and purposes (Figure 4). This offers a broad perspective on the potential of BES dashboards in planning. The cases identified are mainly at local to regional level of decision-making. In terms of supporting targeted planning stages, the reviewed dashboards mostly provide BES information for the 'problem analysis and context definition' stages, followed by 'implementation and

Figure 3. Spatial representation of selected BES dashboard case studies.

Table 2. Selected BES dashboards with full names, scale, URLs, and country information.

No.	Selected Dashboards	Country	Area (km^2)	Scale	Stand-alone
1	Alto Mayo Peru Sub-Watershed Dashboard	Peru	1,820	Regional	Yes
2	Arizona Region's Environmental Dashboard	USA	295,233	Regional	No
3	City of Salinas Green Infrastructure Dashboard	USA	60.7	Local	Yes
4	Eco-Paris Dashboard	France	105.4	Regional	Yes
5	Florence City Environmental Dashboard	Italy	102.4	Local	No
6	Hongkong City Dashboard	China	1,106	Local	No
7	Jersey City Tree Canopy Dashboard	USA	54.7	Local	Yes
8	Monitoring Conservation Forests Dashboard	Indonesia	475,892	Regional	Yes
9	Perth City Tree Canopy Dashboard	Australia	20.0	Local	Yes
10	Singapore Biodiversity Dashboard	Singapore	728.6	Local	No
11	Surrey Sustainability Dashboard	Canada	316.4	Local	No
12	Water Usage Dashboard in New South Whales	Australia	801,150	Regional	Yes

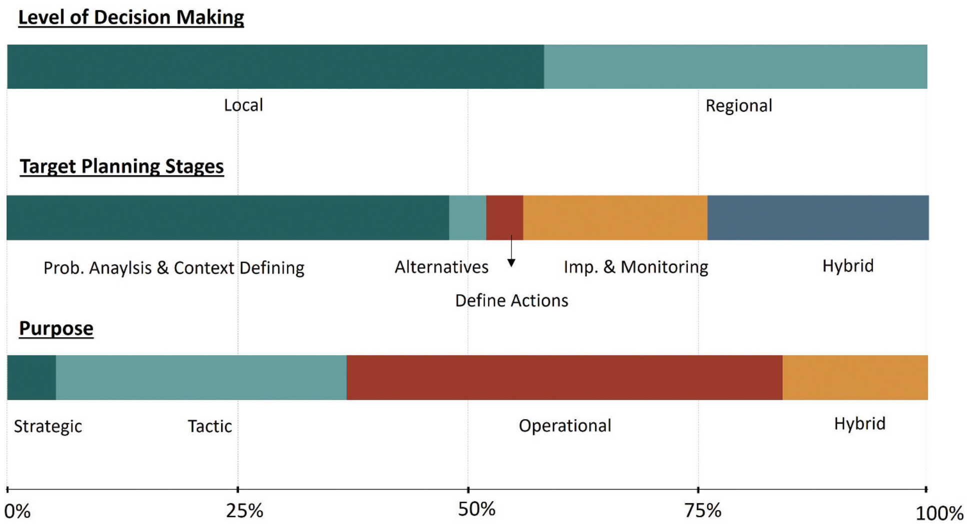


Figure 4. Results of BES dashboards context including level of decision making, targeted planning stages and purpose analysis.

monitoring' stages. Half of them offer a hybrid function that could provide BES information for two or more targeted planning stages at the same time, e.g. Surrey Sustainability, Jersey City, and Eco-Paris Dashboards.

In terms of purpose, most of the BES dashboard case studies are characterized as addressing either an operational or a tactical/analytical purpose, while few support a strategic purpose. Notably, 3 out of 12 dashboards are categorized as hybrid purpose i.e. Alto Mayo Peru with tactical and operational purposes, Surrey Sustainability with all purposes, and New South Wales Water Usage with tactical and operational purposes.

4.1.2 Design and process characteristics of the BES dashboards

Similar to a generalized planning process, the dashboard design and development process depends on various aspects such as: targeted users, type of BES information considered, data used, public participation, methods used for participation, designers, and managers (Figures 5 and 6). Moreover, 66 indicators related to BES information are identified, with 45 biophysical and 21 socio-economic indicators. According to the DPSIR framework, most of the indicators relate to status (mainly biodiversity and ecosystems); while only 12 relate to pressures and impacts, and 17 to responses. None addresses the driver components.

Public participation during the design and implementation stages is generally limited, with about 75% of the cases classified as 'non-participatory' and the remaining as 'tokenism' (Figure 6). No evidence of active citizen participation, collaboration and/or empowerment were found. Most of the BES data presented is evaluated as status and trends over time; few indicators from different BES dashboards used thresholds and predicted values, while only one was evaluated as score based. In all 12 analyzed cases, designers and planners were mainly involved in the design, while management involved mainly city or local officials followed by specific authorities.

4.1.3 Outputs and outcomes of BES dashboards

The outputs of the dashboards were analyzed based on their visual features, interaction opportunities and output data features. Visual features (Figure 7a) represent commonly used visualization styles in 'at a glance' format, as a summary or in timeline format.

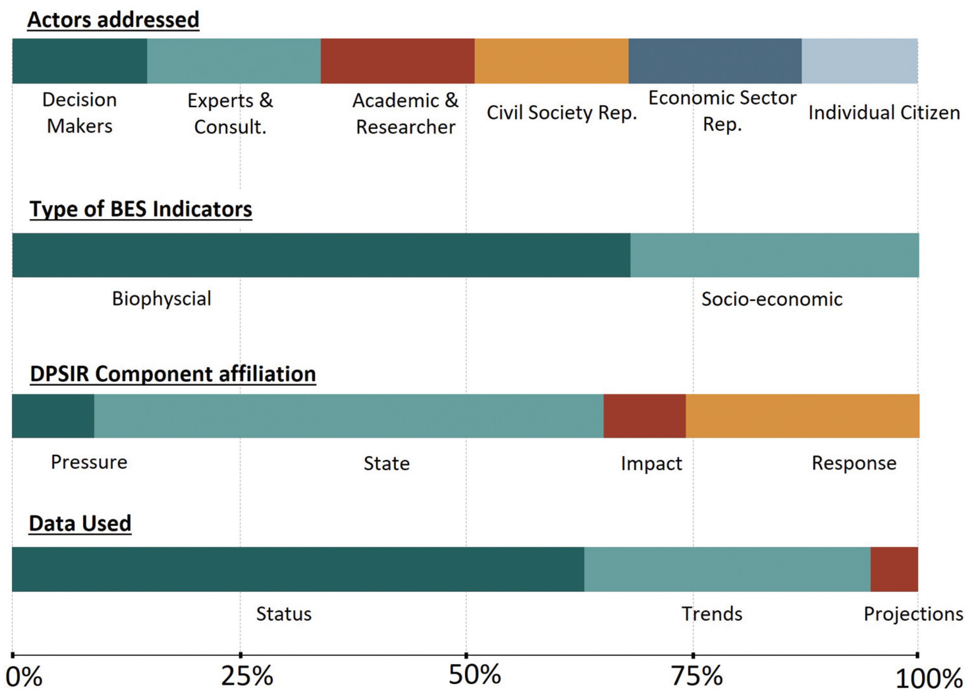


Figure 5. Distribution of findings of BES dashboard design features.

Usually, single page dashboards with the possibility to scroll down are common. The use of legible colors, consideration for the color-blind community, and color accessibility (Marriott et al. 2021) are also observed; yet, about 30% of dashboards, including Jersey City Tree Canopy and Surrey Sustainability dashboards, were more likely to use less legible colors. Moreover, dashboards typically displayed their information using monochromatic and complementary color schemes. In terms of interaction

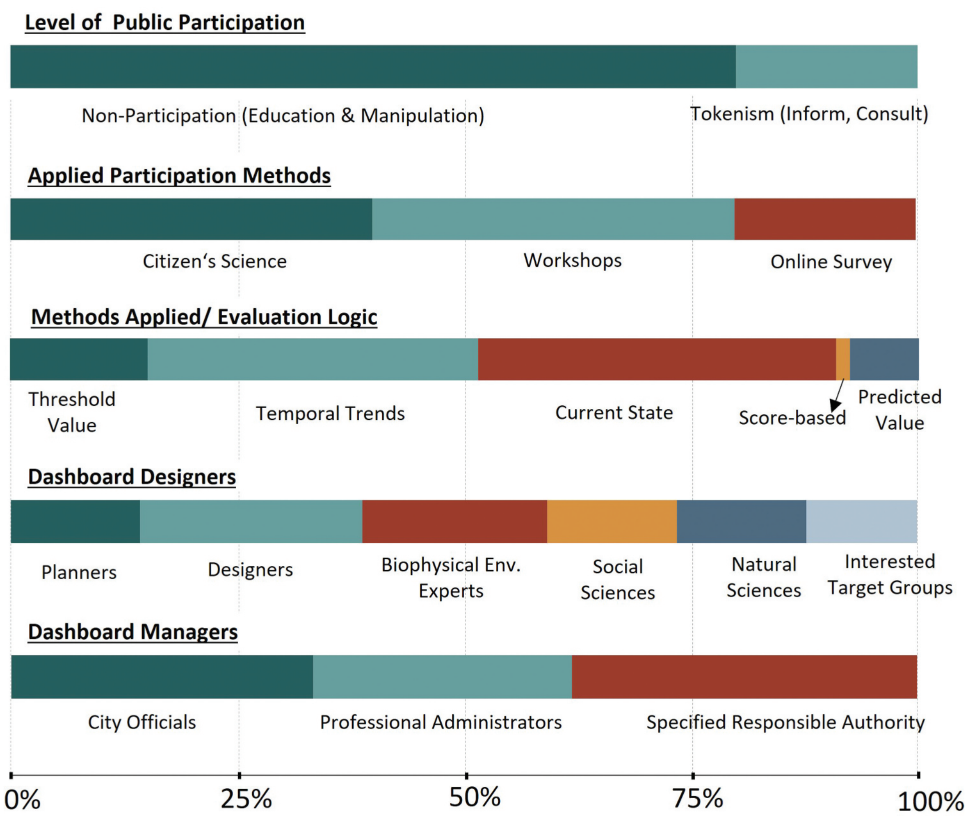


Figure 6. Distribution of findings of BES dashboard process features.

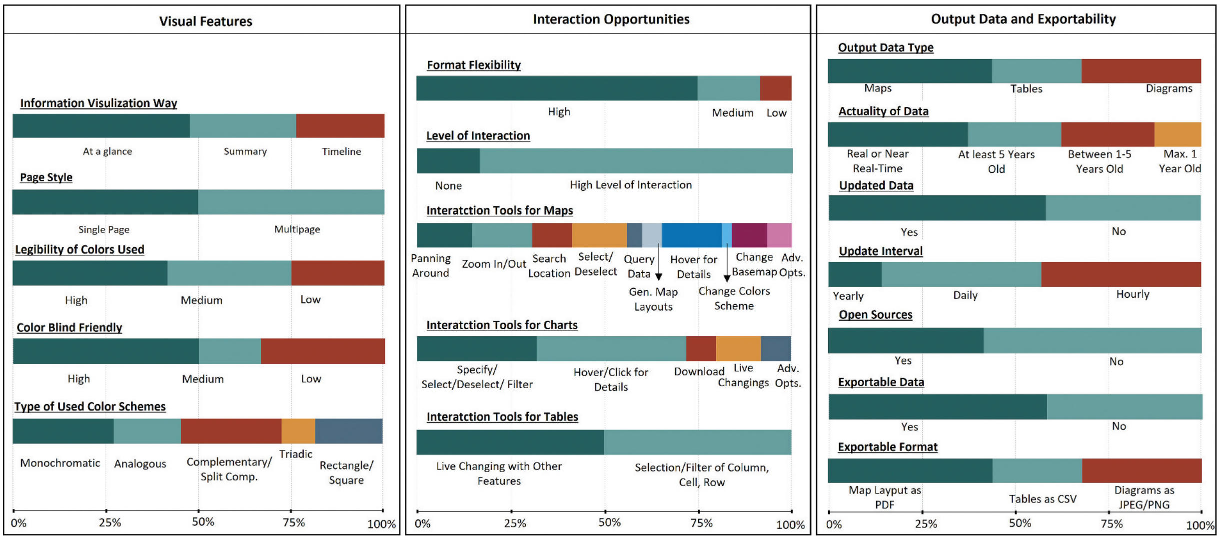


Figure 7. Dashboards outputs in alignment of planning outcomes; (a) visual features of dashboards, (b) interaction opportunities offered by dashboards, (c) output data and exportability features.

possibilities (Figure 7b), most BES dashboards offer format flexibility, and all analyzed dashboards also offer a navigation tool, but they all lack an automatic alerting or feedback system. Interactive dashboards are prominent in our results and stand out from static ones. Figure 7b shows various interaction opportunities that dashboards offer for maps, diagrams, and tables. The interaction tools that we have observed the most are 'live changing feature' linked to all other information, and 'hover/click for more details'. For maps, panning, zoom-in and zoom-out, selection by query, search locations, hover for details and changing base maps were most common in almost all cases. In particular, Perth City Tree Canopy Dashboard stands out with the highest number of tool options for maps. Regarding the characteristics of the output data (Figure 7c), the type of output data is predominantly in the form of maps, then diagrams or charts, and tables. The age of the data used by most analyzed dashboards ranged from 1 to 5 years, with only a few showing information with real-time data. The real-time data is mainly updated daily or hourly, where 40% of the analyzed dashboards get data from open-source systems. Our results confirm that most of the dashboards offer the possibility to export the visualized data. Maps in dashboards can mostly be saved and exported in PDF format, and diagrams/charts in PNG or JPEG format, and tables in CSV format in a few cases. These output features of BES dashboards represent the potential to disseminate and communicate scientific information on biodiversity and ecosystems to decision-makers. The analyzed dashboards were expected to yield significant outcomes by their developers, including improving understanding of ecological resources, identifying priority conservation areas, integrating ecosystem services into planning decisions, evaluating development impacts, and promoting public engagement and awareness. These outcomes offer valuable insights for landscape and urban planning processes, enabling informed decision-making and fostering the implementation of sustainable development practices.

5 Discussion

The objective of analyzing the BES dashboard case studies was to gain a comprehensive understanding of their potential use in planning processes, with a specific focus on their implementation contexts, design characteristics and outcomes. Rather than analyzing the real-world impact of these BES dashboards in supporting complex decision making and planning processes, our aim was to provide insights into their context, design, and outputs. First, we delved into the context of BES dashboards and their role in addressing socio-ecological challenges in planning and decision-making processes. Second, we explored the design and process characteristics of these dashboards, as well as the outputs they facilitate and the potential outcomes they offer. Subsequently, we investigated the implications of BES dashboards in future landscape and urban planning, highlighting their broader applicability and usability analysis. By considering their wider applications and analyzing their usability, we can now discuss the key factors to maximize the benefits of BES dashboards in supporting sustainable and equitable planning practices.

5.1 Insights into the context of BES dashboards

Our study highlights the context of BES dashboards in which they have been applied to address socio-ecological challenges in line with planning and decision-making processes. It reveals that primarily the local and regional levels are increasingly recognizing the value of digital dashboards for incorporating BES information into their planning systems. In practice, the efforts to integrate BES information with emerging tools in planning processes may occur at different levels of decision-making, and the extent to which this is achieved may also vary depending on the specific contexts (Ruckelshaus et al. 2015). Review studies by Longato et al. (2021) and Grêt-Regamey et al. (2015) reveal that local to regional scales consider higher uptake of BES information during planning and decision-making than national and global scales. Planners and decision-makers are striving for better technological advancements to integrate BES information into the planning systems and test the opportunities to use the available emerging tools (Billger et al. 2017; Stahre Wästberg et al. 2020; Batty and Yang 2022). For example, Beck-O'Brien and Bringezu (2021) suggest the use of digital tools, i.e. dashboards to track the performance of biodiversity in food supply chains and biodiversity impact mitigation.

Another reason for assessing BES dashboards was to shed light on the potentials to support decisions at different planning stages. Our study identifies that BES dashboards can address all planning stages due to their hybrid function (Section 4.1.1). Existing literature provides similar results as analyzed in this study i.e. 'managing' and 'monitoring' across different domains with a strategic, tactical, operational, informational or hybrid purpose of dashboards (Young et al. 2017, 2020; Young and Kitchin 2020). Mannaro et al. (2018) argue that 'every city can benefit from having a dashboard if it knows the use of it'.

5.2 Insights into the design and process characteristics of BES dashboards

Our findings emphasize the involvement of a diverse group of actors during the design and development processes of dashboards (Section 4.1.2). These results align with the study of Billger et al. (2017) which identifies similar categories of actors involved by reviewing a set of digital visualization tools to support dialogue in the planning process.

The assessed BES dashboards focus only on a few BES indicators. Most commonly applied indicators are biophysical, similar to findings by Han et al. (2014) for biodiversity monitoring dashboards. It is partly due to the common practice of the majority of ecosystem services evaluation tools available that evaluate ecosystem services in biophysical units, instead of socio-economic units. Schägner et al. (2013) describe in their review that mostly monodisciplinary approaches are used to determine ecosystem services, which focus on either the biophysical or the socio-economic aspects. Moreover, a bias in ecosystem services selection towards easily identifiable or popular services may be another reason for the representation of most common BES indicators on analyzed dashboards (Maes et al. 2012; Primmer and Furman 2012).

Public participation is crucial in capturing individual preferences during the development process of BES dashboards. While many studies discuss the benefits of using dashboards to enhance public engagement and transparency in planning processes (Matheus et al. 2020; Fürstenau et al. 2021), few highlight the importance of user participation during the development process (Young et al. 2020; Young and Kitchin 2020). Unfortunately, the level of public participation analyzed in this research is limited to non-participation, with only a few case studies conducting surveys and workshops for data collection and informing the public about the developed dashboard tool. Of note, the potential of participatory GIS (PGIS) (e.g. Gottwald et al. 2022) as a key input for developing BES dashboards remains untapped.

5.3 Insights into the output characteristics of BES dashboards

Studies on dashboards from diverse disciplines (Velcu-Laitinen and Yigitbasioglu 2012; Bartlett and Tkacz 2017; Jing et al. 2019; Farmanbar and Rong 2020) find some recurring visual and functional features. This is consistent with our results (Section 4.1.3), where a comparable set of visualization features and interaction opportunities of BES dashboards are identified and highlighted. These output features (Section 4.1.3) offered by BES dashboards can potentially assist in changing thinking and knowledge regarding BES information for its end-users by enhancing its usability. Research is emerging on how these features may support planning and governance (Jing et al. 2019; Lock et al. 2020).

Despite the use of legible color schemes, generally suitable for color-blind people, in most of the analyzed dashboards to effectively present BES information, we emphasize that the solutions to better data accessibility need a little more attention in dashboard design. These solutions such as changing styles, adding annotations and using monochrome or non-ambiguous colors for deuteranopia, protanopia and tritanopia, are indeed interesting subjects for future research. With the data accessibility option, we can consider designs that support wider and more comprehensive user engagement (Billger et al. 2017). These findings resonate with the study of Young and Kitchin (2020), which highlights the use of nice and systematic colors for data presentation on dashboards. Moreover, the existing literature on generic dashboards (Farmanbar and Rong 2020; Dobraja and Kraak 2020) emphasizes the feature of '*frugal use of colors*' to represent the information. Stahre Wästberg et al. (2020) underline the challenge of visualizing environmental data in a user-friendly way using digital city models. Altogether, output features of BES dashboards can be potentially useful to enhance understanding of the complicated spatially distributed socio-ecological data on biodiversity and ecosystems.

5.4 Towards wider applications of dashboards and their usability analysis

Our results show that the BES dashboards could provide BES information to multiple stakeholders at different planning stages in landscape and urban planning. It highlights the need to identify possible connections between the use of BES dashboards and challenges during the planning process, which could lead to higher integration and communication of BES knowledge in planning. Moreover, our conceptual framework can be adapted to incorporate other thematic areas (such as transport, renewable energy, water, waste etc.) in the planning process. While relevant scientific papers mainly concentrate on a single case study, such as biodiversity indicator dashboards for monitoring and tracking purposes (Han et al. 2014) and ecosystems services dashboard for agriculture systems to monitor and track (Fegraus et al. 2012), without explicitly acknowledging its embeddedness in the planning process. Therefore, reviewing and analyzing available case studies is valuable to understanding the capacities of BES dashboards in general.

Overall, BES dashboards are important tools with the potential to integrate BES knowledge into planning processes in this digital era. Their potential lies in supporting landscape and urban planning by integrating BES information, facilitating cross-sectoral information dissemination, collaborative working with professionals and stakeholders, and providing effective feedback systems. However, there are several challenges that need to be addressed to ensure the success of these dashboards. These challenges encompass engaging diverse audiences, promoting increased public participation, and ensuring the legitimacy and credibility of the data used in the dashboards. Additionally, incorporating feedback features into the dashboards can provide valuable insights into human behavior in relation to nature. By addressing these challenges and harnessing the potential of BES dashboards, planners can enhance the usability and effectiveness of these tools in supporting sustainable and equitable planning processes. This, in turn, advances shared goals and facilitates informed decisions, as suggested by Zapata and Bates (2015). Furthermore, by engaging in inclusive and diverse public reasoning, users of BES dashboards can cultivate a public realm that considers a wide range of issues and perspectives. In this context, the 'new wave of planning' proposed by Healey (1996), which emphasizes the importance of communicative rationality and inclusionary argumentation (Healey 1996), is further enhanced.

5.5 Limitations

As BES dashboards are a relatively new digital tool, they are available in practice but less studied in the literature. A search of several databases including Web of Science, Scopus, Elsevier and Google Scholar returned only limited literature on BES dashboards (Fegraus et al. 2012; Han et al. 2014), whereas sufficient scientific literature is already available for urban dashboards (Lock et al. 2020). Our study addresses this key knowledge gap; however, a major limitation is that the selected BES dashboards are biased towards the English language: a well-recognized limitation (e.g. Konno et al. 2020). We may have overlooked BES dashboards that did not use the term 'dashboard*' in their web paths.

Moreover, capturing the exact essence of their creation process is difficult as the reviewed BES dashboards are not available in scientific literature. In addition, it is difficult to track the exact impact that the dashboards had on planning and decision-making. Such an analysis would have required in-depth interviews and surveys of people engaged with the dashboards which was beyond the scope of this manuscript. Assessing the actual impact of BES dashboards, for example, through a series of interviews with users and stakeholders, could yield highly relevant information but was beyond the scope of this manuscript. It may inevitably cause a partially subjective assessment of some aspects (e.g. context and process) of BES dashboards in our sample. Moreover, a review of BES dashboards at a global and national level could lead to different conclusions in terms of dashboard design features and contexts; however, this does not affect the applicability of conceptual understanding that is anticipated in our study. Instead, our conceptual understanding allows flexibility in dashboard analysis and would allow more insight into the essential components of BES dashboards to support planning with scientific rigor, from contexts, processes to management and governance. We, therefore, advocate that dashboard developers, planners, managers, and other stakeholders can make full use of our concept to gain a full picture of the role of BES dashboards in the whole landscape and urban planning process so that key actions like public engagement and citizen empowerment can be timely and efficient.

6 Conclusion

Our paper makes two main contributions. First, we complement the literature dealing with BES information communication in planning by offering a first step in understanding the characteristics of BES dashboards to easily communicate the complicated BES information to different stakeholders and target users. Second, we shed light on the state-of-the-art of existing BES dashboards globally. We suggest that dashboard designers and academics could benefit from reviewing and exploring the characteristics of BES dashboards. With the advancement of internet technologies, there is now an opportunity to make use of a much broader range of design options of BES dashboards to support planning. We hope that the conceptual framework of BES dashboards put forward in this study can help future BES dashboard researchers and creators to develop targeted, useful and evidence-based dashboard applications for the respective fields of application in the future. Regardless of the level of technological advancement, however, the actual impact of BES dashboards will always be strongly influenced also by the kind and process of its integration in the informal and formal planning and decision-making processes.

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ORCID

Maria Riffat http://orcid.org/0000-0001-6936-5452
Christian Albert http://orcid.org/0000-0002-2591-4779

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