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Smarter greener cities through a social-ecological-technological systems approach☆

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Smart city development is expanding rapidly globally and is often argued to improve urban sustainability. However, these smart developments are often technology-centred approaches that can miss critical interactions between social and ecological components of urban systems, limiting their real impact. We draw on the social-ecological-technological systems (SETS) literature and framing to expand and improve the impact of smart city agendas. A more holistic systems framing can ensure that 'smart' solutions better address sustainability broadly and extend to issues of equity, power, agency, nature-based solutions and ecological resilience. In this context, smart city infrastructure plays an important role in enabling new ways of measuring, experiencing and engaging with local and temporal dynamics of urban systems. We provide a series of examples of subsystems interactions, or 'couplings', to illustrate how a SETS approach can expand and enhance smart city infrastructure and development to meet normative societal goals.

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Introduction

Mounting pressure from urbanisation and critical challenges of the Anthropocene have elevated cities to the top of the global political agenda [1]. With the majority of humanity living in cities and through these drive global economies, carbon emissions, and energy consumption [2], the future design and development of our cities will have profound implications for human wellbeing and global sustainability [3,4•]. Urbanisation is rapidly transforming our world into an urban planet [5•], and the technological transformation towards digitalization occurring in and beyond cities advances even faster. This technological shift offers new ways to generate large amounts of detailed, spatial and temporal information through sensor and digital infrastructure, opening doors to real-time automation, communication and governance. Digital technology also provides new ways for people to understand and engage with their urban surroundings through widely available Internet of Things (IoT) and

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Information and Communication Technology (ICT) solutions. IoT and ICT form a backbone of 'smart city' development [6•] and are increasingly used to control transportation flows, monitor energy use and optimise production, enhance monitoring for security, assess infrastructure performance, monitor weather and climate impacts and many more [7•,8•]. However, these new uses also raise many systemic, social (ethical, governmental) and ecological concerns that limit the progress towards achieving sustainability goals [8•,9•,10,11].

In this article, we propose to use a systems lens for articulating interactions between 'smart city' development and urban sustainability. We use systems thinking to position the 'smart city' within the connective tissue of the urban system [4•]. We hypothesise that a holistic system approach is more effective at identifying mounting concerns, revealing and providing opportunities to shift and negotiate the intended and unintended consequences of existing and emerging relationships between technology, society and ecosystem management compared with solely 'smart cities' approaches.

To illustrate this point, we foreground the article by illustrating the weak connection between 'smart' and sustainable urban development through a review of recently published topical literature. Then, we highlight the underutilised potential of smart technology in advancing urban systems scholarship. The next section elaborates in detail an urban systems framework by breaking it down into three subsystems: social, ecological and technological, and introducing the concept of dual subsystem relationships. Next, we apply this concept to explore the 'smart city' development to uncover its blind spots and present the added value of fostering connections between the subsystems. We end with presenting examples of *smarter* greener initiatives that merge subsystems while addressing the issues of injustice, inclusivity, nature-based solutions, ecological resilience, wellbeing, sense of place and ecosystem management.

Our ambition is not to conduct a systematic literature review but to focus on how holistic system thinking can challenge and add to the current, primarily from the last three years, smart cities literature. We also bring together different lines of interdisciplinary thinking on urban systems to outline the three conceptual subsystems interactions, relying on additional literature from environmental justice, urban ecology, ecosystem services and related literature in sustainability science.

Smart and sustainable disconnect and the systems framing

The *smart city* is one of several approaches that currently informs the philosophy and prioritisations in urban development [12•]. Whether smart, just or green, each approach is characterised by its hyperfocus on a particular aspect, either technological, social or ecological. We argue that a narrow focus inevitably and unintentionally overlooks other interactions in much bigger, interconnected urban systems, masking opportunities and negative impacts.

Much of the development under the label of 'smart cities' has been techno-centric, siloed, and deeply focused on technological rollout, increasingly disconnecting it from parallel discussions about social and ecological sustainability [7•,9•,13]. This disconnect has generated a number of concerns, including reinforcing injustices [14] and governance models driven by neoliberal ideology [15], and neglecting the critical role of urban ecosystems and nature-based solutions [16–19].

Therefore, we appeal to all urban paradigms, especially smart cities, to widen their focus and aspirations to support real transformations through a plurality of interconnected social-technological-ecological solutions [20–23]. For example, smart city development needs to explicitly and critically include nature and people by connecting technological transformation with the ecology and use of urban green infrastructure [24,25], and by shifting traditional technocratic planning practises towards more democratic models of governance [14,22]. Nature-based solutions also need to support social aspirations of inclusivity, equitability and wellbeing [19]. Thus, a systems approach needs to connect social, ecological and technological agendas [4•,26•], identify trade-offs and synergies among approaches and disparate efforts [27,28], and serve as a conceptual lens to critique [22] and thereby expand the city's focus and actions.

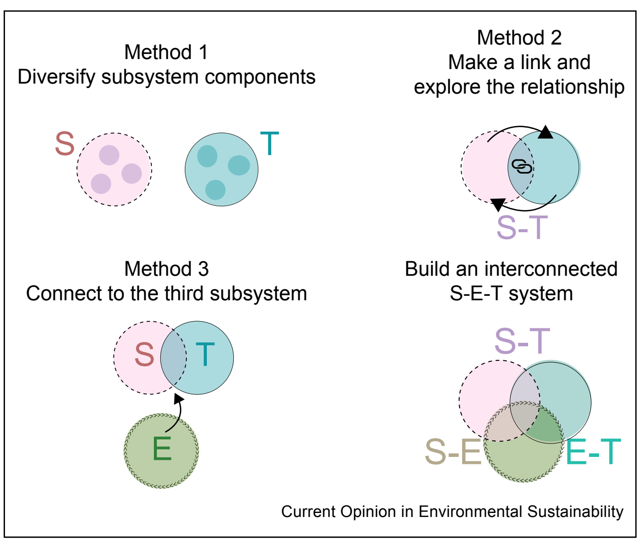
We also posit that 'smart' technology, IoT and ICT in particular, offers an opportunity to enable a better understanding of the complex dynamics that shape cities in real-time and across multiple temporal and spatial scales. Smart solutions can bring social and ecological aspects into dominant infrastructural and technological investments in new ways, through for example participatory engagement or ecological monitoring, enabling cities to foster much more holistic approaches towards sustainability. Examples are investments in smart public transit that are coupled with green corridors, targeted in low income and minority neighbourhoods most in need, and governance practices that include local communities in decision-making [23].

Urban S-E-T systems and their couplings

Recently, social-ecological-technological systems (SETS) research has gained traction as a new approach to understand urban complexity. It holistically brings together over two decades of interdisciplinary work on social-ecological systems (SES) and socio-technical systems (STS) to advance interdisciplinary and critical systems approaches to urban sustainability and resilience [4•,26•,27,29–31]. We see the main utility of the framework in its ability to conceptualise and connect different topics, processes and features, not in providing a universal analytical or methodological framework. The SETS conceptual framework is a heuristic model that provides a critical starting point for positioning and connecting different understandings of different aspects of complex systems. The framework emphasises the dynamic interactions, relationships and interdependencies between a broad array of urban subsystems: social-cultural-economic-governance systems (Social), climate-biophysical-ecological systems (Ecological), *and* technological-engineered-digital-infrastructural systems (Technological). One of the core efforts is revealing how S–T, S–E, and E–T relationships interact to drive and respond to patterns and processes emerging across S-E-T system dynamics at multiple spatial and temporal scales. What is the primary focus chosen for each S, E, and T domain as well critical interactions will depend on the question being asked, key actors, study location, and other factors.

In the SETS framework, a binary connection or a coupling can be understood as a relationship or an overlap between two components from two different subsystems:

Figure 1



A graphical representation of connecting S-E-T subsystems and SETS framing methodology. Each colour-coded circle represents a subsystem: social-cultural-economic-governance (S, in pink, with dashed border), technological-engineered-digital-infrastructural (T, in blue, with solid border), and climate-biophysical-ecological (E, in green, with '>' border). The top panel illustrates method 1, diversifying subsystem components and method 2, an establishment of a binary cross-system coupling and exploring its dynamic relationship, seen as an overlap or a link between S and T. The bottom panel demonstrates method 3, an expansion of a binary coupling to the third subsystem (e.g. including E into S–T coupling). In result, this creates two new binary cross-system couplings — S–E and E–T, and a place where all S-E-T subsystems overlap, creating a bigger interconnected system.

S and E, E and T, or T and S, as shown in Figure 1. This relationship can take on many forms from hidden to weakly or strongly pronounced, from parallel to asymmetric or mutually co-evolving relations. For example, an E–T coupling can be the impact of urban sprawl (T) on degradation of natural habitat and biodiversity (E). Services provided by ecosystems (E) for the benefits of human population (S) such as water filtration and food production exemplify E–S couplings. The Internet and social media are technologies (T) that facilitate global interactions and communication between people (S), and can be seen as S–T couplings. Finally, a holistic approach would lie at the overlap of all S-E-T subsystems (see Figure 1), for example a citizen-led initiative (S) that waters urban trees during droughts (E) informed by an online platform and sensor-based data (T).

The SETS framing helps to position smart city initiatives more holistically in three different ways, illustrated in Figure 1: (method 1) by differentiating and further subdividing the content of social subsystem, seen as building blocks or 'parts' (i.e. governance, justice, inclusivity, safety, sense of place; (method 2) by looking into dynamic relationships between parts, for example between top-down and bottom-up governance models that S–T processes reinforce or challenge; and (method 3) by looking for connections to the third absent ecological subsystem. These steps will be repeatedly followed in the subsequent sections.

The way SETS is used matters. It can mask complexity of urban systems or reveal simplification of urban agendas, empower or overlook marginalised voices [25,32,33]. Although the potential of using SETS in reductionist terms exists, in this work, SETS has been a guiding heuristic for an open and inclusive exploration of the dimensionality of smart agendas which led us to identify unacknowledged linkages. SETS as we use it, is informed by multiple ways of studying features and dynamics of the 'system', and plural ways of synthesising insights. The primary points are making connections and examining interactions across multiple domains and scales, between actors and components of systems. There is always a possibility of building a larger, more comprehensive yet manageable systemic view on sustainability issues which, in effect, asks for a wider interdisciplinary and transdisciplinary effort and more diverse perspectives. Here, we invite supporters of all city agendas, especially smart cities, to make such an effort.

Social-technological (S–T) couplings

'Smart' governance

Modern cities already utilise many smart technologies that are of a social scope. In many countries, online platforms offer opportunities to participate in budgeting, mapping, voting, polling, idea generation and citizen science [34–36]. Viewed from the SETS perspective, these become connectors of social and technological systems which provide new vistas for engaging with urban infrastructure, from influencing how it is governed to co-designing what it is made of.

However, citizen engagement digital tools may also exacerbate existing inequalities, for example by neglecting the importance of representation and agency in governance [34,37] and reproducing the so-called digital divide [38]. The smart agenda is criticised for overlooking the role of existing governance arrangements, the multiple values of nature and social aspects such as justice, inclusivity and safety. For example, Fincher *et al.* [39] demonstrated that citizens from marginalised communities in the City of Melbourne do not feel empowered despite being engaged in place-based community design processes. Online and open tools also create concerns about data storage and access, allowing for manipulation of data that favours corporate and technocratic interests over wider societal values [25,40]. This tension can further undermine democratic decision-making in the smart city agenda [21,41].

From the governance perspective, smart S–T processes could be grouped into two categories. Those which feed into and enrich the existing governance arrangements and those which attempt to influence deeper power relationships within society. In the former, communities are enabled to voice social opinions and needs *through* government officials, such as planners and managers who engage with citizens in dialogues regarding their local environment [41]. In the latter, smart S–T processes aim to distribute power by granting public judgement real agency in decision-making outcomes [37]. At the heart of these S–T interactions lie structural social inequalities which still constitute a blind spot of the smart agenda and pose a threat to the diversity of experiences and value systems among urban residents, for example through 'standardizing' indicators of urban space with technological solutions [25,32].

Therefore, it is important to continuously develop, test and discuss how technological tools contribute to or diminish the added social value. This requires a thorough consideration of their design, scope, data quality and outcomes as well as a comprehensive examination of *who* has the legitimacy to decide what counts as data or knowledge, to plan and steer the participation and frame a S–T process [14,15,32,34,37,42].

SETS perspectives and critical reflection

To follow the methodology from the Section 'Urban S-E-T systems and their couplings', first, one could add a sense of place concept to the social subsystem (method 1) and find that technology can enrich senses of place by providing a wealth of information about local and remote places through sharing experiences and enabling social relations to be maintained from a distance [43]. Conversely, technology can diminish senses of place by diverting attention from physical places to 'virtual elsewhere' leading to the erosion of social relationships and facilitating the spread of false information [44].

Second, the SETS framework can be useful in governance to uncover especially structural power relations, rules of the game and actors, as shown for a S–T process of automatising urban green infrastructure [40]. Such an integrated assessment of SETS couplings opens for critical questioning of the role of the state and paradigms of ownership and allocation of resources frequently shaped by neoliberal and technocratic approaches to the governance of smart cities [15,25]. This type of re-thinking could shift the discourse from neoliberal drivers of transformation to more systemic drivers towards a good Anthropocene and more just approaches to climate resilience (method 2) [4•]. For example, the city of Melbourne case study demonstrates the shift between authority-led to society-led governing models by empowering community action and engagement and connecting diverse knowledge systems, where residents 'own' and are the primary driver of the initiative [45,46] (method 2).

Third, the SETS framing offers an insight that S–T couplings are inherently connected to the sense of place, life worlds and ecological subsystems. This insight is increasingly attracting the attention of governance studies of nature-based solutions and urban ecosystem services [47] but smart development still needs to better connect to how people feel about their local environment of which local plants and animals are part of (method 3) [48].

Ecological-technological (E–T) couplings

Cities are a display of how built and natural environments interact, compete for space, co-exist and share resources. This relationship presents an ongoing challenge for global sustainability. Seen through a SETS lens, relations between nature and the built environment are examples of E–T couplings. Other technological components such as sensors, internet, digital, and information technologies foster an important interface for ecological subsystems. They enable us to observe and understand the natural world, from the smallest building blocks of life to large-scale planetary processes thanks to microscopes, cameras and remote sensing from space. In this section, we inquire how E–T couplings are pronounced in 'smart' development by looking into environmental monitoring and hybrid infrastructure. Then we suggest how these E–T couplings can be further connected to other aspects such as ecological resilience of green infrastructure, adaptive ecosystem management and stewardship.

Smart environmental monitoring

Environmental monitoring is one of the core pillars of smart development [6•] and an example of E–T coupling.

Sensor-based observations (T) provide information on the natural world in the form of variables that underpin the understanding about the state and dynamics of nature (E). The current understanding is that cities will continue to grapple with environmental challenges such as pollution, heat waves and flash flooding [49], which are hyperlocal and short-lived due to heterogeneity of urban environment [50]. The solutions to those, nature-based or otherwise, require further knowledge about unique local contexts. Monitoring of green infrastructure is much needed in cities because suboptimal environmental conditions of urban habitat lead to high mortality rates of urban trees, low lifespans and decreased quality of ecosystem services, relative to its rural counterparts [51]. Smart technology holds the promise of quantifying those environmental phenomena and the context with sufficient degree of detail [52]. While there are many examples of implementing dense networks of sensors for environmental monitoring in cities worldwide ([53] for example see 'smart Santander' [54]), where very little is said about their benefits for urban nature [6•,9•,55]. We interpret this as a consequence of prioritising technological rollout over ecological experimental design, which limits the usability of technology for supporting environmental management.

Smart, hybrid and S-E-T infrastructures

Smart infrastructure merges digital and already *existing* physical infrastructures to enable faster decision making, data-driven optimisation and redistribution of resources, by using sensor-based information in real-time [6•]. Therefore, we conceptualise smart infrastructure as a T–T coupling that connects digital technology (T) with built environment (T). However, smart infrastructure shows a limited degree of connectedness to social and ecological subsystems. This is the result, we argue, of focusing mainly on the existing grey subset of urban infrastructure, leaving the green counterpart circumvented [7•,13].

In contrast, hybrid infrastructure advocates for the 'right' level of green–grey integration that fits into site-specific context with the aim of providing the optimum level of benefits [56]. The continuous gradient between the grey and the green has been recognised, conceptualised and further detailed [57]. Applying the SETS framework, we conceptualise hybrid infrastructure as an E–T coupling because it integrates nature (E) with built environment (T) (see green facade project in Vienna, https://50gh.at/). Thanks to its focus on green, the hybrid infrastructure has been able to make diverse connections between ecological and social subsystems by contributing to biodiversity conservation [58], recreation [59], social cohesion [60], sense of place [61], while maintaining its technological qualities such as cost-effectiveness and reliability [56]. Interestingly, the hybrid infrastructure tends to lack diversity in the technological systems and overlooks the potential of digitalisation and IoT/ICT (method 1) [7•].

SETS perspectives and critical reflection

From the SETS perspective, there is a clear need for a more detailed understanding of the role of the ecological subsystem (method 1). Namely, to go beyond environmental smart monitoring and move towards a new E–T process of maintaining ecological functions and healthy urban nature. This shift requires the E–T smart process to expand to the third social subsystem and involve owners in acts of care (method 3). Later, we introduce a holistic SETS case study where sensor-based environmental monitoring was used to successfully support top-down urban forestry management.

Either green, grey, blue, smart or digital, urban infrastructure, as whole, provides services to human and non-human residents. These infrastructures act as an interface between social and ecological subsystems, making them an interconnected and intertwined S-E-T system [22,28]. Although green and smart urban agendas are motivated by the same goal of providing services by increasing the performance and functionality of existing urban infrastructure, they represent different approaches of connecting S-E-T subsystems — one integrating green, another digital into the grey (method 2). This results in a disconnect between green-digital agendas. We argue that bridging the green-digital gap offers an opportunity for smart city development to reconnect with urban sustainability and to engage users and makers of urban infrastructure through several S–T processes that we described above.

Social-ecological (S–E) couplings

Systems perspective on people–nature interactions

Largely absent from the smart city agenda, social-ecological couplings encompass interactions between people and the natural world. Social-ecological studies have taken an interest in different types of interactions, what motivates them and what they mean for people and the ecosystems we are part of. The sheer density of the social and technological subsystems in urban areas has obscured the fact that people still depend on nature and functioning ecosystems for their wellbeing [62]. This dependence goes beyond health and economic benefits [63] — diverse studies have shown how nature constitutes a part of our identities, worldviews, cultural heritage and everyday experiences [64]. The tradition of social-ecological studies that has fed into SETS has focused on the role of people in nature, and how experiences and multiple meanings shape knowledge and agency [65]. One of the most researched S–E connections relates to the adaptive co-management of ecosystems and the associated learning that occurs through improved understanding of the feedbacks between human and natural processes [66,67]. Early approaches took a structural perspective, drawing heavily on Ostrom's work on institutions and their role in mediating human–nature interactions [68,69]. This approach has been complemented and enriched by more actor-focused work emphasising the multiple subjective mediators of human-nature experiences and looking in-depth at phenomena and conceptualizations like sense of place [70,71], relationality [72], social movements and networks, co-governance and stewardship [65,73].

The most developed concepts that contribute to the understanding of S–E couplings have been *ecosystem services* and *nature's contribution to people*, frameworks that have evolved with the general understanding of the different ways in which people benefit from and relate to nature [64,74]. At its core, the ecosystem service framework positions human *wellbeing* as the universal, many-faceted connector between people and nature. Wellbeing can be material or immaterial, be extended to the non-human, focus more specifically on health or livelihoods or look to biocultural connections and identities. Furthermore, it is interwoven with knowledge and learning — knowledge guides actions to improve wellbeing, and experiences through those actions in turn keep knowledge alive and evolving. Connected to this core set of feedback loops are multiple lines of more specific studies on motivations, values, worldviews, lifestyles, enabling or prohibiting systemic circumstances, equal opportunities and power issues, ownership, mandate and agency. And this melded with an understanding of nature as a complex adaptive system itself, and many of the features of direct interest to people emerging from dynamic couplings between humans and nature rather than biophysical 'objects' [72].

SETS perspectives and critical reflection

Recent developments in urban ecosystem service and urban environmental justice research are establishing justice, equity and power as another lens for evaluating E–S couplings [75], which further diversify the E–T system perspective (method 1). Reconciliation and consolidation of ecological-environmental and social justice, and the means through which they are enacted have raised the need to pay attention to recognition, procedural and distributive justice across different spatial and temporal scales [76].

One example of supplementing and altering the relation in an S–E coupling (method 2), such as ecosystem services, is shifting the emphasis of 'knowing' — observing and making sense of the world from the outside — towards a matter of 'being-in-the-world' through embodied experiences [77].

From an S–E perspective, technology often takes the role of a mediator of the exchange between people and nature. This may lead to undesirable consequences such as perceived disconnect [9•,78] and loss of ecological literacy [79]. SETS framework encourages the E–S perspective to expand the system (method 3) by recognising that smart technology also offers new opportunities in relation to citizen science, conservation planning, monitoring and management of natural resources [43,80,81•,82–84]. For instance, human-nature relations and experiences can be better understood with new technology such as virtual reality, multisensory and wearable sensors that provide local data of human response to environmental exposure in real-time [85,86]. Moreover, visualisations and sonification of data can make our dependence on nature more visible and relatable [87]. In its digital form, technology can become a link between multiple E–T and S–T processes we described above, increasing the connectedness within the tissue of urban systems.

Discussion — smarter cities through the lens of subsystem couplings

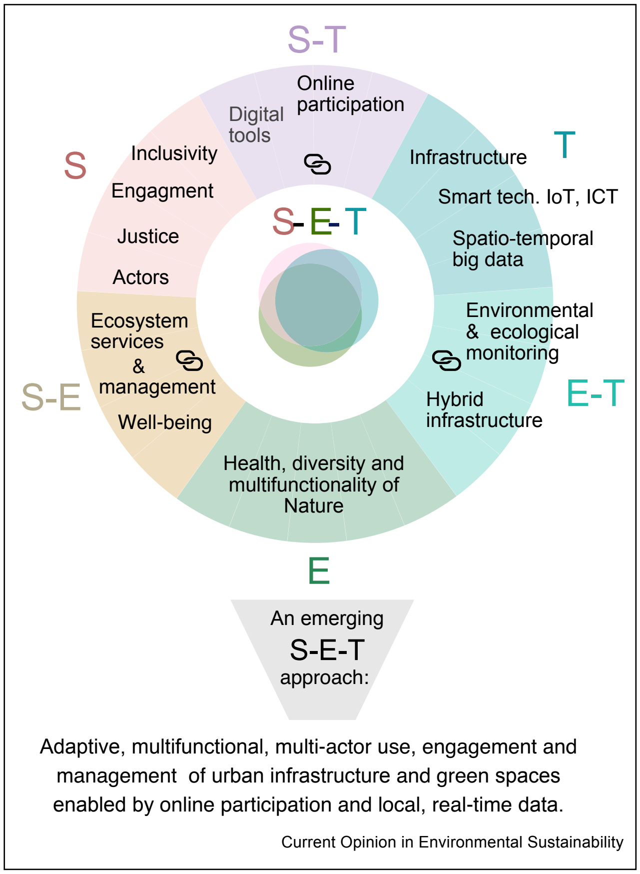
In the previous sections, we showed how smart, green and social agendas interact or evolve independently. To establish stronger connections between smart city development and sustainability, we suggested a methodology that begins with identifying binary smart SETS couplings followed by three ways of making the couplings more comprehensive: differentiating the number of considered parts, examining in depth relationships between them, and seeking connections to the third absent subsystem.

Expanding each binary S-E-T cross-system coupling to connect also to the third subsystem is a first step towards merging the different focal areas and critical discussions into a holistic perspective on the urban system. Figure 2 summarises this by bringing all three binary couplings together into a single picture. Outcomes of such SETS analysis are holistic approaches that utilise opportunities such as bridging the green-digital gap and connecting deeply and with care to the social subsystem. This might include adaptive, multifunctional, multi-actor use, engagement and management of urban infrastructure and green spaces enabled by online participation and local, real-time data. To demonstrate and discuss the applicability of the approach we present two urban initiatives that follow what we have outlined above.

Smarter greener initiatives — weaving smart technology into interconnected SETS

Using smart technology to enhance the scale and the quality of social engagement with urban nature mends the disconnect between green and digital infrastructures, one of the gaps identified earlier through the SETS framing. A number of projects, framed as smart forests [46,88], digital urban nature [55], internet of nature [81•], and smarter ecosystems [89], together provide a comprehensive view on this notion and include a wide range of empirical examples therein.

Figure 2



A graphical summary of SETS analysis for 'smart city' development. It displays examples of all three binary cross-system couplings and their components, presented in this paper, around the core of a highly integrated S-E-T system. Lists within each color-coded petal section are open and should be expanded accordingly to a particular need and focus. At the base is an example of an outcome that emerges from the SETS analysis. It is a holistic approach that mobilises all S-E-T components and many of their couplings.

Here, we highlight two case studies that support top-down and bottom-up environmental management practises respectively. Smarter greener initiatives use smart and satellite infrastructure to quantify the health and diversity of urban trees and the stressors that they are exposed to, such as droughts and heatwaves ([82,89] for case studies see Green City Watch, TreeMania and Climasens therein). The digital tree inventories and sensor-based soil data provide real-time information about when trees require human assistance. These companies provide technological means to improve the flow of information between nature and people which increases the effectiveness of urban forest management, ensuring that trees thrive and their ecological function is preserved even in the challenging conditions of urban habitat. From the SETS perspective, this approach brings together components from all S-E-T subsystems, and has the potential to support a system that fosters awareness, care and accountability with the aim of enhancing ecological resilience and supporting urban biodiversity in cities.

Potentially complementing this top-down forestry management, *Melbourne urban forest visual* provides an example of an initiative that supports more diverse social involvement. It utilises an on-line digital platform to engage citizens in discussions of ecosystem services through an invitation to explore the 'big tree data' of the publicly managed urban forest. The platform monitors the health and predicted life-duration of Melbourne's approximately 70 000 publicly owned trees. This E–T system situates every municipal tree on an interactive map with rich place-specific data, consisting of current tree diversity, tree canopy cover, and health performance of Melbourne's urban forest. What makes it a SETS is that the Urban Forest Visual gives residents a tool to visualise and better understand the diverse values of the city's urban forest. S–T interactions on the platform include resident ability to track the progress of the implementation of neighbourhood tree planting plans. Importantly, residents have also been given an opportunity to celebrate and mourn the current transformations in the urban forest by sending a direct email to each publicly owned tree. This has allowed the City of Melbourne to collect information from citizens regarding their personal social-ecological perceptions of trees and engage with the diverse and subjective appreciation for trees in Melbourne. Since the strategy's implementation in 2012, citizens have engaged in the planting of over 3000 trees annually. A diverse swath of citizens is now actively engaged in the implementation of the initiative by contributing critical urban tree data and participating in stewardship activities as citizen urban foresters of existing and newly planted trees, contributing to a stronger local attachment.

Seen through the SETS lens, we argue that the success of these greener and smarter initiatives is partly due to strong links between all S-E-T subsystems that work in concert to provide a holistic and multifunctional service and creates new opportunities for sustainable development.

Conclusions

We appeal to smart cities planning and investments to adopt a more holistic urban SETS lens to position and connect the initiatives to a wider range of social and environmental issues. Otherwise, ignoring fundamental interactions and dynamics can produce unintended consequences or limit the efficacy of smart technological solutions to deliver services and benefits to urban residents. Although smart city programs have invested in technology as a solution to a variety of urban challenges, they still remain an underutilised, underproblematised resource, and their features and impact are underexplored for advancing the ecological and social needs of cities. A core argument from the SETS literature is that a smart initiative is 'smarter' if it connects across all S-E-T subsystems including especially E–T interactions – reconnecting smart development to the biosphere, and S–T interactions – modifying existing governance models and bringing resident visions, actions and priorities into urban decision-making. Bringing SETS thinking to smart city initiatives can mean, for example, supporting grassroots stewardship initiatives and adaptive management through technology and thus including ecosystem needs into technological solutions (E–T section), while also bringing IoT/ICT technology into the way we incorporate diverse voices and perspectives through codesign and co-development (S–T section). The SETS perspective also offers a way for connecting to, for example, the discourse on ecosystem services and nature's contributions to people. With wellbeing at its core, it can inform which, and in what ways, smart technological solutions can improve the interactions between people and nature, for example, by supporting co-governance and stewardship initiatives (E–S section).

We encourage smart city development, through SETS thinking, to widen its horizons and see itself as a part of a much bigger and complex urban system in which it operates and interacts, knowingly or not, with other ecological and social subsystems. Taking such a broad perspective, we argue that the convergence of interdependent social, ecological, and technological subsystems, integrated to envision and promote urban futures, will allow for transformative change in cities that increases sustainability.

Contributions

AB, MSM, TM and EA led the conceptual development and framing of the paper. All authors contributed to the development of key principles, literature review, case study development, writing and editing.

Conflict of interest statement

Nothing declared.

Data availability

Data will be made available on request.

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Declaration of Competing Interest

The authors report no declarations of interest.

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