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ANALYSIS

Guiding cities under increased droughts: The limits to sustainable urban futures

Roger Cremades[a,b,*], Anabel Sanchez-Plaza[c], Richard J Hewitt[d,e,k], Hermine Mitter[f], Jacopo A. Baggio[g,h], Marta Olazabal[i], Annelies Broekman[c], Bernadette Kropf[f], Nicu Constantin Tudose[j]

[a] Wageningen University and Research, Leeuwenborch Building, Hollandseweg 1, 6706, KN, Wageningen, the Netherlands
[b] Climate Service Center Germany (GERICS), Helmholtz-Zentrum Hereon, Fischertwiete 1, 20095 Hamburg, Germany
[c] CREAF, Centre de Recerca Ecològica i Aplicacions Forestals, E08193 Bellaterra Cerdanyola de Vallès, Catalonia, Spain
[d] Observatorio para una Cultura del Territorio (OCT), Calle del Duque de Fernán Núñez 2, 1, 28012, Madrid, Spain
[e] Informational and Computational Sciences Group, The James Hutton Institute, Craigiebuckler, 8, Aberdeen, AB15 8QH, Scotland, UK
[f] Institute for Sustainable Economic Development, Department of Economics and Social Sciences, University of Natural Resources and Life Sciences, Vienna (BOKU), Feistmantelstrasse 4, 1180 Vienna, Austria
[g] School of Politics, Security and International Affairs, University of Central Florida Orlando, FL, USA
[h] National Center for Integrated Coastal Research, University of Central Florida Orlando, FL, USA
[i] Basque Centre for Climate Change, BC3, E-48940, Leioa, Spain
[j] National Institute for Research and Development in Forestry "Marin Dracea" (INCDS), 077190 Jud, Ilfov, Romania
[k] Transport, Infrastructure, and Territory Research Group (tGIS), Geography Department, Faculty of Geography and History, Universidad Complutense de Madrid (UCM), C/ Profesor Aranguren, s/n, Ciudad Universitaria, 28040, Madrid, Spain

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ABSTRACT

Climate change is likely to increase droughts. The vulnerability of cities to droughts is increasing worldwide. Policy responses from cities to droughts lack consideration of long-term climatic and socio-economic scenarios, and focus on short-term emergency actions that disregard sustainability in the connected regional and river basin systems. We aim to explore the dynamics of the water-energy-land nexus in urban systems suffering increased climate change-related droughts, and their implications for sustainability. We complement a case study with a literature review providing cross-regional insights, and detail pervasive knowledge, policy and ambition gaps in the interaction between cities and droughts. We show that water availability with low emissions, without compromising ecosystems and with low costs to society, poses a local-scale limit to sustainable urban growth, a new concept delineating the limits to growth in cities. We conclude that urban and river basin planners need to institutionalize transparency and cross-sectoral integration in multi-sector partnerships, to consider long-term land use planning together with water and energy, and to apply integrated climate services to cities. Our study reveals the importance of including land, water and energy in long-term urban planning, and to connect them with the county, region, river basin and global scales.

1. Introduction

Climate change is likely to increase drought duration and intensity (Vicente-Serrano et al., 2020; IPCC, 2013), while widespread urbanisation processes contribute to increased urban water demands. In this context, the vulnerability of cities to droughts is increasing in many world regions (Wang et al., 2020; Sudradjat et al., 2020; Elmqvist et al., 2019; UNDESA, 2018; UNISDR, 2013). The millennium drought 2000–2009 in Australia, California's 2012–2016 drought, and the countdown to "day 0" exhaustion of the water supply in 2018 in Cape Town, are all clear examples of the complex relationship between urban systems and water demand/supply, and showcase the different ways in which cities have dealt with water shortages: mainly by imposing severe restrictions in urban areas and diverting environmental water flows for

* Corresponding author at: Transport, Infrastructure, and Territory Research Group (tGIS), Geography Department, Faculty of Geography and History, Universidad Complutense de Madrid (UCM), C/ Profesor Aranguren, s/n, Ciudad Universitaria, 28040, Madrid, Spain
E-mail address: roger.cremades@wur.nl (R. Cremades).

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human use (Simpson et al., 2019; Lund et al., 2018; Low et al., 2015). (See Figs. 1 and 2.)

Here we address the following overarching question: how can changes in available water under climate change be translated into attainable options for long-term sustainability in urban systems? This question has no clear answers yet, and it triggers further questions about the mutual implications between (i) the cross-scale and cross-sector interactions and related trade-offs within the water-energy-land nexus, emerging from the interactions between water demand from land uses, water supply under climate change, and energy demand to make more water available, (ii) the feedbacks between urban governance and surrounding regions, and (iii) whether the Sustainable Development Goals (SDGs) can be achieved without limits to growth in urban systems (Nilsson et al., 2016). To respond to these questions we will combine several methodological approaches: we will obtain local knowledge from transdisciplinary knowledge co-creation in a case study, combine it with global knowledge from a literature review, and then explore the emerging information through the lens of the water-energy-land nexus. Combining these research methods will allow us to provide new policy recommendations helping cities to achieve sustainable futures under increasing droughts.

While sustainability research has traditionally addressed similar questions by focusing on specific entities (i.e. cities, hydropower installations, water sector stakeholders, etc.), understanding the interaction between cities and droughts requires a focus on the complex system-level interactions between entities. It requires us to see cities in the context of their relations with water sources, and how urban land use and water availability interact with global change. In this context, we define drought as an existing or predicted imbalance between urban water supply and urban water demand.

Research on cities and climate change is still limited: it lacks sound analyses of the long-term interactions between droughts, urban water systems, urban land use, and their regional context of ecosystems, institutions and economic sectors (Hagenlocher et al., 2019). Correspondingly the science-policy interface for the particular case of cities and droughts is weak: the problem is still receiving very limited attention by policy makers (de Waegemaeker et al., 2016; 2016; Obringer et al., 2016; 2016). Until recently, the problem was not considered a priority in many middle-income (Marks, 2019; Simpson et al., 2019) and high-income countries. For instance, drought-related policies in the European Union have traditionally been scattered and never reached the status of a goal-setting *directive* like in the cases of water and of floods; instead, further communications and technical guidance complementing the Water Framework Directive just recommend developing "supplementary" drought management plans (Hervás-Gámez and Delgado-Ramos, 2019; Stein et al., 2016; European Parliament, 2007). However, the events in Cape Town, California and Australia, and several droughts between 2016 and 2019 in Europe (García-Herrera et al., 2019; de Brito et al., 2020), highlighted the relevance of droughts across world regions.

A clear sign of important knowledge gaps and of a weak science-policy interface for droughts and cities is that there are very few

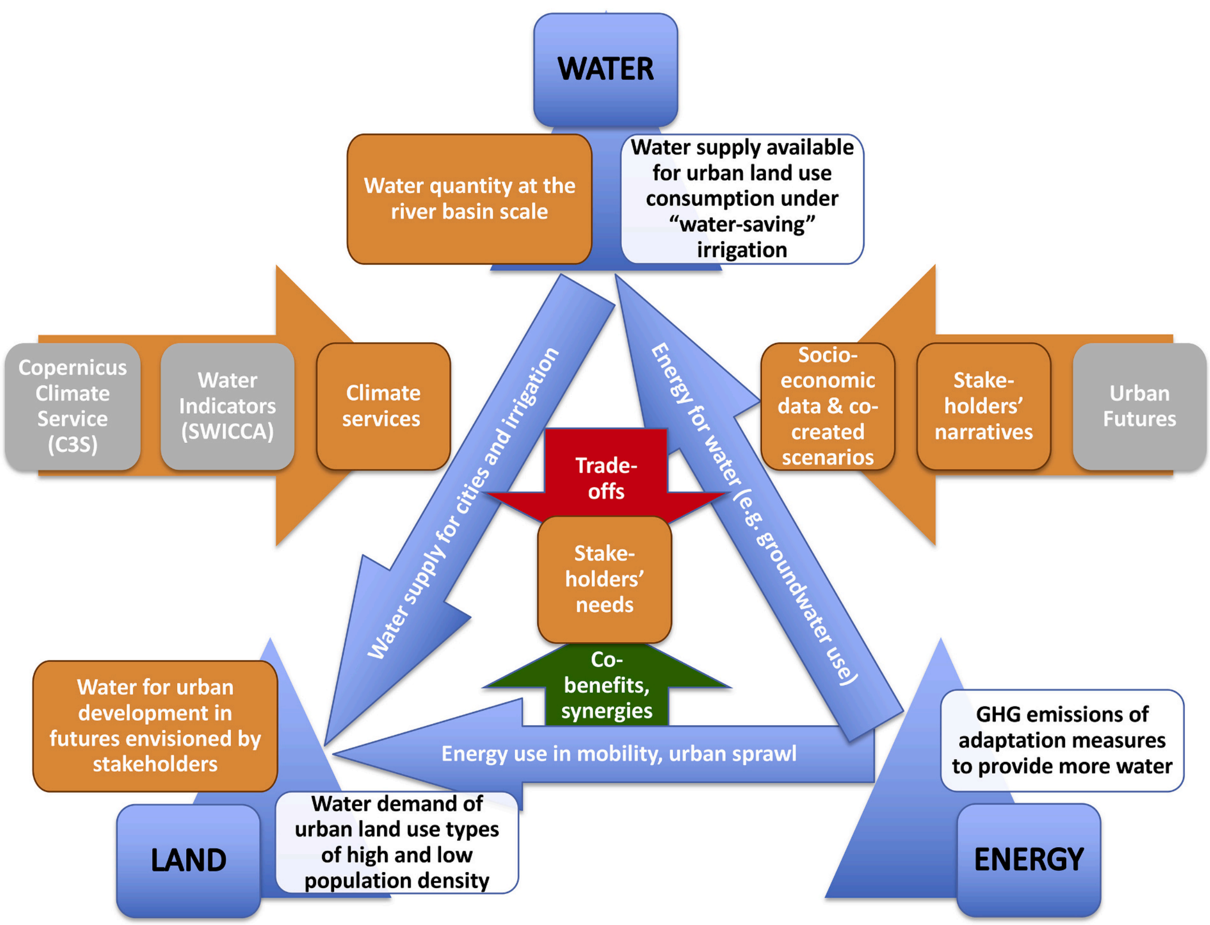

Fig. 1. Graphical abstract of the water-energy-land nexus applied to cities under increasing droughts related to climate change and to urban land use growth, and in particular to the case study of Benidorm (Spain) in relation to the availability of the Service for Water Indicators in Climate Change Adaptation (SWICCA) data in the European Union's Copernicus Climate Change Service (C3S) (see Section 5.2 below for details of these services; see Lottle et al., 2017). White boxes indicate the assessment of aspects related to urban sustainable futures, orange boxes indicate climate services, and blue arrows links between nexus components. (Source: after Cremades et al., 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Fig. 2. The left panel locates the context of the case study area in the Eastern Mediterranean and Southern Europe; the middle panel locates Benidorm with a blue square within the Valencian autonomous community; the right panel shows the Mediterranean Sea and the skyscrapers in Benidorm, with a golf course with lakes near a hotel in the coastal hinterland. (Sources of left and middle panels: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Source of photograph: the authors). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

integrative tools, projects, policies and institutions that try to jointly address the interdependencies between the most important uses, namely biodiversity, agriculture and urban systems, and to analyse the effects of mid-to-long-term plausible climate and socioeconomic scenarios with co-creation at the local scale (Cremades, 2017; Johnson et al., 2019; Gober et al., 2016). Additionally, research shows that policy responses at the local scale lack consideration of long-term effects and focus on short-term emergency actions, and that this problem is pervasive across world regions (Buurman et al., 2017; Carmona et al., 2017).

To study the dynamic relations behind urban sustainability under increased droughts, it is relevant to focus on the interactions altering the balances between water supply and demand. The most important such interactions occur between urban land use growth, which increases water demands, and climate change, which endangers supply in those places where it causes more variability, more evapotranspiration, and or lower precipitation.

In addition to facilitating the analysis of increasing water demand due to urban land expansion, and of the limitations of water supply resulting from climate change, the water-energy-land nexus approach also enables analysing the implications of land and water on energy use. The water-energy-land nexus thus provides a way to study trade-offs and maladaptation in cities and the water sector (Cremades et al., 2016; Cremades et al., 2019). The governance of the water-energy-land nexus, its related institutional dynamics, and its policy implementation, are characterized by mismatches in space, time and scope. These mismatches include siloed policy-making (between land and water policies, between economic growth and environmental quality, i.a.), and disconnection between levels of governance contributing to inexistent or unclear specifications for nationally-endorsed global policies (e.g. the SDGs) at the local scales — neighbourhood, municipal or metropolitan. These mismatches contribute to ambition and policy gaps in planning, which calls for research urgently producing further evidence and guiding science-based integrated and coordinated policy developments for sustainability.

In this context, we address prominent gaps in the knowledge and policy dimensions of droughts in cities. We discuss the demand side of water in relation to urban land use planning, the supply side of water in relation to climate change, and the implications of the emerging imbalances of supply vs. demand of water on the limits to growth in cities. Additionally, we discuss the associated energy consumption, its consequences, and its costs.

In the context of the signalled gaps, the overall aim of this article is to understand the policy challenges created by the dynamics of the nexus between water, land and energy in cities suffering increased droughts related to climate change, and their implications for sustainable futures. With this aim in mind, four objectives have been specified: First, to provide examples from a relevant policy and economic landscape, by exploring how the feasible space for co-benefits in water-energy-land nexus interacts with a case study. Second, to discuss gaps related to the challenges encountered in trying to achieve synergies across sustainability goals, and in managing their trade-offs under climate change. Third, to provide policy recommendations for urban land use planning in world regions under increasing drought risk related to climate change. And fourth, to discuss the insights and policy recommendations provided in the light of the limits to growth applied to urban land use.

After the following methodological Section 2, each section consecutively responds to each of the objectives above: Section 3 exemplifies the interactions between droughts and cities in a case study, detailing its policy context. Building on the previous example and on a literature review, Section 4 generalises policy gaps in relation to droughts and cities. Section 5 draws policy recommendations for cities at the global scale. Section 6 discusses our analysis and its implications onto the limits to growth and how they apply to urban land use, and Section 7 presents the main conclusions of the article.

2. Methods

The methods aimed to provide answers to the objectives above by combining ways of gathering knowledge about urban systems with both bottom-up and top-down strategies. A case study with a transdisciplinary knowledge co-creation process with its stakeholders was used to learn from a specific example, and a literature review was used to see what knowledge is generally applicable beyond the case study, and to complement the case study with cross-regional insights. Then, the most important dynamics behind water supply and demand from urban land use, and their potential for maladaptation consequences due to increased emissions, are connected to the concept of the water-energy-land nexus. The nexus approach was used as a lens for understanding the relationships between specific elements of the urban system under droughts and to derive policy guidance. Details on each of these methods are provided as follows.

2.1. Literature review

A literature review was carried out in order to gather available knowledge on urban areas and droughts representing the diversity of local conditions and policy landscapes across the globe with a focus on gaps and policy guidance, and thus to go beyond a single case study area and its biophysical, policy, and socio-economic context. The search was performed using the keywords city, urban, drought, and their related terms, in article titles in Scopus "*TITLE ((cities OR city OR urban*) AND drought*)*". We considered the last 5 entire years, i.e. since 2015 inclusively until end of July 2020. Our search results confirm the limited scientific attention given to the topic, but show rapid recent growth: the number of published articles per year of the above selection in Scopus stays in the low-single digits (1–3) until 1992, it grows to the mid-single digits (4–6) between 1993 and 2012, exceeding 10 papers per year in 2013, and only intermittently surpassing 20 papers per year in 2017 and in 2019.

The resulting initial list comprised 112 articles. The initial list was filtered by close examination of each abstract, first to include only original contributions with emphasis on water policy and planning in relation to urban land use, and second to exclude analyses focussing solely on the study of short-term responses to droughts in cities, as falling outside the scope of the article. The excluded articles mostly fell in two abundant categories: analysis based only on climate data, and analyses centred on urban vegetation. The final list after these two thematic filters comprised 31 articles (see Supplementary Materials).

After these filters, and in case of doubt about a valuable contribution in the excluded list, the complete articles were read in detail to identify gaps and insights. Because of the limited number of articles comprised in the final list (31), we further explored literature citing this set of selected articles, and complemented it with literature that was found relevant to the aims of the article. The selected articles were used to connect the insights from the case study with other geographical areas, and to explore knowledge, ambition, and policy gaps in the interaction between droughts and urban planning across world regions. The knowledge derived from this literature review was used to provide insights and context to all sections of the article, and in particular it provides the basis for identifying and discussing gaps in Section 4 and policy guidance in Section 5.

2.2. Transdisciplinary knowledge co-creation in a case study

Empirical evidence of the policy and implementation challenges that we have highlighted was obtained by investigating the integrated biophysical, governance and socio-economic dimensions of the water-energy-land nexus in a case study area. For our exemplar case study, we chose Benidorm and the surrounding urban coastal areas in the Marina Baixa county in Spain (henceforward, in short: coastal Marina Baixa), an area well known for its problems with droughts, as well as with rapid and poorly controlled urban development (Romero et al., 2012; Burriel de Orueta, 2009). Detailed description of the case study area is given in Section 3.

The research in the case study area was undertaken in two principal stages. First, a transdisciplinary knowledge co-creation process was carried out in the Marina Baixa area between 2016 and 2021 (Mauser et al., 2013), and is detailed in the next paragraphs. Second, a review and analysis of policy documents was undertaken, with particular focus on the key laws and decrees creating the legal context for policy around the water-energy-land nexus in the case study area. The aim was to understand how policy-making interacted with the water-energy-land nexus in the case study, and the relevance of the legal context to the observed dynamics in the case study. The legal context in the case study area is described in detail in Section 3.

We followed a transdisciplinary knowledge co-creation approach (Mauser et al., 2013), by engaging a selection of societal stakeholders from a range of policy and economic domains related to the nexus and its environmental services. The transdisciplinary knowledge co-creation approach comprised three phases: research co-design, co-production, and ex-post co-dissemination. The co-design phase was carried out at the pre-proposal stage of the funded research project and aimed to identify research and policy gaps around water scarcity and urban areas. The co-design phase was executed with in-person and follow-up telephone interviews with water-related authorities from the administration of the Valencian Autonomous Community during 2016. With these societal stakeholders, once research and policy gaps were jointly identified, a case study and set of research questions were co-designed. Shortly afterwards, a proposal was written on this basis, and funding was obtained (Cremades, 2017).

The co-production phase involved multiple activities with a focus on providing climate services to support decision- and policy-making in urban areas (Bahri and Cremades, 2021; Cremades et al., 2019; Bahri et al., 2018), and involved the mutual exchange of information between societal stakeholders and researchers. The identification and selection of the stakeholders for the co-production phase started from the initial set of water-related authorities involved on the co-designed phase. Specifically, from the initial set of stakeholders we employed a snowballing approach to identify all relevant stakeholders for the co-production phase. This allowed to get insight into the diversity of visions, actions and perceptions across the relevant levels of administration, their areas of management, and the most important economic sectors.

The stakeholders involved in the co-production phase included water-related representatives of the national administration, water- and land- representatives of the autonomous regional administration, water-related representatives of the provincial administration, and water-, land-, tourism-, and agriculture-related representatives of several local municipal administrations in coastal Marina Baixa, with an additional case-specific supra-local institution for water management. Tourism and agriculture are the most relevant economic sectors in the area in relation to water demand, representatives from both sectors were included. Other societal stakeholders were also included in relation to environmental NGOs and to expertise in the case study area. With all these societal stakeholders face-to-face, semi-structured interviews were carried out in two rounds (February 2018 and March 2019).

The semi-structured interviews were based on a set of questions that can be summarized as follows (see Box 1 in Cremades et al., 2019): (i) What economic impacts resulting from droughts did you experience in your decision- or policy-making domain in the past? (ii) How do general concerns about water scarcity interfere with the management and planning activities of your decision- or policy-making activities? (iii) What is your perception about what other economic sectors and decision- or policy-making domains, e.g. on sustainability, are planning and doing in this regard? (iv) What information about droughts and about climate change would be of interest to you? (v) What future scenarios are you considering for future planning in your professional domain? (vi) How would these scenarios influence water scarcity? And energy consumption for water management? (vii) Are you aware of other nexus interactions of relevance amongst water use, land use and implications for energy-related greenhouse gas emissions?

Each open-ended semi-structured interview continued with specific questions related to the particular activities of the stakeholder. These specific questions were focussed on their area of management or economic sector, and its respective links to other nexus components and spatial scales. These interviews were part of a process aimed at scientific co-design, co-production and co-dissemination, involving a two-way process of information exchange and feedback, e.g. on available information from stakeholders to scientists, and on frameworks of analysis and scientific results from scientists to stakeholders. Further exchanges related to co-dissemination activities followed with those interviewed and with additional societal stakeholders.

Due to a history of water-related conflicts and political tensions in the case-study area and the broader region (Novell and Sorribes, 2017; Torregrosa, 2008; Matvieychuc et al., 2006), it was perceived important to provide a degree of confidentiality.I In order to make stakeholders comfortable on sharing their views and agendas, they were informed that the result of each individual interview would not be made public, and that any derived knowledge published would not include specific quotes or attributions, thus granting the confidentiality of the information source.

2.3. The lens of the water-energy-land nexus

To develop the analysis of the case study, and to deepen our understanding of the interactions between urban systems and droughts, we connected the participating entities using a water-energy-land nexus approach. The nexus provided the lens we used to explore the interactions between droughts and the urban areas of coastal Marina Baixa, together with their cross-sectoral and cross-scale implications. For an updated overview of the water-energy-land nexus and its cross-sectoral and cross-scale application as framed in this article, and not to repeat content already introduced and further elaborated below, we provide a graphical abstract summarizing the nexus framing (see Fig. 1), and refer the reader to Cremades et al. (2019) for more details.

3. Droughts and urban sustainability in Benidorm

3.1. Urban expansion in a drought-prone tourism hotspot

Benidorm is located in the Mediterranean coast in south-eastern Spain (see Fig. 2), in the Marina Baixa county within Alicante province, which, together with the provinces of Valencia and Castellón, form the Valencian Autonomous Community. With over 11 M overnight stays in 2019 and 2018, Benidorm was the 3rd most visited city in Spain, and 4th in the Iberian Peninsula after Barcelona, Madrid, and Lisbon (INE, 2020; SP, 2020).

Benidorm is at the centre of a flourishing tourism industry that has driven strong urban land expansion all along the coast. For context, in the 10 km coastal strip of Alicante province, 800 ha were urbanised every year in the period 1987–2011, leaving barely any unprotected space to build in the first line of the coast (OS, 2016).

As the most populated urban area in Marina Baixa county, Benidorm has grown from a farming and fishing village of roughly 2.5 k inhabitants before 1940, reaching around 5 k inhabitants in 1950, 50 k in 2000 and 69 k in 2019, in an urban land use expansion process shaped by the tourism industry (Rodríguez, 2003; DA, 2020). The impact of droughts increases non-linearly with population increase (Kuil et al., 2019), and Benidorm's unrestricted urban growth could become a source of challenges under increasing droughts.

The urban land use expansion process in Benidorm was similarly reproduced in other neighbouring towns in Marina Baixa. Other towns in the coast and in the coastal hinterland, like L'Alfàs del Pi, Altea, Benidorm, Finestrat, La Nucia, Polop, and La Vila Joiosa, now form, together with Benidorm, the Marina Baixa urban coastal system. This system is characterized by a large-scale urbanisation process that has occurred during recent decades and by shared water supply infrastructures.

Benidorm is located in one of the most arid regions of Europe (Fernández Montes and Sánchez Rodrigo, 2014). An increase of frequency and intensity of droughts in the Mediterranean basin has been observed since 1950, and this increase poses additional challenges to existing environmental problems (Cramer et al., 2018). In the Iberian Peninsula there is a pattern of increased evaporation and greater drought severity in between 1961 and 2011 (Vicente-Serrano et al., 2014). Particularly in Alicante, a steady rise in minimum temperatures has been detected, while precipitation shows high variability in the interannual and interdecadal trends across the last decades (Fernández Montes and Sánchez Rodrigo, 2014).

An example of how this drought-prone context interacts with local urban systems occurred in 1978 (Martinez-Ibarra, 2015): on the 24th of August the municipal council of Benidorm made public that it reached what nowadays is known as "day zero", a term used for the day when a city has no more water to serve through its supply system. Benidorm had exhausted its water supply, and cancellations of hotel bookings and transfers of tourists to other sunny destinations followed, which had long-term reputation implications (Martinez-Ibarra, 2015).

Benidorm is an ideal location for a case study to research droughts because of its climatic and socio-economic context, which is characterized by the real estate booms in Spain and by a housing demand historically shaped by the tourism industry (Rodríguez, 2003). The international relevance of the tourism industry is reflected in a 15% of registered residents from other European countries, and a 13% of registered residents from Africa, Asia and the Americas in 2019 (DA, 2020).

A myth has been built by generations of tourists going to Benidorm since the early second half of the 20th century, partly fuelled by media presence, from cultivated literary depictions of the area — chiefly those of Gabriel Miró, a writer of the Spanish Generation of '14 — to movies like "Benidorm, mon amour" (Ferrer, 2010). The touristic attractions and the self-reinforcing nature of the myth contributed to trigger a demand for second homes amongst Spanish and international tourists and workers in the sector, which was facilitated by an enabling legal framework from the supply side.

3.2. A legal framework enabling unlimited urban growth

The Valencian Autonomous Community has its own legal framework for land use, within the context of Spanish and European laws. The derived local land use policies are mostly designed and implemented at the municipal scale, requiring approval of the administration of the Autonomous Community. Legal frameworks for land use in the Valencian Autonomous Community and the policies implementing them locally have been one of the most controversial issues in local and regional politics over the last 20 years, reaching European institutions several times (Burriel de Orueta, 2009), and having had multiple changes along successive governments. These changes had major implications for land use dynamics, because they enabled urban land use expansion, which became particularly visible in the Marina Baixa coastal system.

The Law 6/1994 of the regional Valencian Government established a permissive legal framework encouraging the proliferation of low-density urban sprawl areas with contested effects on urban sustainability in the Valencian coast and in the case study area (Romero et al., 2012; Burriel de Orueta, 2009). After a period of rampant urban land use development and a real estate boom, it followed a burst of the Spanish real state property bubble and a related economic crisis. By the time a new legal framework appeared (the Law 16/2005 of the regional Valencian Government) the market conditions did not allow large developments, except for some spots in highly demanded coastal areas. The succeeding Law 5/2014 of the regional Valencian Government included several protection measures, especially for the very few locations in the coastline that remained without an urbanised front (García-Amaya et al., 2018).

In this way, the Marina Baixa coastal system evolved into a skyscraper coastal strip in and around Benidorm surrounded by nearly united sprawling towns. In part, this happened because the sphere of influence of Benidorm grew over the neighbouring municipalities, particularly in La Nucia, and the road infrastructure was improved to accommodate larger mobility flows. As a consequence, Benidorm lost population that moved to the sprawling urban areas in the surrounding municipalities. At the time of writing (November 2020), in the municipalities surrounding Benidorm there are large areas of fully developed urban land use — i.e. with streets lights, water and power installations — without houses, as a result of attempts to build more houses during favourable market conditions that could not be completed before the Spanish real state property bubble burst in 2007 (Naredo, 2010). Once the economic conditions are again favourable for real estate developments, these areas could be expected to be immediately built.

These developments mean higher water demand in an area subject to important water constraints in relation to climate change. This urban land use expansion has consequences in the water-energy-land nexus, particularly in the energy intensity of water use, i.e. the amount of energy required to deliver a water supply (kWh/m^3). The increased water demands linked to land use expansion could mean a 6-fold increase in the energy intensity of water use in a dry year (Yoon et al., 2018), due to the use of desalination plants and conductions from outside the Marina Baixa urban coastal system. Larger energy intensities come with a cost increase for household budgets in times of increased socio-economic inequality (Yoon et al., 2019). And crucially, a higher energy intensity limits the scope for co-beneficial outcomes in policies dealing with the elements of the water-energy-land nexus.

There are links between water and land in the regulatory framework.

The national level Legislative Royal Decree Law 1/2001, and the Valencian Law 4/2004 established an administrative reporting procedure to be issued by water authorities, with the intended function of guaranteeing the availability of water resources for further urban land use developments. This report is a way to connect different water and land administrations and thus to break siloed policy-making across nexus elements, which is indeed a very good practice of cross-level governance (Brondizio et al., 2009). However, the report was not legally "binding". It was only a "determining" report to the final approval of further urban land use developments, due to legal conflicts on establishing a "binding" condition; the precise legal meanings of "binding" and "determining" are well detailed by López (2013). The non-binding nature of the report created multiple controversies as hundreds of urban land use development plans were approved in spite of the negative reports on the availability of water resources in several Spanish regions, including several in the Valencian Autonomous Community (López, 2013). Urban land use development plans approved without guaranteed water resources are a prominent policy gap, ultimately setting no water-related limits to urban growth.

This legal and political context, together with a boom in the real-state sector in Spain, facilitated short-termism in urban planning decisions and ambition gaps in the sustainability of land use planning. In particular, the approach of the Valencian government in the 2000s was characterized by a lack of consideration of the impacts of climate change on water scarcity, and also of the opportunities for the sustainability of future generations, thus falling short of ambition on what would be required to achieve sustainability. Furthermore, this short-termism has been attributed to "political capture" by lobbying interest groups in several parts of the broader Valencia coast (Romero et al., 2012).

3.3. *Is Benidorm sustainable?*

Despite the accelerated growth in population and urban land use, and its consequences for energy intensity and mobility, Benidorm still managed to achieve a reputation for sustainability. This reputation has two main pillars: (i) high population density, and (ii) a careful use of water resources. While a high density of population of urban land use is associated with sustainability (Cremades and Sommer, 2019), a single high-density nucleus needs to be explored in the context of the urban system in which it is embedded in order to understand its contributions to (un)sustainability. And while a local interest in the prudent use of water resources manifests in several initiatives in the hospitality sector (FFA, 2019; Rico et al., 2020), a systemic water-energy-land nexus view of the context disentangles the reasoning behind the reputation of Benidorm.

Benidorm is a prominent example of why sustainability science needs to look at systems, rather than at isolated elements. Assuming that neighbouring and obviously connected elements are isolated might provide misleading impressions. In the case of Benidorm, it is necessary to look at the entire Marina Baixa urban coastal system, in which Benidorm is the most important hub. The Marina Baixa urban coastal system shares critical infrastructure with Benidorm, including water and roads. During the case study interviews, it emerged that in recent years a large number of people previously living in Benidorm have moved to nearby towns like La Nucia while they continue working in Benidorm. In La Nucia and nearby towns large low-density urban developments have ubiquitously grown in the last decades. These nearby towns have developed substantial portions of their municipal areas into low population density areas, where the part of the employees of the tourism industry lives (see Gimenez-Font and Díez Santo, 2009). Therefore, Benidorm and the system in which is embedded increased the consumption of urban land use, energy for mobility, and related water, because low-density urban areas trigger larger land, water and energy consumption per capita than high-density skyscrapers (Rico-Amoros et al., 2009).

Urban developments characterized by low population density are linked in the area to speculative construction, and to high levels of water consumption (Rico-Amoros et al., 2009), both characteristics of unsustainable urban systems. The economic model of tourism and urban development has been strongly criticised due to its unsustainability (Morote-Seguido and Hernández-Hernández, 2019). While Benidorm itself has a fairly high density, other related municipalities in the Marina Baixa urban coastal system — like Polop or La Nucia — are characterized by sprawling, low-density development. Thus, by looking at the whole system and its interactions rather than at its elements, a rather different, more complete, and less favourable picture of the sustainability of Benidorm emerges.

4. Gaps in the interaction between drought impacts and urban planning

In this section we use the case study presented before and the literature review to infer knowledge, ambition, and policy gaps in the interaction between droughts and urban planning. By identifying key areas where knowledge, policy, and ambition are insufficient, we provide context for policy guidance. Exemplary instances of these gap types have been already introduced. *Knowledge* gaps were built by the lack of understanding of the interdependencies between water-connected biodiversity, agriculture and urban systems under long-term climate and socioeconomic scenarios. *Policy* gaps were created by urban growth approved without guaranteed water. And *ambition* gaps were present in urban planning decisions leading to insufficient or contradictory action to achieve the targets of the SDGs, e.g. when urban sprawl was triggered by short-termism and lobbying.

Worldwide, most of the measures conceived to deal with droughts in cities are implemented by the time the drought is already happening; there is a lack of proactive planning by cities in relation to droughts, and even when planning exists it mostly relates to implementation of measures after the onset of the drought (Buurman et al., 2017). It has been observed that, in many cases, awareness arises from extreme events, and then action is triggered that improves adaptation to future events (Cremades et al., 2018). Still, the contribution of these actions to challenges to surrounding water ecosystems and greenhouse gas emissions related to the energy intensity of water are only considered *ex-post*, thus legitimating earlier unsustainable planning with emergency measures.

Some studies about droughts and cities incorporate the evaluation of future options, but without considering climate scenario data (Trindade et al., 2017). When climate data was considered, drought studies for cities focused solely on their climatic dimension (Liang et al., 2019; Guerreiro et al., 2018). Similarly, when the focus is on the economic dimension of drought impacts, the use of climate data has not been considered (Desbureaux and Rodella, 2019). These knowledge gaps about urban systems act as a brake on the policy arena.

In cities located in low-income and middle-income economies there are issues with the ability to plan and finance proactive action against future droughts (Rain et al., 2011). However, in high-income economies, where these obstacles are less severe, cities do not take advantage of their possibilities to plan proactively, and in addition there are few studies covering knowledge gaps for particular urban areas (see Gober et al., 2016). Cities in countries from all income brackets present knowledge, ambition and policy gaps in relation to droughts and climate change, while the impact of droughts in cities worldwide shows little geographical or socioeconomic distinctions (Buurman et al., 2017).

The nature of knowledge gaps in relation to urban planning and droughts under climate change is multiple and widespread. Knowledge gaps exist in nearly all urban systems due to lack of understanding of climate projections and their impact on the local economy, for which science has not yet provided convincing bottom-up methods. There are continuous discussions about co-benefits and trade-offs, but the reality leaves few options beyond managing the trade-offs: even the opportunities from aquifer recharge and rainwater harvesting might lead to increases in emissions, because water stored in the underground needs energy to pump it to where it will be used (King-Okumu et al., 2019).

Knowledge gaps are especially prevalent in local and regional governments (Charbit, 2011), and are a root cause for other gap types: neither ambition nor objective policy can exist without information. In addition, cities display ambition gaps, and short-termism in policy-making is a driver behind these ambition gaps, as exemplified in the previous section. Policy gaps are also widespread, as long-term planning is not commonly adopted (Buurman et al., 2017).

The implementation of global agendas into urban land use policies, and of these into specific urban areas is a challenge: higher policy levels often only provide general details, so that when implementation happens there are both knowledge and ambition gaps. While the principle of subsidiarity provides an opportunity to create functional polycentric governance for sustainable outcomes (Kellner et al., 2019; Stephan et al., 2019; Marshall, 2009), in reality, polycentricity can also lead to competition, problems of overlapping and or unattended competences, and dysfunction. Our interviews in the case study area revealed a number of less attractive characteristics of polycentricity, for example: multiple neighbouring municipalities competing for water resources, the influence of lobbies, a lack of knowledge and ambition about how to deal with future climate impacts, and a lack of oversight and citizen involvement about the implementation of global agendas. In effect, the freedom to interpret global agendas and top-down local or regional policies provided by polycentric governance seems to have led to ambition and policy implementation gaps, rather than to coherent multiscale governance.

Future urban land-use policies driving the demand side of the drought equation, i.e. leading to water consumption derived from the implementation of urban land use planning, often lack sufficient detail and often leave policy implementation gaps that can end up raising water consumption levels. For example, the volume of water to be used in pools, the maximum number of pools, and the water for gardening are frequently not considered in planning. In such context, even when emergency measures such as a ban on filling swimming pools is used, often its implementation is not enforced by the authorities. This was particularly observed in the case study of coastal Marina Baixa, where local stakeholders perceived such limitations on pool filling as a trade-off against the touristic appeal of the area. Policy and policy implementation gaps could be helped by tools linking urban land use areas to sustainability goals at the metropolitan and river basin scales, and focussing e.g. on the energy intensity of water, as we explain in next Section 5.

The quality of social participative processes — commonly included in environmental policies (e.g. European Parliament, 2003) — present another policy implementation gap. These processes are usually limited in the content and in their representation of society, and often reflect a lack of deliberative culture (Parés et al., 2015). Participants are often a set of usual regulars originating from the leadership of organised civil society, economic lobbies, and public institutions, a situation that limits the scope of the representation (Parés et al., 2015). Particularly, it was observed in the case study area that water policy processes were strongly top-down in the design of the topics to cover, and the opportunities to deliver insights beyond those topics were very limited, hence the organising administration ended up ignoring topics outside of its own pre-defined areas of interest.

Because of lack of noticeable impacts and limited ex-ante public debates, the consequences of these gaps might go unnoticed until a certain extreme hydrometeorological drought event occurs that compromises the supply side of water availability, as with the Millennium droughts experienced in Australia, or until demand-side local factors make the gaps noticeable, as with the rapid urban growth seen in the case study described in Benidorm (Spain). Rapid urban growth can be related to socio-economic development and or to particular economic sectors, in particular to housing demands related to touristic appeal. Ultimately, these gaps can jump into the political arena and amplify context-related debates about water scarcity across cities, between cities and rural areas, and between economic sectors, e.g. tourism vs. agriculture (Dilling et al., 2019; Hernández et al., 2010).

Furthermore, despite the potential role of consumer-level demand-side policies on water savings, and despite some evidence that these urban savings can provide adaptive buffers to other sectors (Zipper et al., 2017), consumer-level demand-side policies are still not always considered in the policy arena (Du et al., 2018), and when they are, they ultimately leave less room for future action. It should be noted that there is also some evidence that the flexibility in the demand side could be more limited than previously thought (Dilling et al., 2019).

To summarize the landscape of gaps on droughts and cities, knowledge gaps can only increase the size of policy gaps. And even where there are policies in place, they might not be implemented. Ultimately, ambition gaps may be related to contextual factors such as ideology, and a growth-oriented economic paradigm. Furthermore, all these gaps have consequences for the future options of cities and regions to achieve the SDGs and to follow pathways for sustainability. There is therefore an urgent need to address these knowledge gaps and research the drivers behind all gap types across world regions.

5. Policy guidance for urban planning under increasing droughts

In drought-prone areas the competition for water use between cities and other economic activities, particularly agriculture, needs to be integrated into planning tools dealing with long-term climatic and socio-economic projections, and into institutions dealing ex-ante with water scarcity across sectors, that ultimately co-produce information signalling what are the limits of urban development and growth within sustainability targets at the local scale.

5.1. Integrating cities with competing sectors in co-produced nexus tools

The water-energy-land nexus is a useful framework to integrate land-derived water uses from urban and agricultural land use and to understand their linked biophysical, social, and institutional dynamics under climate change. The multilayer network for the water-energy-land nexus proposed by Cremades et al. (2019) suggests starting with the identification of the relevant biophysical and artificial elements of the water network, and their related agents and institutions, to continue with other nexus domains, and to focus on how they interact. This approach enables exploring which agents and institutions have agency over which nodes and links in each of the connected layers included in the nexus analysis, including layers, where relevant, for water, land, energy, trade, etc. This can help visualise how different agents and different institutional levels interact, and thus identify issues with political capture and siloed policy domains, and see which existing gaps could ultimately impact the balance between water supply and demand. The suggested multilayer network exploration and the knowledge derived thereof can be the basis for building local and regional integrated planning tools, in which the biophysical limitations of water scarcity under climate change interact with the agency of stakeholders and institutions in co-produced socio-economic projections. One example of this tools is WaterSim 5 (Gober et al., 2016), another example is the Urban Drought Nexus Tool (Bahri and Cremades, 2021), which is open source and can be adjusted across urban systems if hydrological information under climate projections is available. Using these types of tools can highlight the imbalances between projected supply and demand. They can be complemented with other tools for short-term planning, e.g. to improve the management of demand (Bolorinos et al., 2020).

5.2. Applying climate services to urban systems under increased droughts

How to best use climate projections in such nexus tools? Climate services, i.e. the transformation of information related to climate projections into data and products to support planning and decision making in society (Street, 2016), can be instrumental to understanding the consequences of climate projections for the interactions between projected droughts and urban water supply systems.

Policy makers and practitioners in urban areas increasingly get information from climate services highlighting changes in the total amounts of precipitation, but have more difficult access to drought-related key variables like the number of events of consecutive months under a precipitation value threshold. To provide an example of a state-of-the-art climate service, the European Union's Copernicus Climate Change Service (C3S) (Lottle et al., 2017) provides information sufficient to get all these values in its operational service for the water sector, but only an expert could create information about the number of events of consecutive months under a precipitation value threshold. From the interviews carried out, we noted stakeholders and decision-makers in the Marina Baixa urban coastal system are confident on their dams and aquifers being full in the future, based on observed increases in the mean of the total amounts of winter precipitation in the last 30 years, despite disregarding scientific knowledge about high interannual and interdecadal variability in the total amounts of precipitation in Alicante province (Fernández Montes and Sánchez Rodrigo, 2014).

Similarly, statistical analyses of ensemble data projected onto a map come often with an indication of the degree of agreement of members in the model ensemble from which the information has been obtained. However, this was not available in the Service for Water Indicators in Climate Change Adaptation (SWICCA) proof-of-concept maps for water services in the C3S (Lottle et al., 2017). Hence it was not possible to immediately communicate to stakeholders the degree of agreement between the ensemble members and the relation between projected changes and internal variability, which would be relevant as an indication of the reliability of climate projections.

Despite these shortcomings, which can be amended with relative ease, climate services based solely on climate projections can provide information about water availability until 2100 and beyond, but only solve the supply side of the knowledge gaps in the water use equation. The supply side should be coupled with the demand side in local and regional integrated assessments models, capable of integrating the related drivers and factors — e.g. the water-energy-land nexus, but not only — and to consider socio-economic projections (Cremades et al., 2019).

5.3. Institutionalising transparency and integration in multi-sector partnerships

With respect to the management of such competing demands through institutions dealing with water scarcity, examples are found in regions adjacent to the Benidorm case study. The neighbouring Jucar river basin, for example, has specific institutional arrangements in place for drought management at the regional scale. These arrangements are part of a long history of water management institutions in the Valencia region (Carmona et al., 2017), going back at least a thousand years — as far as there are records — to the famous Valencian "Tribunal de les Aigües" water court. Recent institutional developments in the management of droughts take the form of a multi-sector partnerships formed in a "Permanent Drought Commission", which has been shown to be effective for the management of drought events (Carmona et al., 2017). In future, these institutional arrangements/procedures should be integrated *ex-ante*, and should include land use in addition to water use, as part of long-term planning across the involved sectors.

The Benidorm case study is administratively part of the Jucar river basin and therefore included in these institutional arrangements. However, the particularities of local water conflicts between actors and municipalities — some enduring across generations — hindered the potential intervention of these institutional developments in the case study.

Intense urbanisation and an extreme hydrometeorological event caused a "day zero" in Benidorm, triggering a learning process about how to avoid the limits to adaptation against the combined effects of urbanisation and climate change and the resulting water scarcity (Cremades et al., 2018). This learning process led to an innovation in the form of a new supra-municipal institutional partnership deployed to manage droughts and secure urban water supply in the Marina Baixa urban coastal system. However, the partnership focussed mostly on the creation of infrastructure, thus dealing only with the supply side. Such supply side interventions are known to weaken the support for demand management policies (Lindsay et al., 2017). Indeed, the urban land use and its related demands have grown in the case study area as the supply infrastructure increased water availability. At the time our interviews were carried out, this supra-municipal institution was, involved in negotiations about water use with the agricultural sector in the area, because the connection to a desalination plant outside the system leads to undesirable higher water costs.

In this context, increased coordination and connection between neighbouring municipalities is a promising measure to deal with deep uncertainties about the future (Elmqvist et al., 2019) and to bridge spatial and social-ecological scale mismatches (Sayles and Baggio, 2017), thus enhancing institutional fit (Epstein, 2015). However, some case study stakeholders expressed concerns about lack of transparency in the management of water of the Marina Baixa urban coastal system supra-municipal institutional partnership. Likewise, previous studies in the case study area made it clear that sufficient data were not available (Yoon et al., 2018).

Once coordination between multiple stakeholders in water management is achieved, the next milestone to consider is how to achieve a similar level of coordination in the planning of future land use. Land use change at the municipal level implies increased water use across multiple scales, from the supra-municipal to the river basin, and multiple sectors, e.g. agriculture, industry, and tourism. Careful strategic planning of land use change is important everywhere, but especially so in drought-prone areas. Making all water, land and energy information transparent and institutionalising local mechanisms for transparency and dialogue would therefore facilitate future sustainability planning.

5.4. Introduce the energy intensity of water use in urban land use in policy-making

The sustainability of urban land use expansion can be compromised by the amount of energy required to make water available. Thus, information about the energy intensity of water use (kWh/m^3) of urban developments can cover some of the knowledge and policy gaps indicated in the previous section, and also can contribute to social movements highlighting the necessity of decreasing the energy intensity of society (Wahlström et al., 2019).

Making the energy intensity of water use a material consideration in urban planning would help to incorporate the cross-scale and cross-sectoral nature of water-energy-land nexus into policy-making at the urban and river basin scale, keeping future sustainability options open (i.e. not locking in high resource use far into the future by building unsustainably today). Since energy costs are an important indicator for policy makers, and costs increase with energy intensity, adoption of energy intensity as an indicator seems like an obvious source for co-benefits.

5.5. Implications for cities in middle-income and low-income economies

While cities in high-income countries resort to tanker boats and emergency water transfers as shown in examples above, in low-income economies the situation is more severe and a "day zero" can lead to an emergency of a higher order of magnitude. Nevertheless similar lessons seem to apply. The Cape Town drought teaches that transparency and partnership between institutional levels and with local stakeholders are crucial for enhancing drought resilience (Ziervogel, 2019; Simpson et al., 2019). However, as we have shown, these principles triggering information exchange and accountability between partners are not always applied in cities in high-income economies.

In low-income economies, vulnerable communities in informal settlements are likely to suffer more. In such cases existing inequalities are exacerbated of as case-specific vulnerabilities add to multiple sources of marginalisation, making a case for climate injustice (Marks, 2019). While informal settlements are not exclusive to low- and middle-income economies, they can be also a consequence of a drought in nearby areas, as documented in Al-Hasakah (Syria, see Akhmedkhodjaeva, 2015).

When transboundary water arrangements are discussed for sharing water between bordering nations, it must be considered that they could be a source of tension in cross-country politics at a later stage (Chuah et al., 2018), especially if countries, regions and cities have a development roadmap that imply higher water consumption futures in the short- and mid-term.

The nexus between water consumption and hydropower production means that damage to urban economic activities caused by drought is effectively doubled. In this sense, the multiple related vulnerabilities around urban water infrastructure need to be further explored (Gannon et al., 2018). In terms of the design of such infrastructure, it is important to put in perspective the needs of other sectors, like agriculture, that are crucial for the livelihood of population in rural areas (Alauddin and Sarker, 2014).

6. Discussion on urban planning and the limits to urban land use growth

6.1. Are there limits to growth in cities?

In this section we explore the diverse potential limits to growth (Meadows et al., 1972) in urban land use that cities might encounter, in particular we explore whether the role of these limits could involve *limits to growth* in cities, or *limits to sustainable urban futures*. The former refers to unavoidable limits to growth in cities, the latter to inescapable issues with sustainability arising from urban development, particularly to those that can have long-term consequences constraining the options for a sustainable future in the urban land use and its linked systems. Both types of limits could occur either within urban land use, or within the systems in which the urban land use is integrated, e.g. surrounding ecosystems or a river basin. Finally, an outlook for future work is presented. The connections between these *limits to sustainable urban futures* and the SDGs is discussed below (Zhang et al., 2019). These *limits to sustainable urban futures* have an additional dimension: they focus on interactions across systems and scales.

Water availability and security (SDG 6) is a known *limit to growth* in cities (SDG 11) that constrains urban development at the scale of the city or metropolitan region, and is linked to the river basin scale (Smith et al., 2014). The quality of water-related ecosystems (SDGs 14 and 15) in the river basin(s) related to the urban area constitute a *limit to sustainable urban futures*. Both these limits can become more stringent under climate change due to lower precipitation and higher evapotranspiration, and in addition, in areas with increased precipitation trends under climate change projections (SDG 13), water can be a growing constraint because of increased variability.

The *limits to sustainable urban futures* also relate to the amount of energy used to make water available. The millennium drought 2000–2009 in Australia triggered an adaptive cycle of innovative responses to avoid the limits to adaptation (Cremades et al., 2018), which were mostly of a technological nature and involved a higher energy use for creating water supply. The energy intensity for water supply thus increased two- to four-fold in three South-Eastern Australian cities while coping with this drought event, leading water prices to double (Stavenhagen, 2017).

Additionally, these two- to four-fold increases in energy intensity (SDG 7) can be conceptualised as a maladaptation problem. Maladaptation is defined as a detrimental or adverse impact caused by an attempt to decrease vulnerability to impacts of climate change (SDG 13) like increased droughts, and in the context of the water-energy-nexus often relates to undesirable increases in greenhouse gas emissions due to changes in water management that require higher levels of energy consumption, which also involve higher costs (Cremades et al., 2019; Cremades et al., 2016).

Equity is an important criterion for the evaluation of successful adaptation and of sustainable development pathways (Adger et al., 2005), and in these cases of increases in energy intensity, additional social impacts appear as droughts reach tax-paying households with a burden of a two-fold increase in water price. This could lead to social and economic inequalities in how the costs are distributed, because households with less available income can be expected to feel the change more intensely (Yoon et al., 2019). In the Marina Baixa urban coastal system, decision-makers developed all supply infrastructures with the specific aim of avoiding expensive desalination. Even so, projections show that these efforts would not be sufficient during dry years, and external water input from desalination plants would be necessary (Yoon et al., 2018). Here we see that *limits to sustainable urban futures* could also emerge from the social equity side (SDG 1).

At least in theory, there could be opportunities to partly offset these maladaptation outcomes that would ideally rely on large-scale diffusion and household-level adoption of water efficient devices and practices on the demand side, leading to energy savings that can potentially compensate the increase of energy intensity on the supply side (Lam et al., 2018). However, this kind of large-scale diffusion of sustainable behaviour is not always technically and socially achievable. In this respect, Lindsay and Supski (2017) show that measures to reduce water use in private gardens and in showering practices in households during a drought encountered resistance, with much less success and smaller long-lasting effects in showering practices. Additionally, it is known that high-income households and hotels lack responsiveness to water conservation policies (Palazzo et al., 2017; Rico et al., 2020), that once cities grow and increase water use, it cannot be decreased in practice, and that management plans and targets for reduced water use are often not met at the (supra-)municipal and river basin scales in different world regions (Vargas-Molina, 2020; Palazzo et al., 2017; Gómez and Blanco, 2012).

Desalination of seawater for water supply production creates significant negative impacts (see Raha, 2006), and these impacts question the sustainability of producing it even with low-carbon energy sources. For example, marine ecosystems are severely affected by the discharge of excess salts (Mumbah et al., 2015; Ahmed and Anwar, 2012; El Saliby et al., 2009). Other impacts of the activity refer to the production of the energy required, which even when coming from renewable sources like wind, solar or hydropower, has substantial implications on land cover change and ecosystem degradation, inter alia (Hernandez et al., 2014; Jaber, 2013). Thus, even where cheap and low-carbon energy sources are available, increases of water demand from urban land use would lead to *limits to sustainable urban futures*. Ultimately, wastewater reuse gives room for manoeuvre to cities for mitigating drought risk (Liu and Fu, 2015; Lottering et al., 2015), but it relies also on additional energy intensities and presents similar problems to desalination.

From the governance point of view, aspects of an institutional agenda for water governance seem something of a double-edged sword in terms of the *limits to growth* in cities. Redundancy and connectivity as provided in the coastal Marina Baixa case study by a supra-municipal institution are clear signals of sustainability and resilience for cities (Elmqvist et al., 2019), and indeed in California those cities situated outside or at the margin of water exchange networks suffered the most during drought events (Lund et al., 2018). At the same time where governance or political systems are in conflict, connecting water exchanges across different urban systems can lead to political strains at the national level (Chuah et al., 2018). Redundancy and connectivity can also create unexpected surprises and problems at the local level, for example, it has been observed in the coastal Marina Baixa case study that some local urban land use planners have unrealistic expectations of water availability, hoping that it will enable exponential urban land use growth in particular municipalities of the connected water system. These hopes relate to a sense of aggravation by the earlier actions of other municipalities, which grew earlier and are now consuming the available water. A sense of intermunicipal competition has been observed in many aspects across world regions (Bolorinos et al., 2020; Taylor, 1992), and again points towards managing the commons from the roots of the demand, that is, including urban and agricultural land use change — together with all relevant water consumption sectors — in all water governance institutions.

From a nexus perspective, urban planners aiming to find sustainable co-benefits between the elements of the water-energy-land nexus and the environmental services associated with the adequate functioning of related ecosystems, should consider how the feasible space for these sustainable co-benefits is reduced by increased water demands coming from land use, and by increased energy intensity coming from higher water demands. The cross-scale implications range from local water ecosystems to river basin and to climate-related global commons that require institutions and partnerships departing from the local scale (SDGs 16 and 17). This stresses the interdependence of urban systems with components of the Earth system understood as cross-scale commons, like water ecosystems in river basins at the local or regional scale, and the atmosphere at global scale.

Summarizing, in those urban land use areas where large amounts of water are not available, and the energy intensity and the costs of water provision are mounting, urban land use growth can only continue at the cost of compromising sustainability. Eventually, the only sustainable option in such cases is to prohibit further urban development, which is likely to be politically unfeasible in most cases. This applies especially to areas under climate change induced droughts and areas where climate change is increasing the variability of precipitations, and could also apply to urban areas subject to accelerated urbanisation processes.

6.2. Further work

Given the *limits to growth* in cities and *limits to sustainable urban futures* discussed within urban land use and their related systems, it is necessary to research how these limits could be applied in a quantitative way to cities. The definition of how these limits apply to them should include an urban land use size after which these limits manifest, from which urban growth would impede future pathways for sustainability. This limiting urban land use size for sustainability could be, in mathematical terms, the feasible space for urban sustainability, and would be populated by several possible solutions — giving alternative options of implementation showing different pathways towards sustainability. Policies and plans within this feasible space would not compromise the achievement of long-term sustainability.

It would be necessary to link these limits with limits in other systems of the Earth and the economy and understand the implications for the management of cross-sectoral and cross-scale commons. It is necessary that the cross-scale relations between cities and their related ecosystems are studied in an integrated way, including the production and consumption of goods along supply chains and trade agreements, and what socio-economic and political factors influence or condition their characteristics.

A spatially-explicit approach linking urban metabolism with ecosystems could be a promising entry point, potentially responding to some of the most interesting questions left open by our contribution. Specifically, we encourage research on how to find co-benefits between climate-smart urban land use (Cremades and Sommer, 2019), circularity in urban metabolism, urban heat mitigation strategies (that ultimately rely on limited water), sustainable production and consumption in cities, and long-term ecosystem resilience. This research could help to understand questions about the cross-scale nature of planetary boundaries, namely how they could apply to smaller scales and to ecosystems, and their implications for Earth system cycles and biosphere integrity.

Since the biophysical, governance and socio-economic context of every city is different, top-down scenario projections may struggle to capture the future visions that municipal stakeholders might have or might already be implementing. New approaches to bottom-up scenario analysis are therefore needed, e.g., frameworks that account for different degrees of policy implementation (Hewitt et al., 2020). Additionally, all knowledge, ambition, and policy gaps have long-term implications for urban sustainability. For cities to be able to follow pathways for sustainability, it is therefore urgent to explore these gaps and classify them across world regions.

7. Conclusions

We aimed to explore the implications of the dynamics of the water-energy-land nexus for sustainable futures in cities suffering increased climate change-related droughts. The increasing frequency of meteorological droughts due to climate change, together with urban growth, drives water scarcity and socio-economic droughts. In this context, we conclude that the feasible space for sustainable co-benefits in the water-energy-land nexus and its related environmental services is reduced. Increased costs to obtain water compromise equity, increased energy consumption and emissions to obtain water compromise climate goals, and the water available for ecosystem integrity becomes scarcer.

To deal with the difficulties to achieve such co-benefits, and to manage the related trade-offs, urban planners need to institutionalize transparency and cross-sectoral integration in multi-sector partnerships, to apply climate services to urban systems, and to integrate cities with competing sectors. These approaches should inform about the energy intensity of water use in urban land use, so that this information can be used in policy-making.

Our study has shown that water supply with low emissions, without compromising water related ecosystems, and with low costs to society is a local-scale *limit to sustainable urban growth*, and is linked to the management of common pool resources at larger scales, particularly water at the river basin scale.

Our findings suggest that unless local governments consider the limits to sustainable urban growth and implement them in their planning, the SDGs will not be achieved. This research extends our knowledge of the interaction between urban planning, droughts, and the SDGs, and what dilemmas will be faced by local urban planners in the implementation of global sustainability agendas.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

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