Article:

Taylor Buck, N. and While, A. (2020) The urban bioeconomy: extracting value from the ecological and biophysical. Journal of Environmental Planning and Management, 64 (2). pp. 182-201. ISSN 0964-0568

https://doi.org/10.1080/09640568.2020.1763931

The urban bioeconomy: extracting value from the ecological and biophysical

Abstract

Cities have tended to be seen as net consumers of ecological goods and exporters of ecological bads. However over recent years urban metabolism, circular economy and bioeconomy concepts have sought to rebalance this seemingly parasitical relationship by seeing the urban as an ecological resource to be exploited for profit. In this review paper we investigate the ways in which the assets and metabolic flows of the city are being recharacterised as a source of value to be maintained, extracted, enhanced and exploited. Our approach is twofold. First, we examine areas of latent potential for urban bioeconomic exploitation and issues raised in terms of fair and just cities. Second, we examine issues, tensions and challenges in reimagining the city as a site of bioeconomic value. The paper makes a distinctive contribution to the literature by defining and critically analysing the new urban bioeconomy as a form of environmental value creation.

Keywords
Cities, environmental value, bioeconomy; circular economy, value from waste

1. Introduction

Global cities have tended to be seen as net consumers of ecological goods and exporters of ecological bads (Heynen, Kaika, & Swyngedouw, 2006, p. 14; Wolman, 1965). However two key drivers are forcing a reappraisal of this simple dichotomy. Firstly, more stringent environmental and ecological regulation means that the task of expunging solid and liquid urban wastes has become increasingly costly as restrictions are placed on cities' ability to deflect the waste problem to urban hinterlands (Gandy, 1994, p. 1). Secondly, there has been growing interest in the intrinsic financial value embedded within urban wastes and how it might be extracted (Buscher & Doody, 2013). In this paper we analyse this process of reappraisal to explore the ways in which the assets and metabolic flows of the city are being recharacterised as a source of value to be maintained, extracted, enhanced and exploited within the context of the circular economy.

We frame this recharacterisation as the new *urban bioeconomy*. The bioeconomy term is used in different ways, for example as in bioprospecting (the commercialisation of products and drugs based on biological resources such as plant extracts, or extracting minerals from waste) (Fitter et al., 2010; Goldstein & Johnson, 2015) and the harnessing of biological processes (e.g. producing energy and useful products from waste or growing biomass for food and energy) (Martinez-Hernandez & Samsatli, 2017; Scarlat, Dallemand, Monforti-Ferrario, & Nita, 2015). We use the *urban bioeconomy* term to refer to green capitalism's exploitation of latent urban assets in the form of biological models and processes for various direct or indirect economic benefits. If nature and protected biophysical functioning are properly valued, nature conservation can be a source of value creation (Hossain, 2019; Knuth, 2016; Ponte, 2019).

These potential or latent urban assets form new resource frontiers of bioaccumulation within the second nature of cities (where buildings are seen as a second natural resource) (Knuth, 2016; Labban, 2014). As such, they are being brought into play by a range of factors, including pressure to justify public investment in ecological management, interest in extracting latent value and changes in urban economics associated with climate change, decarbonisation, and the stigmatisation of the linear 'take-make-forsake' resource-use paradigm. To date little work has focused on the juncture of urbanism and the bioeconomy. Here we address this gap, uncovering the synergies and interdependencies between economic, ecological and social modes of organisation and the ideologies informing them (Sanz-Hernández, Sanagustín-Fons, & López-Rodríguez, 2019).

The paper does not present new empirical research. Rather it is a conceptual framework based on a systematic review of bioeconomy literature, practice and debates in a range of fields and geographical contexts. This review resulted in a database of initiatives, which were used to inform the conceptual framework. Our focus was on the development of a typology of different sectors and domains that might constitute the urban bioeconomy based on the biophysical resources of urban food production, solid and liquid waste recycling, urban resource mining, and biological processes. The examples we use are intended to be illustrative of the wider range of possible bioeconomic interventions, and emphasis was placed on the opportunities to rework urban areas around bioeconomic principles. We initially analysed the English language literature indexed during the decade from 2008 to 2018 in Web of Science. This was supplemented by a further search in February 2020 to update the data. By February 2020, the initial core sample comprised zero papers on 'urban bioeconomy'; 1,486 papers on 'bioeconomy'; 380 papers on 'bio-economy'; and 1,769 papers on 'bioeconomy OR bio-economy'. We then applied the word "urban" in titles, abstracts, and keywords as an inclusion criterion, resulting in 41 papers. In order to improve our understanding of the underpinnings and conditions for the emergence of the urban bioeconomy we screened these 41 papers to select those that focused on conceptual factors such as drivers, governance, innovation and value creation, and the spatial focus of the bioeconomy. We therefore excluded papers that focused primarily on technical issues. A selection of 21 papers that were considered relevant to the analysis was made. This sample encompassed a broad range of environmental and socio-technical sciences disciplines. The academic journals in which they were published include fields such as rural economics (1), agriculture (2), philosophy and ethics (2), land use (3), energy (4), sustainable materials and manufacturing (4), and sustainability (5). A detailed analysis of these 21 papers using narrative synthesis (Popay et al., 2006) enabled us to identify some key themes for our conceptual framework. This framework was then bolstered by further searches of academic and grey literature.

In Section 2 we start by setting out what is meant by the bioeconomy concept and its growth and expansion, discussing the historic conceptual precedents of urban metabolisms and the circular economy, and the uptake of the bioeconomic imaginary through moves to conceive ecological processes as potential resources. Competing bioeconomic visions are described, and various examples of the emerging bioeconomy are explored. Section 3 examines the changing conceptual and political conditions that might encourage interest in an urban bioeconomy, reflecting on new logics within urban restructuring around three spheres of latent technical potential in the urban bioeconomy: (i) value from waste; (ii) harnessing biological assets for economic value; and (iii) controlled / artificial environments. Section 4 then discusses some of the tensions between the new urban bioeconomy and the sustainable cities concept. The conclusions in Section 5 then address some of the tensions around the three spheres of latent potential, and conclude by leaving open the possibility that a new urban bio-eco-economic approach could challenge the bioeconomy's current narrow framing as an engine of green capitalism.

2. What is the bioeconomy?

Whilst still existing mainly at a strategic level (Golembiewski, Sick, & Bröring, 2015), the concept of a bioeconomy and bioaccumulation have generated powerful imaginaries that are transforming how we consider, use, access and legislate 'life' (Goldstein & Johnson, 2015). As a concept, the idea of a bioeconomy is contested and evolving. Definitions include: (a) utopian imaginaries where economic growth is driven by the development of renewable biological resources and biotechnologies to produce sustainable products, employment and income (Rosegrant, Ringler, Zhu, Tokgoz, & Bhandary, 2013); (b) holistic approaches where economic output involves biotechnological knowledge, renewable biomass, and integration across applications (Wield, 2013); and, (c) utilitarian views of any and all industrial and economic sectors that produce, manage and otherwise exploit biological resources and related services (Sasson & Malpica, 2017). Here we adapt Zilberman et al.'s (2013) conceptualisation to define the bioeconomy as *the exploitation of biological knowledge to support a profitable transition from mining non-renewable resources to farming, growing and harvesting biomass-based ones, with associated benefits to society*.

Conceptually then, the idea of a bioeconomy asserts the role and value of technological innovation in capturing the latent value in biological processes and renewable bio-resources. This value could be social (health and wellbeing), economic (profit, offsetting climate change related costs) or ecological (reduced impact on ecosystems at local, national or global scale) (Philp, 2017; Sanz-Hernández, Sanagustín-Fons, et al., 2019). This broad framework allows for different emphases to be overlaid onto the bioeconomic imaginary, and in their review of academic literature Bugge et al., (2016) identified three broad bioeconomic visions:

- The *bio-technology* vision emphasises the application and commercialisation of bio-technology research in different sectors of the economy
- The *bio-resource* vision focuses on processing and upgrading of biological raw materials, and establishing new value chains
- The *bio-ecology* vision highlights sustainability and ecological processes that optimise the use of energy and nutrients, promote biodiversity, and avoid monocultures and soil degradation

The number of countries with truly integrated strategies that address the multiple facets of the bioeconomy (health, chemicals, agriculture, forestry, bioenergy etc.) was growing but limited at the time of writing this paper. In the EU, only Austria, Belgium, Finland, France, Germany, Holland, Italy, Latvia, Norway, Spain and Sweden have published integrated strategies (Diakosavvas & Frezal, 2019; Dutch Government, 2018; Italian Government, 2019; Latvian Ministry of Agriculture, 2018; Meyer, 2017; Norwegian Government, 2016; Republic of Austria, 2019; Smáradóttir et al., 2014). These strategies tend to coalesce around two general visions (After Meyer, 2017). The first is a *Biotechnology-centred* vision, where life science and biotechnology are drivers of innovation, and where new findings lead to economic growth, improved international competitiveness and additional jobs. The second *Transformation-centred* vision is primarily concerned with the role of biotechnology in helping to address global challenges such as climate change, food security and unpicking reliance on the waning fossil fuel economy (Brown et al, 2000; Lösch & Schneider, 2016). Table 1 highlights how the various strategic and academic bioeconomic visions broadly align.

[Table 1 near here]

The enthusiasm for such strategies stems in part from the fact that the multi-faceted nature of the bioeconomy and the often closely related circular economy (i.e. using the waste outputs from one process as the material inputs for a different process) have the potential to provide new overarching frameworks that reject traditional concepts of economic sectors and help to break down disciplinary siloes in favour of more systemic understanding of industrial synergies (European Academies Science Advisory Council, 2017). In this context the potential to capture latent and un- or under-exploited economic and social value in biological resources and processes has stimulated significant interest, with many seeing the bioeconomy as representing nothing less than the next revolution that builds upon its agrarian, industrial and digital forebears (Bagshaw, 2017; Sanz-Hernández, Esteban, & Garrido, 2019; Schütte, 2017).

Despite such scope, the success of governmental measures to stimulate bioeconomic markets and circular economies has been limited (Dupont-Inglis & Borg, 2017). This could be because austerity after the 2008 economic crisis encouraged a period of economic intensification within the sustainable city concept and a shift away from holistic approaches towards narrower frameworks involving increased selectivity and exclusion (e.g. Ramaswami et al., 2012). The bioeconomic framework also constitutes a young research field encompassing multiple sectors, meaning there is little consensus over its content. This is exacerbated by the visions outlined above not being mutually exclusive, and potentially being both antagonistic and internally inconsistent. For example, the bio-resource vision aims to develop new products and economic value chains based on waste-streams whilst simultaneously significantly reducing such waste-streams. Similarly, tensions between the different uses of biomass for food, material and energy production, could lead to antagonistic policy support (Meyer, 2017).

This uncertainty is unhelpful for governments and financial investors. The strategies above have been accompanied by numerous incubators and experiments (Ellen MacArthur Foundation, 2017), but the lack of systemic intervention required from the state to redirect entrenched resource flows has made revenue streams less than certain in the face of the socio-technical challenges of full-scale implementation.

However, the great attraction of the bioeconomy is its potentially vast scale of underexploited resource and value. In the EU it is estimated that 100 million tonnes of unexploited biomass could be valorised without adversely impacting upon the environment or food production (Dupont-Inglis & Borg, 2017). The bioeconomy incorporates the various components of the food system (farmers, traders, wholesalers, food manufacturing companies, and retailers), which in combination constitute the world's largest economic sector. In 2013 this generated around $12.5 trillion, or 17% of world gross domestic product (GDP) (Natural Capital Coalition, 2016). In the USA, measures to support development of a bioeconomy have generated almost $400 billion and supported over 4 million jobs through direct, indirect, and induced contributions (Dupont-Inglis & Borg, 2017). In the EU the annual turnover for the bioeconomy was €2.1 trillion in 2013, and 5.2 million jobs are supported by the UK bioeconomy (BBSRC, 2017).

Much of this economic activity is driven by governments attempting to embed externalities into production decisions through environmental regulation and associated financial penalties (Davis et al., 2016). For example, all OECD countries regulate waste streams to ensure they do not harm the environment or human health. The costs associated with complying with such regulation has led to a paradigm shift where new sources of value within the waste have been sought and identified (Venkata Mohan et al., 2016). There has also been a move towards environmental regulations being imposed on the chemical industry. This was stimulated in part by tragedies such as the Bhopal disaster in India, where thousands of people died within days of a toxic gas leak. The resulting "green chemistry" sees chemical processes redesigned to make them safer, cleaner and more energy-efficient (Ásgeirsdóttir, 2013).

However, regulation can also hinder the bioeconomy. The Ellen MacArthur Foundation (2017), found that the circular bioeconomy is being hindered by trade regulations around the classification of waste products, which make it difficult to import and export fertilisers and soil enhancers derived from organic waste. It has also been suggested that layers of stringent and lengthy regulation are 'holding back the evolution of the biosciences and their applications' (Wield, Hanlin, Mittra, & Smith, 2013). This suggests that more sympathetic regulation is required to support the bioeconomy to solve the great challenges of our time, without recourse to the underlying socio-political and economic causes of those challenges.

Even when regulation is fully aligned and supportive, its practical application can still be challenging. In the case of Green Infrastructure (or GI - networks of natural and semi-natural areas that deliver a wide range of ecosystem services), the application of ecosystem services can require coordination of multiple public and private sector urban, peri-urban and rural landowners. They must collaborate in terms of land use, monitoring and maintenance. The business case for investment in such projects is still immature, and funding often relies on scarce state support. Then there are wider questions over the wisdom of paying for ecosystem services at all. Concerns around the influence of market forces include: questions over what elements of nature are deemed useful to human society; how natural flows and processes are 'regulated' to suit human needs; the temptation to use exotic species to engineer and maximise ecosystem services at the expense of biodiversity; the impetus to bioengineer novel organisms to provide particular services; and the spatial relationship between particular ecosystems and the major consumers that can afford to pay for their services (Redford & Adams, 2009). These factors could combine to create clear winners and losers in ecosystem service markets, both in terms of those who cannot afford to pay, and the collateral damage done to biodiversity in the name of ecosystem management (Redford & Adams, 2009).

In summary it can be seen that despite recent grandiose framing, much of the bio-technology and bio-resource content of the bioeconomic imaginary is not new, and instead reflects a reengagement with the potential of bio-ecological and transformation-centred visions to use resources more efficiently and exploit new or latent biophysical, ecological and biological resources. Some of these opportunities have been stimulated by the changing calculations of environmental/climate policy, and are not uncontested. We would therefore suggest a reading of the current bioeconomy as simply the search for a new resource frontier, generating economic value from biological resources, either by exploiting existing resources, preventing further extraction of natural resources by shifting towards more efficient circular economies, or by producing or cultivating new biological resources. We now turn to the conditions that might encourage interest in a suite of processes and opportunities that we argue constitute a distinctly urban bioeconomy.

3. Urbanising the bioeconomy

The scientific paradigms that accompanied early capitalism rejected messy holism, and instead turned to reductionism, simplistic linear notions of cause and effect, and the desire to control nature and ignore its limits. This was manifest in the 1960s and 1970s, when global economic and ecological pressures led to a period of experimentation with modes of ecological control that attempted to bypass limits to growth. However ecological limits were eventually acknowledged (O'Connor, 1987; Wallerstein, 1974), and by the 1980s and 1990s, efficiency-focused arguments had permeated the governance discourse of international institutions.

At this point cities globally were seen as both a problem and as the most promising sites for new technologies to improve the performance of infrastructures, increase innovation and economic growth, and increase justice and equity (Fainstein, 2014). By the late-2000s the global financial crisis placed significant constraints upon local authority budgets and deepened concerns about cities' resilience to ecological change (Evans, 2011). Concurrently many scholars asserted the natural-ness of cities, exploring this 'second nature' in various ways (Heynen et al., 2006; Keil, 2005; Lawhon, Ernstson, & Silver, 2014; Smith, 2008).

Throughout this timeframe, the urban metabolism concept was a continual refrain in the quest to understand and control city ecologies. Thermodynamically, the urban metabolism requires continuous flows of energy and material to and from the environment for our technology and capital to function (Sterrer, 1993). This city-as-organism concept was first applied when Wolman (1965) proposed modelling dynamic flows of resources taken in and wastes expelled. The related Ecological “footprint” analysis concept gained importance as a heuristic tool for city planners in defining the land/ecosystem area necessary to provide the material and energy flows that sustain a defined urban area, city, region, or nation (Rees & Wackernagel, 2008, p. 538). Such analysis considers the direct and indirect impacts of human populations in consuming or degrading land. Both the urban metabolism and ecological footprint concepts therefore tend to see cities as greedy consumers that extract ecological value from ‘outside’, before thoughtlessly expelling waste to be managed elsewhere. In this sense cities are the epicentre of Moore’s ‘Cheap Nature’, where nature is corralled and appropriated, capital is accumulated and wastes are ‘dumped overboard’ (Moore, 2015, p. 291).

However in recent years worsening global ecological and austerity crises, and the growth of discourses around green capitalism, the circular economy and competitive cities have underpinned a concerted effort to reposition cities as responsible environmental custodians rather than needy parasites. Efforts to gain a competitive edge through the development of low carbon or green technologies have led to new logics of urban restructuring which are focussing more selectively on particular urban ecologies and on redefining what might constitute an urban ecological ‘resource’ (Hodson & Marvin, 2017). The justification often used for this shift is that thinking about ecological processes differently could unlock potential economic development. This runs counter to the holistic view of the urban environment contained in sustainable cities’ discourse, and raises questions about whether such efforts are explicitly intended to decouple economic growth from ecological limits under conditions of turbulence (e.g. extreme weather, energy and water stress) (Hodson & Marvin, 2017). This could be seen as a signifier of the shift in urban planning away from the dominant policy narrative of sustainability, towards the development of ‘climate-friendly’ and ‘climate-resilient’ global cities – something Long & Rice (2019) term ‘climate urbanism’.

There are numerous local, national and international examples of the ways in which selected aspects of urban nature (green/blue infrastructure, urban agriculture, air, sound) are reconfigured within urban economic strategies, including: the outdoor economy in Sheffield (Sheffield City Council, 2016); the Yorkshire and Humberside BioVale biotechnology regional strategy (BioVale Innovation Cluster, 2018); growing interest in urban food economies (Morrow, 2019); various low carbon city economic strategies (e.g. Sugiyama, 2012); and national and international urban ‘green’ economy policy (e.g. HM Government, 2017; Vallentin, Xia-Bauer, & Dienst, 2014). As highlighted by Goldstein & Johnson (2015), it is essential to examine the ways in which life is routinely cast in economic terms, and how this can contribute to an impoverished techno-scientific future imaginary. Life has been reduced to a commoditised form and traded across time and space – biopolitics has become inextricably linked with bioeconomics (Petersen & Krisjansen, 2015). The issues here centre around what processes of selection, measurement, calculation, standardisation, and modification are being used to render aspects of urban nature/ecology into an economic resource (Hehl-lange et al., 2012; e.g. Mell, Henneberry, Hehl-Lange, & Keskin, 2013), how are they contested, and what are the implications and consequences?

The extent to which waste and under-utilised space can be reconceptualised as an exploitable resource within a circular bioeconomy (Scarlat et al., 2015) is another example of shifting perspectives. A number of issues arise from this, including: how visible and invisible urban resource flows can be mapped, understood and exploited; how these processes can be integrated with current technology; how culturally embedded practices within the city would need to be understood and resistance to process 'valorisation' challenged; how open innovation and collaboration approaches can be encouraged across the entire waste/resource value chain to enable comprehensive, interdisciplinary organisation of future biomass flows that cut across sector boundaries; and how new resource governance models could underpin the development of an alternative eco-economic paradigm (Marsden & Farioli, 2015).

To date discussion of the bioeconomy has been largely spatially agnostic, or has tended to focus on non-urban agrarian landscapes. However cities are beginning to be seen as a major bioeconomic opportunity due to their inherent characteristics, notably: they are the source of concentrated but undervalued environmental and ecological wastes often collected in centralised infrastructure; minimising environmental waste can save money to fund investment in the bioeconomy; and, more stringent environmental regulation is leading cities to reduce and recycle their waste (Ellen MacArthur Foundation, 2017). In the following sections we exemplify the distinctive *urban* dimension of bioeconomy through three key spheres of potential bioaccumulation in cities: (i) value from waste; (ii) harnessing biological assets for economic value; and (iii) controlled/artificial environments. This conceptual framework was drawn from our analysis and database of literature and practices, where we categorised each bioeconomic intervention by type, and then considered the consequences for the urban environment (Table 2). These three spheres map onto the bioeconomic visions set out in Table 1 as follows: (i) aligns to Bio-resource visions; (ii) is a hybrid that aligns to both Bio-ecology and Biotechnology visions; and (iii) aligns to Biotechnology visions. These three spheres are not intended to be exhaustive of all the possibilities for the urban bioeconomy. Rather they are examples of some key elements of emerging urban bioeconomic practices that allow us to explore issues raised in the preceding sections.

[Table 2 near here]

3.1 Value from waste: waste mining, circular economies and bioprospecting

As long as there have been human settlements, there have been accumulations of human waste. This waste can take many forms, and is often characterised as organic and non-organic streams (Venus, Fiore, Demichelis, & Pleissner, 2018). In urban contexts organic waste includes food waste, agricultural waste, garden and arboricultural waste, biomedical waste and sewage. Non-organic urban waste streams include construction and demolition waste, chemicals, industrial waste post-consumer waste, electronic waste, and metals. Referring back to the Wolman's (1965) city-as-organism concept discussed above, the accumulation of waste products is toxic to organisms, which have developed complex methods of removing them – organs such as the liver and kidneys in our case. Similarly cities need to avoid accumulating wastes, which would have negative effects on movement, health and amenity (Gandy, 2006). Cities have therefore developed a number of ways to process waste, often centred on linear solutions such as landfill dumping, and incineration. However resource efficiency is not a recent phenomenon, and for centuries these linear solutions have occurred alongside organised sorting, reuse and recycling of waste materials (Velis, Wilson, & Cheeseman, 2009). A more recent phenomenon, however, is the sophisticated use of biological knowledge and processes to convert urban wastes (food, materials, chemicals, by-products) into resources through urban mining or 'bioprospecting'.

Urban bioprospecting involves extracting minerals, metals, nutrients and carbon from waste streams – a key tenet of the circular economy. New techniques and technologies have facilitated more efficient extraction of minerals from sewage, which must take place in or near to the urban area. Westerhoff et al. (2015) estimate that a city of 1 million inhabitants flushes around £8.7m worth of precious metals down toilets and sewer drains each year. Extracting those metals using specialized metal reducing and oxidizing organisms is a valuable source of income that can also reduce harmful elements entering ecosystems (Venkata Mohan et al., 2016). Moreover, a study of Amsterdam's annual wastewater production (population approx. 800,000) highlighted numerous useful and valuable resources that could be extracted (Ellen MacArthur Foundation, 2017), including water (72 million cubic metres); organic matter (40,041 tonnes); phosphorus (577 tonnes); nitrogen (4,140 tonnes); heavy metals (28.8 tonnes) and various reusable pharmaceuticals (3.1 tonnes).

Globally, approximately 20% of manufactured nitrogen and phosphorous is contained in domestic wastewater of which the majority is potentially recoverable due to urban concentration (Batstone & Virdis, 2014). Vancouver-based company Ostara has developed the 'Pearl' system, which extracts more than 85% of the phosphorus and approximately up to 30% of the ammonia from waste water. The end result is crystals composed of phosphorus, nitrogen, and magnesium that Ostara markets as 'Crystal Green' fertilizer (Scott, 2017). Pearl systems have been installed in Madison, Chicago, and Gwinnett County, Georgia (Gies, 2014).

The value of carbon in waste water is now also being recognised as a source of biofuels, biopolymers, commodity chemicals, and possibly even animal feeds (Puyol et al., 2017). Waste water contains 1.3 MJ/person/day (6.5 MJ/kL) of chemical energy (Batstone & Virdis, 2014), equivalent to 1% of global energy demand or 4% of global electricity production. Via a suite of bacteria and microalgae, biohydrogen (through fermentation), biogas (through anaerobic digestion) and organic acids can therefore be produced. As well as fuel, these are used to produce bioplastics, thickeners for paints and other products, and oils for making a range of chemical intermediates (Puyol et al., 2017; Scott, 2017). Recovered carbon and nutrients can also be used to produce single cell protein which may be utilised as feed, feed additives, next generation fertilisers, or even probiotics.

3.2 Harnessing biological assets for economic value

The UK provides one example of how local government capacities and capabilities globally have been eroded by aggressive national requirements for the outsourcing and privatisation of urban utility provision, most recently by post-2008 austerity cuts, leaving many critical infrastructure systems in private and often foreign ownership. Consequently, cities have struggled to find ways to compete and innovate in an austerity environment (Taylor Buck & While, 2017). Hodson & Marvin (2017) argue that austerity has opened up space for new private sector involvement and alternative approaches in urban governance. One such alternative is the intensification of the ways in which biology and ecology are seen as assets, justified on economic grounds for both new growth and more efficiency. fWithin this context, the attempts of cities and city-regions to gain competitive advantage and attract new investment has made the opportunities promised by the bioeconomy ever more attractive. As a result of the hunt for these new urban resource frontiers, we are entering an era where urban buildings and land are being seen as agents capable of harnessing biological assets for urban economic value (Edmondson et al., 2020).

At a conceptual level, biomimicry involves systematically taking design principles from nature to realise improved socio-technical efficiency and resilience (Taylor Buck, 2015). Biomimetic urban solutions could mimic ecosystems to: create circular economies that use various city waste streams as resources; provide pervious green corridors to reduce flooding impacts; and create synthetic wetland ecosystems of specific bacteria, plants, zooplankton, and fish to treat water. Similarly, mimicry of specific organisms has resulted in: building integrated dye-sensitive solar cells; Portland cement that locks away atmospheric carbon; multipath, low-grade channel designs for storm-water infrastructures; transport infrastructure design algorithms; and shape changing bridges that can accommodate the stresses of changing environments, including wind, heat and heavy loads. More specifically, bacteria can now be harnessed to produce self-healing concrete (Jonkers, 2016) that can reduce maintenance costs and safeguard embodied carbon by increasing building life span.

In the fight to reduce carbon emissions, sequestration of atmospheric carbon by plants and soil in urban areas could represent key strategic responses. As a carbon sink soil holds three times more carbon than vegetation and twice as much as the atmosphere (Wang et al., 2011). Increasing soil cover also has a concomitant increase in capacity for food production in urban areas. Changing urban land use patterns to support ecosystem services can improve both health and wellbeing and ecological value by improving air quality, reducing air temperatures, and reducing flooding impacts. Indeed, new techniques and practices are being developed for urban ecological control. Digital technologies are rendering extreme weather events as more predictable and manageable in time and space. These new logistical capabilities enable more calibrated ecological responses to facilitate continued urban functioning in the face of climatic shocks through localised and temporary infrastructure shut-downs and the strategic provision of green infrastructure (GI).

Recent work on GI has also highlighted the crucial role that ecosystems can play in supporting conventional technical urban infrastructure. For example, the European Environment Agency (2015) states that GI can provide: storm-water retention to reduce the load on sewers and offer flood protection; storm surge protection; climate regulation; and mass stabilisation to protect against landslides and avalanches. When Graz in Austria was experiencing increasing development pressures, urban heat island effects and air quality issues during economic austerity, the city developed a GI vision that identified a range of complementary delivery mechanisms to combat these problems using its existing ecological resources (Armour, Leubkeman, & Hargrave, 2014).

3.3 Controlled / artificial environments: Augmenting urban resources and urban agri-tech

Technological advances often drive the process of extracting value from existing urban resources. Globally the capacity to create controlled environments is becoming a strategic priority that is being tested through various microclimatic experiments. For cities under stress from climate and economic turbulence, controlled environments can nurture predictable biological processes or synthetic ecologies that offer a number of benefits over external nature, particularly in the fields of ecological conservation, human-leisure, and food production (Marvin & Rutherford, 2018). Focussing on the latter, urban agriculture has grown in popularity as one response to conditions of crisis and austerity (Corcoran, Kettle, & O'Callaghan, 2017), and food system resilience is a growing concern for cities with restricted budgets to tackle climate change impacts. As a result, many are searching for effective and creative ways of collaboration with the voluntary, business and investment sectors (Carey, 2013) to foster more stable local bioeconomies. Urban Controlled Environment Agriculture (CEA) potentially offers such stability, as it is more compatible with current just-in-time supply chains, operates independently of season, has faster production cycles, offers enhanced food security in the face of climate impacts, is more efficient in land use terms (Edmondson et al., 2020), and hints at the potential for smart city integration. CEA is a key element of the urban bioeconomy, facilitating the conversion of under-utilised buildings and spaces into ecological assets where conventional urban farming is not an option. Easy and cheap systems for producing food on balconies or rooftops, or within 'vertical' farms (De Cunto et al., 2017) are being sought. Vertical farms grow food inside environment-controlled, multi-storey buildings that often recycle organic waste and wastewater (Lindfield & Steinberg, 2012), and there are several notable examples of commercial successes.

Urban Crop Solutions have developed 'Farmflex' – a climate controlled shipping container with LED growing technology and irrigation systems that provides 'fully automated' 4-layer growing (Urban Crop Solutions, 2018a). Similar technology is being used in Square Roots' Urban Farming Campus located in Brooklyn, New York, where food is grown using hydroponics in climate-controlled container farms located in a car park. Each container can yield around 23kg of greens each week (Square Roots, 2018). Gotham Greens, also in New York City, operates a larger 186m^2 hydroponic indoor farm which remained fully operational during Hurricane Sandy (Berkowitz, 2014; Gotham Greens, 2018). Sky Greens' Vertical Farming System in Singapore is a low carbon hydraulic commercial farming system consisting of 38 rotating tiers of growing troughs mounted on a 9 metre aluminium frame. The rotation ensures that the plants receive uniform sunlight, irrigation and nutrients as they pass through different points in the structure. Compared to conventional farming, Sky Greens claim a tenfold increase in yield per unit land area (Sky Greens, 2018).

At larger scales, Urban Crop Solutions can also provide a custom built 'PlantFactory' of up to 130,000m^2 that facilitates industrial growing in any available space, whether basement or warehouse (Urban Crop Solutions, 2018b). AeroFarms in Newark, New Jersey is also adept at using urban space for growing aeroponically in fully controlled indoor environments. Housed in a warehouse, their aeroponic system is a closed loop system, using 95% less water than conventional farming and 40% less than hydroponics. LEDs and monitoring of macro and micronutrients reportedly lead to growing times being halved, and 390 times more productivity per unit land area than a conventional farm (Aerofarms, 2018).

Purpose-built solutions are also appearing. Swedish firm Plantagon has developed the World Food Building, currently under construction in the Swedish town of Linköping and due for completion in 2020. The building will be half offices and half hydroponic urban greenhouse. Plantagon uses 'symbiotic' solutions that turn excess heat, biomass and CO_2 into assets for local food production, and they see resource recycling as key to the long term success of urban farming (Jordahn, 2018). In 2007, SPREAD built the Kameoka Plant in Japan that produces 21,000 heads of lettuce per day, which at the time was the world's largest vertical farm. Their brand, "Vegetus", can currently be found in approximately 2,400 supermarkets nationwide. (Spread, 2018).

4. The urban bioeconomy and sustainable cities

There is growing interest in the urban bioeconomy as a means of harnessing and maximising the potential ecological and biophysical value of urban areas. However, there are several tensions around this new urban bioeconomy and its relationship with the sustainable cities discourse.

The new urban bioeconomy reflects a growing emphasis on minimising ecological footprints, but it also reflects a new focus on technologies for extracting or harnessing ecological value and the potential for making profit. Indeed, the urban bioeconomy is likely to be driven by the search for profit, as reflected in literature on resource frontiers (Knuth, 2016) and the potential enclosure of urban ecological assets (Tornaghi, 2017). For example, if we consider growing biomass for energy, we must acknowledge that in addition to the significant spatial requirements, biomass fuel requires 70 to 400 times more water to produce than other fuel sources such as fossil fuels, wind and solar (Rosegrant et al., 2013). Such high water demands could exacerbate water scarcity in many areas of the world (Scarlat et al., 2015). Pursuit of bioeconomic value may also run counter to the accepted view of a 'sustainable' city, as demonstrated by the Renewable Heat Incentive scandal that ultimately led to the collapse of devolved government in Northern Ireland, where biomass was burnt for no purpose other than to qualify for financial incentives (BBC News, 2017).

There are key questions around the inherent tensions between the drive to manage ecological turbulence, and the fundamental tenets of resilience and adaptability. Such efforts might be supported by the recent growth in companies and other ventures that aim to turn resource conservation into profit. Examples include Energy Services Companies (ESCos), and financial instruments such as Climate Change Funds and Real Estate Investment Trusts (REITs) that are evolving from their original purpose of making property more 'investable' to enabling unconventional investment opportunities. In combination these developments are increasingly allowing investors to invest in and speculate on the future of cities (Knuth, 2016).

The economics of controlled environment agriculture can be a barrier to uptake, which currently undermines its claim to triple-bottom-line sustainability. Whilst the sale of high-turnover micro herbs and salad crops to restaurants, supermarkets and sandwich chains can be viable, the economic justification for slower growing dietary staples such as root vegetables is not as clear (Baraniuk, 2017). The GrowUp Farms aquaponics facility in London provides an example of how small-scale urban farms might struggle to compete in current global food markets without cooperating and coalescing with each other at urban scales to offer the product range and prices demanded by the market. GrowUp was intended as a commercial prototype of urban CEA, receiving £1m funding from Ignite Social Enterprise, plus an Innovate UK Agritech grant. Based inside an industrial warehouse the 762m^2 facility produced more than 20,000 kg of salads and herbs and 4,000 kg of fish annually (GrowUp Urban Farms, 2017). Despite this output, GrowUp were not able to compete with established industrial supply chains on price, and the farm shut down in 2017.

The importance of actively involving society in shaping the urban bioeconomy, and developing new approaches for this dialogue, is also becoming increasingly apparent (Schütte, 2017). This is essential to address the need to expand the bioeconomy away from a narrow agro-industrial focus to include alternative forms of urban agriculture, greater social and community based innovation, and the use of local knowledge as an important means of adding value to biological resources (De Besi & McCormick, 2015).

Ideally the public sector would therefore be at the forefront of capturing the value of urban ecologies, but that will depend on its capacity to engage with the private sector as well the prevailing structures of land and utility ownership. There is a key tension within the urban bioeconomy arising from the fact that ecosystems are boundary-less networks, yet we desperately need to integrate them into our boundaried urban governance systems. In attempting to apply existing cookie-cutter governance templates over holistic natural systems, we create unhelpful delineation, false dichotomies and over-simplification.

5. Conclusions

Our aim in this paper has been to advance the notion of the urban bioeconomy as a means of conceptualising and analysing the growing interest in extracting value from the biophysical basis of cities and urban resource flows. Environmental regulation, a renewed emphasis on urban environmental stewardship and new applications of science and technology are combining to open up the city as a source of bioeconomic assets. We have examined the roots of the bioeconomic imaginary and its competing visions. Moreover, we have argued that little work exists on understanding and defining the urban bioeconomy and its inherent potentials and pitfalls. This analysis has focused on three potential spheres of latent potential for bioeconomic exploitation in cities.

First, 'value from waste' involves bioprospecting to extract minerals, metals, nutrients and carbon from waste streams. New techniques and technologies continue to facilitate more efficient extraction in this field. However, a transformational approach based purely on these technological fixes is unlikely to meet the promise of the bioeconomic imaginary. Bioeconomic visions present a future in which current global social and environmental problems have been overcome because green capitalism has facilitated the development of profitable technoscientific innovation, and much effort has been devoted to concocting policies and strategies to enable this. However technological innovation is often less about creating new technologies, and more about framing problems to suit existing or nascent ones (Goven & Pavone, 2014).

Arguably this is not an inherent fault in the bioeconomic imaginary itself, but rather a manifestation of green capitalism's protean search for new ways to apply existing knowledge and tools to new problems.

Second, 'harnessing biological assets for economic value' involves exploiting biological assets for urban economic value. This could be indirect, as in the use of biomimicry design principles, or direct as in the creation and maintenance of soils for carbon sequestration, or the exploitation of biomass for food or energy. It is important to recognise however, that although the bioeconomy is based on 'renewable' resources, it is not inherently sustainable (De Besi & McCormick, 2015; Pfau, Hagens, Dankbaar, & Smits, 2014). It is the way that these biological resources are produced and managed and the way those processes are embedded into the socio-eco-technical urban fabric that underpin the sustainability of any transition from fossil fuel to bio-based economic models (De Besi & McCormick, 2015). However, this is systematically ignored under the green capitalism drive that is evident in many of the examples and case studies set out above, and is symptomatic of the shift towards climate urbanism. Clearly careful thought needs to be given to how urban bioeconomic incentives are framed and policed if claimed benefits are to be captured.

Third, the move to augment urban resources through 'controlled / artificial environments' is an attempt at 'climate hedging' – a search for predictability and seasonal independence that is more compatible with current just-in-time supply chains, and is more efficient in land use terms. However, there are crucial spatial tensions at the heart of the bioeconomy. If farming activities expand to include the production of fuels, chemicals and products, reconciling the competing needs of agriculture and industry will present the dual challenge of a runaway environmental footprint and potential shortages of land to grow food (Philp, 2017; Zilberman et al., 2013). Ignoring debates on agriculture and food could have the potential to derail acceptance of the bioeconomic imaginary (Meyer, 2017), particularly where there is the potential for spatial inequalities. For example, the ability of wealthy elites to annex particular ecosystem services or biological resources needs careful consideration in terms of social equity and biodiversity management (Redford & Adams, 2009). Given this, it is all the more important to exploit non-agrarian urban space as much as possible to reduce this tension, and allow urban populations access to the promise of controlled environment agriculture.

These three logics are intended to be suggestive of urban bioeconomic potential rather than a complete mapping of future possibilities. Whilst the logic of a new urban bioeconomy is far from complete, its potential implications for cities are becoming apparent. We have demonstrated that the scope of the urban bioeconomy is hugely diverse, and potentially problematic because of the tension between ecological and economic gains, and the lack of capacity for the public sector to capture the value of urban ecologies. This potential (and potential contestation) has led to calls for more cross-cultural research regarding consumer attitudes to technological transitions, business and investment models, and accurate measurement and prediction tools to guide the regulatory process. In addition, a new boundary spanning urban bio-eco-economic approach that crosses the borders of social and natural science research is required to challenge the bioeconomy's current narrow framing as an engine of green capitalism. This would address the fact that biological innovations may also require a framework of organisational and business model innovations to harness their potential. The ability to influence the contextual factors that may be hampering uptake of useful bioeconomic innovations requires a thorough understanding of the intertwined technical and social bioeconomic processes, and their coevolution (Dries, Klomp, van Ophem, & Zhu, 2016), something that is currently very limited within urban studies.

References

Aerofarms. (2018). AeroFarms - Our Technology - AeroFarms. Retrieved September 26, 2018, from https://aerofarms.com/technology/

Armour, T., Leubkeman, C., & Hargrave, J. (2014). *Cities Alive: Rethinking Green Infrastructure*. London. https://doi.org/10.5326/48.5.toc

Ásgeirsdóttir, S. A. (2013). *Biomimicry in Iceland: Present Status and Future Significance*. University of Iceland.

Bagshaw, S. (2017). Towards a global bioeconomy - what is our role? *Biotechnology Journal*, *12*(7), 1600527. https://doi.org/10.1002/biot.201600527

Baraniuk, C. (2017). How Vertical Farm Reinvents Agriculture. Retrieved from http://www.bbc.com/future/story/20170405-how-vertical-farming-reinvents-agriculture

Batstone, D. J., & Virdis, B. (2014). The role of anaerobic digestion in the emerging energy economy. *Current Opinion in Biotechnology*, *27*, 142–149. https://doi.org/10.1016/j.copbio.2014.01.013

BBC News. (2017). Timeline: Renewable Heat Incentive scandal. Retrieved October 11, 2018, from https://www.bbc.co.uk/news/uk-northern-ireland-38301428

BBSRC. (2017). *Bioscience facts and figures*. BBSRC. Retrieved from http://www.env.gov.bc.ca/bcparks/aboutBCParks/fact_fig.html#attendance

Berkowitz, R. B. R. (2014). Vertical farms. *Physics Today*. https://doi.org/10.1063/PT.5.4002

BioVale Innovation Cluster. (2018). *BioVale Strategy*. Retrieved from www.BioVale.org

Brown, N.; Rappert, B.; Webster, A. (Ed.). (2000). *Contested Futures. A Sociology of Prospective Techno-Science*. Ashgate: Aldershot, UK.

Bugge, M., Hansen, T., & Klitkou, A. (2016). What Is the Bioeconomy? A Review of the Literature. *Sustainability*, *8*(7), 691. https://doi.org/10.3390/su8070691

Buscher, V., & Doody, L. (2013). *The Smart City Market : Opportunities for the UK*. London. Retrieved from www.gov.uk/bis

Carey, J. (2013). Urban and Community Food Strategies. The Case of Bristol. *International Planning Studies*, *18*(1), 111–128. https://doi.org/10.1080/13563475.2013.750938

Corcoran, M. P., Kettle, P. H., & O'Callaghan, C. (2017). Green shoots in vacant plots? Urban agriculture and austerity in post-crash Ireland. *Acme*, *16*(2), 305–331.

Davis, S. C., Kauneckis, D., Kruse, N. A., Miller, K. E., Zimmer, M., & Dabelko, G. D. (2016). Closing the loop: integrative systems management of waste in food, energy, and water systems. *Journal of Environmental Studies and Sciences*, *6*(1), 11–24. https://doi.org/10.1007/s13412-016-0370-0

De Besi, M., & McCormick, K. (2015). Towards a bioeconomy in Europe: National, regional and industrial strategies. *Sustainability (Switzerland)*, *7*(8), 10461–10478. https://doi.org/10.3390/su70810461

De Cunto, A., Tegoni, C., Sonnino, R., Michel, C., Lajili-djalaï, F., Dragonetti, W., … Lajili-djalaï, F. (2017). *Food in cities: study on innovation for a sustainable and healthy production, delivery, and food in cities*. Retrieved from https://ec.europa.eu/research/openvision/pdf/rise/food_in_cities.pdf

Diakosavvas, D., & Frezal, C. (2019). *Bio-economy and the sustainability of the agriculture and food system. OECD Food, Agriculture and Fisheries Papers, No. 136*. Paris: OECD Publishing. Retrieved from https://www.oecd-ilibrary.org/docserver/d0ad045d-en.pdf?expires=1582482454&id=id&accname=guest&checksum=1EC458BF18C7B28B9132AF2D35292B30

Dries, L., Klomp, J., van Ophem, J., & Zhu, X. (2016). Social science perspectives on the bio-economy. *NJAS - Wageningen Journal of Life Sciences*, 1–4.

https://doi.org/10.1016/j.njas.2016.04.001
Dupont-Inglis, J., & Borg, A. (2017). Destination bioeconomy - The path towards a smarter, more sustainable future. *New Biotechnology*, *40*, 140–143. https://doi.org/10.1016/j.nbt.2017.05.010
Dutch Government. (2018). *The position of the bioeconomy in the Netherlands*. Ministry of Economic Affairs and Climate Policy. Retrieved from https://gbs2020.net/fileadmin/gbs2020/documents/bioeconomy_Netherlands.pdf
Edmondson, J. L., Cunningham, H., Densley Tingley, D. O., Dobson, M. C., Grafius, D. R., Leake, J. R., … Warren, P. H. (2020). Space to grow: understanding the hidden potential of urban horticulture. *Nature Food*, *In Press*.
Ellen MacArthur Foundation. (2017). *Urban Biocycles*. Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/FINALUrban-Biocycles_EllenMacArthurFoundation.pdf
European Academies Science Advisory Council. (2017). *Opportunities and challenges for research on food and nutrition security and agriculture in Europe*. EASAC.
European Environment Agency. (2015). *Exploring nature-based solutions: The role of green infrastructure in mitigating the impacts of weather- and climate change-related natural hazards*. https://doi.org/10.2800/946387
Evans, J. P. (2011). Resilience, ecology and adaptation in the experimental city. *Transactions of the Institute of British Geographers*, *36*(2), 223–237. https://doi.org/10.1111/j.1475-5661.2010.00420.x
Fainstein, S. (2014). Financialisation and justice in the city: A commentary. *Urban Studies*, *53*(7), 1503–1508. https://doi.org/10.1177/0042098016630488
Fitter, A., Elmqvist, T., Haines-young, R. O. Y., Potschin, M., Rinaldo, A., Seta, H., … Zobel, M. (2010). An Assessment of Ecosystem Services and Biodiversity in Europe. *Issues in Environmental Science and Technology*, *30*, 1–28.
Gandy, M. (1994). *Recycling and the politics of urban waste*. Abingdon, Oxon: Earthscan - Routledge.
Gandy, M. (2006). The bacteriological city and its discontents. *Historical Geography*, *34*, 14–25.
Gies, E. (2014). Value from sewage? A new technology cleans up waste water | Guardian Sustainable Business | The Guardian. Retrieved September 26, 2018, from https://www.theguardian.com/sustainable-business/value-sewage-technology-clean-waste-water-ostara
Goldstein, J., & Johnson, E. (2015). Biomimicry: New Natures, New Enclosures. *Theory, Culture & Society*, *32*(1), 61–81. https://doi.org/10.1177/0263276414551032
Golembiewski, B., Sick, N., & Bröring, S. (2015). The emerging research landscape on bioeconomy: What has been done so far and what is essential from a technology and innovation management perspective? *Innovative Food Science & Emerging Technologies*, *29*, 308–317. https://doi.org/10.1016/j.ifset.2015.03.006
Gotham Greens. (2018). Our Farms || Gotham Greens || Premium quality locally grown vegetables and herbs. Retrieved September 26, 2018, from http://gothamgreens.com/our-farms/greenpoint
Goven, J., & Pavone, V. (2014). The Bioeconomy as Political Project: A Polanyian Analysis. *Science, Technology & Human Values*, *40*(3), 302–337. https://doi.org/10.1177/0162243914552133
GrowUp Urban Farms. (2017). Commercial-scale Controlled Environment Production. Retrieved October 12, 2018, from https://www.growup.org.uk/about-us/
Hehl-lange, S., Gill, L., Henneberry, J., Keskin, B., Lange, E., Mell, I. C., & Morgan, E. (2012). Using 3D Virtual GeoDesigns for Exploring the Economic Value of Alternative Green Infrastructure Options. *Peer Reviewed Proceedings Digital Landscape Architecture 2012 at Anhalt University of Applied Sciences*, (Cv), 273–280.
Heynen, N. C., Kaika, M., & Swyngedouw, E. (2006). *In the nature of cities: urban political ecology and the politics of urban metabolism* (Vol. 3). Routledge.
HM Government. (2017). *The Clean Growth Strategy: Leading the way to a low carbon*

future. London: HM Government. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf
Hodson, M., & Marvin, S. (2017). Intensifying or transforming sustainable cities? Fragmented logics of urban environmentalism. *Local Environment*, *0*(0), 1–15. https://doi.org/10.1080/13549839.2017.1306498
Hossain, M. B. (2019). Dust Bowls of Empire: Imperialism, Environmental Politics, and the Injustice of 'Green' Capitalism. *Journal of World-Systems Research*, *25*(2), 493–495. https://doi.org/10.5195/jwsr.2019.935
Italian Government. (2019). *BIT II: A new Bioeconomy strategy for a sustainable Italy*. Retrieved from http://cnbbsv.palazzochigi.it/media/1774/bit_en_2019_02.pdf
Jonkers, H. (2016). Self-healing of Concrete by Bacterial Mineral Precipitation. Retrieved August 6, 2018, from https://www.tudelft.nl/en/ceg/research/stories-of-science/self-healing-of-concrete-by-bacterial-mineral-precipitation/
Jordahn, S. (2018). Plantagon designs an office block containing a 60-metre-high urban farm. Retrieved September 26, 2018, from https://www.dezeen.com/2018/01/15/video-skyscraper-plantagon-urban-farm-world-food-building-movie/
Keil, R. (2005). Progress Report—Urban Political Ecology. *Urban Geography*, *26*(7), 640–651. https://doi.org/10.2747/0272-3638.26.7.640
Knuth, S. (2016). Seeing Green in San Francisco: City as Resource Frontier. *Antipode*, *48*(3), 626–644. https://doi.org/10.1111/anti.12205
Labban, M. (2014). Deterritorializing Extraction: Bioaccumulation and the Planetary Mine. *Annals of the Association of American Geographers*, *104*(3), 560–576. https://doi.org/10.1080/00045608.2014.892360
Latvian Ministry of Agriculture. (2018). *Latvian Bioeconomy Strategy 2030*.
Lawhon, M., Ernstson, H., & Silver, J. (2014). Provincializing urban political ecology: Towards a situated UPE through African urbanism. *Antipode*, *46*(2), 497–516. https://doi.org/10.1111/anti.12051
Lindfield, M., & Steinberg, F. (Eds.). (2012). *Green Cities*. Mandaluyong City, Phillipines: Asian Development Bank. Retrieved from http://www.adb.org/sites/default/files/pub/2012/green-cities.pdf
Long, J., & Rice, J. L. (2019). From sustainable urbanism to climate urbanism. *Urban Studies*, *56*(5), 992–1008. https://doi.org/10.1177/0042098018770846
Lösch, A., & Schneider, C. (2016). Transforming power/knowledge apparatuses: the smart grid in the German energy transition. *Innovation*, *29*(3), 262–284. https://doi.org/10.1080/13511610.2016.1154783
Marsden, T., & Farioli, F. (2015). Natural powers: from the bio-economy to the eco-economy and sustainable place-making. *Sustainability Science*, *10*(2), 331–344. https://doi.org/10.1007/s11625-014-0287-z
Martinez-Hernandez, E., & Samsatli, S. (2017). Biorefineries and the food, energy, water nexus — towards a whole systems approach to design and planning. *Current Opinion in Chemical Engineering*, *18*, 16–22. https://doi.org/10.1016/j.coche.2017.08.003
Marvin, S., & Rutherford, J. (2018). Controlled environments: An urban research agenda on microclimatic enclosure. *Urban Studies*, *55*(6), 1143–1162. https://doi.org/10.1177/0042098018758909
Mell, I. C., Henneberry, J., Hehl-Lange, S., & Keskin, B. (2013). Promoting urban greening: Valuing the development of green infrastructure investments in the urban core of Manchester, UK. *Urban Forestry and Urban Greening*, *12*(3), 296–306. https://doi.org/10.1016/j.ufug.2013.04.006
Meyer, R. (2017). Bioeconomy strategies: Contexts, visions, guiding implementation principles and resulting debates. *Sustainability (Switzerland)*, *9*(6). https://doi.org/10.3390/su9061031
Moore, J. W. (2015). *Capitalism in the Web of Life*. Verso Books.
Morrow, O. (2019). Geoforum Sharing food and risk in Berlin ' s urban food commons. *Geoforum*, *99*(August 2018), 202–212. https://doi.org/10.1016/j.geoforum.2018.09.003

Natural Capital Coalition. (2016). *Natural Capital Protocol*. https://doi.org/10.1017/s1358246100006536

Norwegian Government. (2016). *Familiar resources - undreamt of possibilities: The Government´s Bioeconomy Strategy*. Ministry of Trade Industry and Fisheries. Retrieved from https://www.regjeringen.no/contentassets/32160cf211df4d3c8f3ab794f885d5be/biookonomi-eng-kortversjon_uu.pdf

O'Connor, J. (1987). *The meaning of crisis*. New York: Blackwell.

Petersen, A., & Krisjansen, I. (2015). Assembling "the bioeconomy": Exploiting the power of the promissory life sciences. *Journal of Sociology*, *51*(1), 28–46. https://doi.org/10.1177/1440783314562314

Pfau, S. F., Hagens, J. E., Dankbaar, B., & Smits, A. J. M. (2014). Visions of sustainability in bioeconomy research. *Sustainability*, *6*(3), 1222–1249. https://doi.org/10.3390/su6031222

Philp, J. (2017). The bioeconomy, the challenge of the century for policy makers. *New Biotechnology*, *40*, 11–19. https://doi.org/10.1016/j.nbt.2017.04.004

Ponte, S. (2019). Green capitalism and unjust sustainabilities. *SAMFUNDSØKONOMEN*, 102–108.

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., … Duffy, S. (2006). *Guidance on the Conduct of Narrative Synthesis in Systematic Reviews*. *ESRC Methods Programme*. https://doi.org/10.1001/archderm.1985.01660090059014

Puyol, D., Batstone, D. J., Hulsen, T., Astals, S., Peces, M., & Kromer, J. O. (2017). Resource recovery from wastewater by biological technologies: Opportunities, challenges, and prospects. *Frontiers in Microbiology*, *7*(JAN), 1–23. https://doi.org/10.3389/fmicb.2016.02106

Ramaswami, A., Weible, C., Main, D., Heikkila, T., Siddiki, S., Duvall, A., … Bernard, M. (2012). A Social-Ecological-Infrastructural Systems Framework for Interdisciplinary Study of Sustainable City Systems: An Integrative Curriculum Across Seven Major Disciplines. *Journal of Industrial Ecology*, *16*(6), 801–813. https://doi.org/10.1111/j.1530-9290.2012.00566.x

Redford, K. H., & Adams, W. M. (2009). Payment for ecosystem services and the challenge of saving nature: Editorial. *Conservation Biology*, *23*(4), 785–787. https://doi.org/10.1111/j.1523-1739.2009.01271.x

Rees, W., & Wackernagel, M. (2008). Urban Ecological Footprints: Why Cities Cannot be Sustainable—and Why They are a Key to Sustainability. In J. M. Marzluff, E. Shulenberger, W. Endlicher, M. Alberti, G. Bradley, C. Ryan, … U. Simon (Eds.), *Urban Ecology: An International Perspective on the Interaction Between Humans and Nature*.

Republic of Austria. (2019). *Bioeconomy: A Strategy for Austria*. Federal Ministry of Transport Innovation and Technology. Retrieved from https://www.bmlrt.gv.at/english/environment/Climateprotect/Austria-s-Bioeconomy-Strategy.html

Rosegrant, M. W., Ringler, C., Zhu, T., Tokgoz, S., & Bhandary, P. (2013). Water and food in the bioeconomy: Challenges and opportunities for development. *Agricultural Economics (United Kingdom)*, *44*(SUPPL1), 139–150. https://doi.org/10.1111/agec.12058

Sanz-Hernández, A., Esteban, E., & Garrido, P. (2019). Transition to a bioeconomy: Perspectives from social sciences. *Journal of Cleaner Production*, *224*, 107–119. https://doi.org/10.1016/j.jclepro.2019.03.168

Sanz-Hernández, A., Sanagustín-Fons, M. V., & López-Rodríguez, M. E. (2019). A transition to an innovative and inclusive bioeconomy in Aragon, Spain. *Environmental Innovation and Societal Transitions*, *33*(January 2019), 301–316. https://doi.org/10.1016/j.eist.2019.08.003

Sasson, A., & Malpica, C. (2017). Bioeconomy in Latin America. *New Biotechnology*. https://doi.org/10.1016/j.nbt.2017.07.007

Scarlat, N., Dallemand, J.-F., Monforti-Ferrario, F., & Nita, V. (2015). The role of biomass and bioenergy in a future bioeconomy: Policies and facts. *Environmental Development*, *15*, 3–34. https://doi.org/10.1016/j.envdev.2015.03.006
Schütte, G. (2017). What kind of innovation policy does the bioeconomy need? *New Biotechnology*, 3–7. https://doi.org/10.1016/j.nbt.2017.04.003
Scott, A. (2017). Tapping sewage as a source of useful materials.
Sheffield City Council. (2016). *The Outdoor City Economic Strategy*. Sheffield: Sheffield City Council. Retrieved from http://www.welcometosheffield.co.uk/content/images/fromassets/100_7296_011216153153.pdf
Sky Greens. (2018). Sky Greens – Technology. Retrieved September 26, 2018, from https://www.skygreens.com/technology/
Smáradóttir, S. E., Magnúsdóttir, L., Smárason, B. Ö., Þórðarson, G., Johannessen, B., Stefánsdóttir, E. K., … Margeirsson, S. (2014). *Future opportunities for bioeconomy in the West Nordic countries*. Matis. Retrieved from http://www.matis.is/media/matis/utgafa/Bioeconomy-in-the-West-Nordic-countries-37-14.pdf
Smith, N. (2008). *Uneven Development: Nature, Capital, and the Production of Space*. Athens: University of Georgia Press.
Spread. (2018). A New Way to Grow Vegetables. Retrieved September 26, 2018, from http://spread.co.jp/en/company/
Square Roots. (2018). The Platform. Retrieved September 26, 2018, from https://squarerootsgrow.com/platform/
Sterrer, W. (1993). Human economics: A non-human perspective. *Ecological Economics*, *7*(3), 183–202. https://doi.org/10.1016/0921-8009(93)90003-O
Sugiyama, N. (2012). Local Climate Policies in Japan: A Case Study of Nagoya City's Strategy. In *Handbook of Sustainability Management* (pp. 513–529). WORLD SCIENTIFIC. https://doi.org/10.1142/9789814354820_0024
Taylor Buck, N. (2015). The art of imitating life: The potential contribution of biomimicry in shaping the future of our cities. *Environment and Planning B: Planning and Design*. https://doi.org/10.1177/0265813515611417
Taylor Buck, N., & While, A. (2017). Competitive urbanism and the limits to smart city innovation: The UK Future Cities initiative. *Urban Studies*, *54*(2), 501–519. https://doi.org/10.1177/0042098015597162
Tornaghi, C. (2017). Urban Agriculture in the Food-Disabling City: (Re)defining Urban Food Justice, Reimagining a Politics of Empowerment. *Antipode*, *49*(3), 781–801. https://doi.org/10.1111/anti.12291
Urban Crop Solutions. (2018a). FarmFlex Container | Urban Crop Solutions. Retrieved September 26, 2018, from https://urbancropsolutions.com/farm-systems/farm-flex/
Urban Crop Solutions. (2018b). PlantFactory | Urban Crop Solutions. Retrieved September 26, 2018, from https://urbancropsolutions.com/farm-systems/plant-factory/
Vallentin, D., Xia-Bauer, C., & Dienst, C. (2014). *Lessons learnt from a Sino-German Low Carbon City Project: A Manual*. Wuppertal: Low Carbon Future Cities. Retrieved from https://seors.unfccc.int/applications/seors/attachments/get_attachment?code=0O6SWVIRI0DIPULKM1VGG13Y2JPJ1S3K
Velis, C. A., Wilson, D. C., & Cheeseman, C. R. (2009). 19th century London dust-yards: A case study in closed-loop resource efficiency. *Waste Management*, *29*(4), 1282–1290. https://doi.org/10.1016/j.wasman.2008.10.018
Venkata Mohan, S., Nikhil, G. N., Chiranjeevi, P., Nagendranatha Reddy, C., Rohit, M. V, Naresh Kumar, A., & Sarkar, O. (2016). Waste Biorefinery Models Towards Sustainable Bioeconomy: Critical Review and Future Perspectives. *Bioresource Technology*. https://doi.org/http://dx.doi.org/10.1016/j.biortech.2016.03.130
Venus, J., Fiore, S., Demichelis, F., & Pleissner, D. (2018). Centralized and decentralized utilization of organic residues for lactic acid production. *JOURNAL OF CLEANER PRODUCTION*, *172*, 778–785. https://doi.org/10.1016/j.jclepro.2017.10.259

Wallerstein, I. (1974). *The modern world-system*. New York: Academic Press.
Wang, Y., Tu, C., Cheng, L., Li, C., Gentry, L. F., Hoyt, G. D., … Hu, S. (2011). Long-term impact of farming practices on soil organic carbon and nitrogen pools and microbial biomass and activity. *Soil and Tillage Research*, *117*, 8–16. https://doi.org/10.1016/j.still.2011.08.002
Westerhoff, P., Lee, S., Yang, Y., Gordon, G. W., Hristovski, K., Halden, R. U., & Herckes, P. (2015). Characterization, Recovery Opportunities, and Valuation of Metals in Municipal Sludges from U.S. Wastewater Treatment Plants Nationwide. *Environmental Science and Technology*, *49*(16), 9479–9488. https://doi.org/10.1021/es505329q
Wield, D. (2013). Bioeconomy and the global economy: Industrial policies and bio-innovation. *Technology Analysis and Strategic Management*, *25*(10), 1209–1221. https://doi.org/10.1080/09537325.2013.843664
Wield, D., Hanlin, R., Mittra, J., & Smith, J. (2013). Twenty-first century bioeconomy: Global challenges of biological knowledge for health and agriculture. *Science and Public Policy*, *40*(1), 17–24. https://doi.org/10.1093/scipol/scs116
Wolman, A. (1965). The Metabolism of Cities. *Scientific American*, *213*(3), 178–193. Retrieved from http://www.jstor.org/stable/pdf/24931120.pdf
Zilberman, D., Kim, E., Kirschner, S., Kaplan, S., & Reeves, J. (2013). Technology and the future bioeconomy. *Agricultural Economics*, *44*, 95–102. https://doi.org/10.1111/agec.12054