# The Limits of the Smart Sustainable City

Tina Ringenson
CESC – Centre for Sustainable Communications &
Division of Environmental Strategies Research, School of Architecture and the Built Environment
KTH Royal Institute of Technology
100 44 Stockholm
krin@kth.se

Elina Eriksson
CESC – Centre for Sustainable Communications &
Department of Media Technology and Interaction Design, School of Computer Science and Communication
KTH Royal Institute of Technology
100 44 Stockholm
elina@kth.se

Miriam Börjesson Rivera
CESC – Centre for Sustainable Communications &
Division of Environmental Strategies Research, School of Architecture and the Built Environment
KTH Royal Institute of Technology
100 44 Stockholm
miriamrg@kth.se

Josefin Wangel
Division of Environmental Strategies Research, School of Architecture and the Built Environment
KTH Royal Institute of Technology
100 44 Stockholm
wangel@kth.se

## ABSTRACT

The ongoing and escalating urbanisation has resulted in a situation where a majority of people worldwide live in cities. Cities stand for a substantial part of the world GDP and are often lifted as possible drivers of sustainable development. However, the city has limitations and vulnerabilities. Cities depend on resources flowing into the city and increasing populations strain their land use. Climate change threatens cities with sea-level rise, heat waves and extreme weather events. Transforming cities into Smart Sustainable Cities by incorporation of Information and Communication Technologies (ICTs) is becoming a recurring proposed solution to these limitations and challenges. The two main areas where ICT are envisioned to function for this are i) as part of the city's infrastructure for monitoring, efficiency and automatization of processes, and ii) as an enabler for sharing of both information and goods among citizens, expectedly leading to more sustainable urban lifestyles.

However, there are several limits to the realisation of the Smart Sustainable City. Manufacturing, implementation and maintenance of its digital infrastructure hold environmental risks and require human and natural resources. Furthermore, there are issues of increased vulnerability of the city due to increased complexity. Already now, the (global) flows that the city depends upon to thrive, are to a large and increasing extent possible due to - and dependent on - ICTs working without disturbances. Considering the fragility of these systems, both physical and virtual, is the Smart Sustainable City a desirable or even feasible path?

We suggest that while ICT may be useful for making cities more sustainable, we need to be heedful so as not to make the city even more vulnerable in the process. We suggest that we should make sure that the ICT systems simply assist the cities, while maintaining analogue backup in case the ICT shuts down; that we should build more resilient ICT systems with higher backward compatibility; and that we should acknowledge increasing complexity as a problem and strive to counteract it.

## KEYWORDS

Smart sustainable cities, urbanisation, limits

**ACM Reference format:**

T. Ringenson, E. Eriksson, M. Börjesson Rivera, J. Wangel. 2017. The Limits of the Smart Sustainable City. In *Proceedings of ACM LIMITS, Santa Barbara, California USA, July 2017*, 8 pages.
DOI: 10.1145/3080556.3080559


*LIMITS '17, June 22-24, 2017, Santa Barbara, CA, USA*

ACM 978-1-4503-4950-5/17/06…$15.00
http://dx.doi.org/10.1145/3080556.3080559

# 1 LIMITS TO URBAN GROWTH

## 1.1 An urbanising world

When describing the appeal of the city and its interdependency with the countryside Lewis Mumford stated: "Within the city the essence of each type of soil and labor and economic goal is concentrated: thus arise greater possibilities for interchange and for new combinations not given in the isolation of their original habitats" [50] The city arises "out of man's social needs and multiply both their modes and their methods of expression"[50].

Urbanisation has been ongoing since the industrial revolution and intensified since the 1950s, leading to that over half of the world's population is now living in cities [76]. Moreover, the urban population is expected to continue to grow substantially the coming decades, both in terms of proportion and absolute numbers. Altogether the urban population is expected to grow from today's 3.9 billion [83] to 6.3 billion in 2050 [77]. The two key factors that cause urbanization are rural-urban migration and urban nativity, both of which lead to an expansion or densification of urban areas, and rural villages growing into urban settlements [9,77].

Urbanisation does not only imply a change in the geographical distribution of people, but also of flows and stocks of resources. The 2.4 billion new urbanites that are expected until 2050 will all need houses, workplaces, services and infrastructures for water provision, sewage treatment, waste management, transportation and communication. And, given that urbanites are getting increasingly wealthy [14], the overall urban consumption can be expected to increase even more.

Although cities only surmount to 54% of the world's population, they stand for 80% of the world's GDP [76]). The UN Habitat [76] describes urbanisation as a transformative power, as it may lead to better employment and higher employment rates, less poverty, educational opportunities and better quality of life. The European Commission states that "[c]ities are seen as both the source of and solution to today's economic, environmental and social challenges" [10]. According to the UN Habitat [76] cities have a central role to play in "moving the sustainable energy agenda forward" (p. 28) and should be a "positive and potent force for addressing sustainable economic growth, development and prosperity" (p. 29). Cities are also increasingly put forth as drivers of sustainable development [41], as a more efficient way of organising society in terms of land-use, service provision, and ecologies of infrastructures.

## 1.2 Urban vulnerabilities

However, cities and urbanisation have both limitations and vulnerabilities. To begin with, there is the mere limitations to suitable land for physical expansion, which could lead to higher land and house prices in such areas and thereby housing injustices and shortage [64]. Traffic congestion is a long-standing and growing problem in cities, and statistics suggest that it is primarily rising in metropolitan areas that are either growing quickly or already very large [15,19].

Cities are also particularly vulnerable to disasters caused by natural hazards and weather extremes [21], which lately have become exacerbated by climate change [1]. Already in 2014, 1.4 billion people (i.e. one third of the world's urban population) lived in cities facing high risk of exposure to a natural disaster [77]. One reason for this is that cities often are situated along coasts or major rivers, making them vulnerable to sea-level rise and storm surge risk [27]. Heat waves tend to hit cities harder than rural areas because of the urban heat island effect [62], a phenomenon that makes urban areas significantly warmer than surrounding areas, especially at night, and that is caused by the concentration of construction materials and energy use in urban areas (ironically enough a lot of the energy is often used for cooling). One effect of the urban heat island effect is that peak demand for energy takes place in the summer rather than the winter in many regions of the world, occasionally leading to energy providers not being able to meet the demand with power blackouts as a consequence [25].

Power blackouts, both rolling and unexpected, present a threat towards cities, as city dwellers are often dependent on electricity for food storage, indoor climate control, and even sometimes to get in and out of their buildings. Urban energy systems are becoming increasingly important to consider with the upcoming shift from energy from fossil fuels to energy from renewable sources, like solar and wind power. To tackle climate change and secure our energy supply for the future, we must change to carbon-free, renewable energy supplies [16]. But these are often intermittent and relatively unpredictable, and much harder to store and transport than high-energy density fossil fuels and thermal electricity generated in stations with high load factors [31,66]. The question is then how renewable energy sources will be able to meet an increasing energy demand.

## 1.3 City-hinterland interactions

Cities have always been dependent on a hinterland as source (of food and other resources) and sink (of pollutants) [22,59] and has thus always had an impact of their surroundings. However, due to industrialisation and rapid urbanisation these impacts have accelerated [71]. The larger a city becomes in terms of population, the larger the flows of resources and waste; the larger the city becomes in terms of spatial expansion, the longer the transports. Moreover, a city that expands physically will often eventually encroach on its hinterland, i.e. land that is already used for agriculture [64]. The hinterland used to be in rather close proximity to the city, at least for bulk flows. But due to colonisation, industrialisation, and the rise of global capitalism, these flows has become increasingly long and complex, leading to a situation where most cities of today are heavily dependent on a globally fragmented hinterland. Where cities once were depicted as the centre of concentric circles of hinterlands (see e.g. [22]), the cities of today have rather become "nodes of a global network of trade exchanges" [3:249].

These flows and trade exchanges, and related extraction of resources for manufacturing and transports, are fundamentally dependent on an equally complex set of infrastructures and would not be possible without the help of information and communication technologies (ICTs) [72]. Townsend [73] even argues that the development of ICT (from couriers to telegraphs to telephones to 4G) and urban growth must be understood as a symbiosis. ICT is also fundamental to the internal operations of cities, for monitoring and managing urban infrastructures for transporting goods, people, waste, water, sewage and information. Hodson et al. [32] describes this as that the "resource flows through cities are conducted by complex networked infrastructures which, in turn, have been designed, built, and operated in accordance with a particular set of technical modalities and governance routines that for the most part assume a continuous supply of resources." [26:790].

Cities (as centres of trade) stand for an unproportionally large share of global GDP (80 %) as compared to their population [76]. This is mainly due to the fact that that the global consumer class can be found in urban areas [14], especially in low-income countries, which leads to unproportionally high levels of consumption taking place in cities [64]. The globalised economy and hinterlands are also fundamentally dependent on the availability and use of cheap energy, namely fossil fuels (see e.g. [48]). Since income and associated consumption practices is the key explanatory factor for people's GHG footprint, this has led to that cities stand for 80 % of global greenhouse gas emissions [67] and 75 % of resource use [36,63]. Hence, even though urban areas might, at least in theory, support a more (resource) efficient way of organising societies and everyday life, this is in many cases counteracted by the relatively higher incomes and associated consumption by urban residents. Moreover, urban areas are rarely developed based on sustainable design principles but are subsumed to the logics of a capitalist urban (re-)development paradigm dictating what is being built, how, for whom and where (see e.g. [6,8,18,38,47]).

Altogether this implies that the internal sustainability of cities (i.e. the city as habitat) is fundamentally vulnerable to 1) the functionality of ICT both within and outside the city, and 2) the availability of cheap energy (i.e. fossil fuel), without which the global resource flows feeding into the urban metabolism and the urban metabolism per se would come to a halt. Indeed, 'cities' is a far from homogenous category. One could expect that cities in countries that import more embodied resources (e.g. energy, GHG, and water) than they produce or export (see e.g. [13]) would be more vulnerable, as would cities in countries with more 'high-tech' industrialised production practices, cities in densely populated countries, and cities in countries with little of natural resources per capita.

## 2 SMART TO THE RESCUE

### 2.1 What is smart, anyway?

The "Smart Sustainable City" (SSC), or sometimes just "the smart city", is recurrently proposed as a possible solution to the limitations and predicaments connected to rapid urbanisation and cities' environmental impacts. In 2016, the United Nations launched the campaign "United for Smart Sustainable Cities" (U4SSC) to advocate ICT use as a catalyst for the transition to smart sustainable cities [78]. The United Nations' International Communication Union (ITU) has a focus group on SSCs, focusing on identifying what standardisation frameworks that are needed to support the integration of ICT services in cities [37]. The European Union has organised the European Innovation Partnership for Smart Cities and Communities, which "combines [ICT], energy management and transport management to come up with innovative solutions to the major environmental, societal and health challenges facing European cities today" [11].

However, an exact definition of the SSC is evasive. In principle, the concept "smart" can be seen as either a normative, an empirical, or an instrumental concept [35]. As a normative concept, smartness can either be seen as inherently valuable in itself or as implicating sustainability [60], and may encompass other characteristics than ICT-use, such as efficiency and good physical planning. As an empirical concept, smart is used to indicate that ICT is an important part of a piece of equipment, a service or a city, but without any evaluation as to whether this is good or bad (see e.g. [51]). Often however, the concept is used instrumentally, i.e. as a combination of the two, with an emphasis on using ICT (as an empirical category of technology) to deal with or avoid problems to a normative end (see e.g. [2,33,40]).

Sometimes "sustainable" is explicitly added, either to indicate it as a goal to which smart should contribute, or as a boundary that the city must stay within, even if the focus lies elsewhere, such as on city competitiveness [35]. Nevertheless, the word "sustainable" in SSC too often suffers the same fate as within the Sustainable HCI community in that "there is little discussion about what actually constitutes sustainability" [14:638], resulting in definitions so broad as to becoming meaningless.

There are however exceptions to this. The ITU focus group on Smart Sustainable Cities defines the term "smart sustainable city" as "an innovative city that uses information and communication technologies (ICTs) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social and environmental aspects" [42]. Another more explicit definition is Höjer and Wangel's [35] definition of a smart sustainable city as "a city that 1) meets the needs of its present inhabitants; 2) without compromising the ability for other people or future generations to meet their needs; 3) and thus, does not exceed local or planetary environmental limitations; 4) and where this is supported by ICT" [35]. With this definition, relational limitations are introduced, not only temporal (now and in/for the future), but also spatial. This implies that, sustainability is understood by using a relational concept of space, that it cannot be an atomized aspect to the city only, and as such must encompass its surrounding hinterland no matter where on Earth (or in space) it is located, as well as the globe as a whole.

### 2.2 Smart for Sustainable

When ICTs are implemented with the purpose of contributing to sustainability goals, they tend to be used for one or both of the following functions: i) as solutions that are part of the city's infrastructure, e.g. for monitoring or automatization of processes so as to make them more efficient, and/or ii) as an enabler for solutions, such as sharing of both information and goods among citizens, expectedly leading to more sustainable urban lifestyles [44,51]. According to Wiig and Wyly [81] "cities have increasingly been augmented by digital hardware and software, producing massive amounts of data about urban processes" [19:488] during the past 15 years, and ICTs are now driving new forms of urban development. Below we will exemplify some of the ways that smartness is proposed to help cities that suffer from sustainability issues.

2.2.1 Smart transports. For transports, ICT can support sustainable travel choices, with traveller information systems, and lessen the travel demand through enabling flexible working [43]. ICT can also be used to manage transports in a more effective way. For both private cars and public transport, pricing can be adjusted to incentivise shifting one's travel times to off-rush hours [26]. For cars and freight transports, it has been suggested that intelligent transport systems can direct drivers to alternative routes to avoid or spread out congestion [26,86], and enable more cars on the roads without congestion, through fleet management systems [43].

*2.2.2 Smart grids and energy use.* Smart grids can both let users understand their energy use better and automatically adjust quantity and timing for more efficient usage of the grid. Sensor-controlled streetlights and (smart) houses serve the purpose of house holding with electricity, so that the less energy will be used even as the city is growing and more places need electricity [46,58].

The previously mentioned fluctuations in energy supply from renewable energy sources could also be handled using smart technologies. Smart grids can be used to enable small-scale energy production to become part of the distribution grid and to mitigate problems with fluctuations in the power generation by making electricity cheaper when there is a lot available, and vice versa [79].

*2.2.3. Smart consumption – services and sharing.* Other types of consumption than energy use can also be addressed with ICT. Höjer et al. [34] and Mitchell [49] have explored how ICT can support the transition from the consumption of goods to the consumption of services, with assumably smaller environmental footprints. One such example is substituting CDs and books with digital services. In the long term this transition could also decrease the user's need for e.g. storage space, thus enabling them to live in smaller and thereby more resource-efficient apartments.

ICT has also enabled the sharing economy, which has been explored as a tool to increase the intensity of usage of things [34,53]. The sharing economy has also been suggested as a way to tackle both the limits of natural resources used to produce the things themselves, as well as the limited space in cities. One example of a sharing activity is renting out one's apartment to tourists and thereby lessening the need for the space for a hotel. Other examples are car sharing or renting out one's parking spot during the day, thus lessening the need to build more parking spots and potentially reducing the amount of cars in cities [60]. Of course, true to its name, ICT can also be used to inform city inhabitants of the impact of their habits and support or persuade them to make better choices [85].

*2.2.4. Smart infrastructure.* Overall, the smartness of cities often implies a larger set of interconnected systems, "a digital nervous system" [44], which will encompass all infrastructure systems to one. The technologies often already exists, and hence the "novelty is thus not so much the individual technologies, products or services but the interconnection and the synchronization of these and the systems they include, so that they work in concerted action" [8: 337]. The goals of these visions is to have a centralized control centre with overview of all flows and activities in the city [24], and through efficiency and effectiveness counteract some of the issues with the unsustainability of cities [73].

# 3 LIMITS TO SMARTING THE CITY

Even though there is optimism and expectancy connected to the possibilities of solving problems with cities through smart technology, there has also been criticism against the SSC.

## 3.2 SSC dependency

The smart city rests upon a contemporary dominant 'cornucopian' design paradigm, [55] rewarding faster, richer and more pervasive digital services. One crucial consequence of this current paradigm is that "[s]ervices most users were happy without become essential to everyday life for the majority of the populace in developed countries." [54: 1326]. Furthermore, if ICT constantly keep stretching the boundaries for what our societies can deliver, we constantly keep expecting more [74]. One example to illustrate this, is how we may once have welcomed being able to use our phones or computers to simply check our bank accounts without going to the bank. Now, services provided by our banks enable us to pay bills using our phones. At the same time, banks are closing down their services for paying bills at the bank office, effectively making the process of paying bills harder for people who want to pay bills using cash or are unaccustomed with smart phones. Another example is how electronic payment is substituting cash payments and thus making even simple transactions, such as buying milk at the grocery store or paying for a beer at the pub, increasingly dependent on functioning ICT systems connected to the internet and powered by electricity. As ICT is becoming more integrated into people's daily lives, we create new energy dependent social practices, and hence lock us into a world where we hardly can live without the technological devices.

## 3.2 Information does not suffice to change behaviours

Many of the proposed SSC solutions are aimed at making individuals change their behaviour to a more sustainable manner. However, this is a heavily criticised perspective, and builds on an assumed ideal rational consumer [68]. Related to transports, there are several studies that indicate that travel information has very little impact on travel habits [20,52]. Studies on pricing schemes, such as congestion charges, also point towards the effect mostly depending on related practices, rather than pricing itself being the most important factor [30,65]. Also, the spatial structure of the city and the transport systems available for the city dwellers have great impact on transport mode choices [17,80].

Priest et al. [55] point out that even though strategies for mitigating environmental impacts of the ever growing digital infrastructure have value, there is currently an unsustainable growth in energy consumption. While ICTs are often used to improve energy efficiency, they may not always actually do so. Svane [69] showed that smart energy saving devices in apartment buildings in Swedish housing area Hammarby Sjöstad were often not used as intended, resulting in a situation where "interactive ICT in smart infrastructure enables energy efficiency but does not provide it" [66: 194]. Sometimes energy efficiency instead lead to rebound effects, such as increased use of the product in question or spending saved money on other things with equal or bigger environmental impact [61]. In that case, the investments in ICT for improving efficiency in energy consumption or labour productivity may mean an absorption of gain, with the investments failing to reach their goals [23]. However, indirect and second order effects are often hard to measure, especially when they are long-term, far-reaching and systemic [4,61]. .

## 3.3 The direct impact of ICT

The Energy is needed to keep the smart city running, but the energy consumption in the use phase of electronic devices is not their only problematic side. The direct effects of ICT can be hard to estimate due to the complexity of the composition of the hardware itself, as well as the energy to power it. Modern ICT s are dependent on rare and highly refined materials, both as part of the devices themselves, as well as part of the manufacturing [82]. These materials are highly resource-consuming to mine and refine, and many of them increase the risk of human exposure to hazardous materials [82]. The short lifecycles of ICTs leave more or less fully functioning devices obsolete, contributing to e-waste which in turn have serious environmental, health, and social consequences [12,28,75]. The rapid development of ICT also leads to a need for continuous maintenance, updating and renewing of more or less constant updates of the system, with the hardware of the smart solutions.

## 3.4 Smart is more vulnerable?

The above critique against the use of ICT in smart sustainable cities is relevant; however, there are more deep issues with building the sustainability of a city around digital technology. In order to reach the climate goals, the amount as well as the share of renewable energy in the energy system will have to increase [16], implying that the future energy supply will be less predictable and controllable than today. While ICTs can be used to improve energy reliability in a future with more renewable and intermittent energy, trying to solve a problem by installing electronic devices or digital solutions can also end up requiring more energy and resources than it saves. Even though energy consumption can be adjusted from the demand side using monetary incentives, and partially be stored using energy storage, it will not be able to change the supply side of energy by changing the inflow. Hilty [31] argues that people living in regions supplied with energy from local renewable sources would need to adapt their lifestyles to the pace of the renewable energy supply, instead of - like now - relying on a consistent energy flow. If we in the present create cities and lifestyles reliant on electronic devices, there will inevitably be complications if some of these might end up having to be turned off during low-energy periods.

Furthermore, extreme weather events, such as hurricane Sandy, have shown that communication network technologies are increasingly vulnerable "as their architectures are more distributed and more relying on power from an electric grid" [44: 521]. Jakubek [39] points out that the wireless devices fail due to network hardware being destroyed but also due to the networks being overloaded by the users. This is a major issue as more and more people rely on wireless devices as their only source of communication, and thus risk being unable to seek help or support [39]. Moreover, if the (global) flows that the city depends upon, are to a large extent dependent on ICTs, these extreme weather events will generate vulnerabilities that will affect more than just the possibility to communicate. Considering the fragility of these systems, is the SSC a desirable or even feasible path?

Moreover, as the functionality of modern ICT is dependent on rare materials, these materials in themselves set limits for the number of devices that can be installed. Even if recycling of these materials improves, there is still a limitation to how much can be mined and processed [29,84]. They cannot continue to solve problems into eternity, in eternally growing cities.

# 4 CONCLUDING DISCUSSION

In this paper we have presented a selection of contemporary challenges and vulnerabilities regarding cities and urbanisation, focusing on the location of cities, characteristics of built environment, and city-hinterland interactions. Thereafter the concept of 'smart sustainable cities' was introduced, describing how ICT could contribute to the mitigation of urban sustainability issues, but also introducing several limitations and possible threats associated with the digitization of urban infrastructures and everyday life. We conclude that even though ICT do have a clear potential to handle sustainability issues in cities, there are good reasons to be heedful so as not to create a sand castle, even more brittle than before.

From a limits point of view, we perceive a couple of key concerns. As elaborated above, a city is a highly complex socio-technical system. Using smart technology to solve precarious issues increases the complexity even more. Following Tainter [70], solving problems usually leads to increased complexity and decreased marginal return of the investment in solving the problem. From this perspective, the future of the smart sustainable city does not look bright in the long run. One option could be to explore the possibilities of refactoring the city, in line with Raghavan and Pargman [57], who suggest that instead of solving problems with increased complexity "we should explicitly aim to redesign existing systems to reduce societal complexity, and this should be considered a worthwhile goal of computing research and engineering" (p. 4). There are however few signs in contemporary SSC practice and policy making of that complexity is acknowledged as a problem.

This points to what has been conceptualized as a more general problem of shortsightedness and particularization in urban and technological development (see e.g. [3]). F.ex. refactoring the smart sustainable city after the ICT investments have been done would be more resource demanding than if doing it as part of the initial investment. This is especially problematic given that the future will only see more of the resource scarcity and other limitations that contemporary society is already starting to feel.

Smart also comes with implications for the resilience of urban infrastructures and other machinery of everyday life. While ICT can contribute to an increased resilience in some cases, like 'self-healing grids', there is a clear risk that the comprehensive digitization implied in visions of SSC and IoT contributes to a substantially lowered resilience of society. Already today can minor power blackouts cause substantial harm, as can failing ICT systems. One possible solution to could be to make sure that the ICT systems are only there to assist, while maintaining analogue backup for normal functionality in case they shut down. It is also important to create robust systems with backward compatibility and functioning hardware recycling. Both academia and the business sector express concerns regarding the mere amount of raw materials needed to smarten our planet (see e.g. [7,56]), as well as if these materials can be extracted and used in a way that does not contribute to domestic or colonial systematic violence.

What has not been discussed in this paper are the social and political issues connected to the smart sustainable city. Smart cities, especially as being promoted by the large ICT corporations, have been criticized for being autocratic, proprietary and where citizens are not invited to be part of the creation of the city [24]. By smarting the city, there is potential exclusion of individuals in the city in light of digital divide and income levels. Even though not discussed in this paper we acknowledge these issues as of great importance when considering the future of cities.

## REFERENCES


[1] Maarten K Van Aalst. 2006. The impacts of climate change on the risk of natural disasters. *Disasters* 30, 1: 5–18.

[2] Sam Allwinkle and Peter Cruickshank. 2011. Creating Smart-er Cities: An Overview. *Journal of Urban Technology* 18, 2: 1–16. https://doi.org/10.1080/10630732.2011.601103

[3] Franco Archibugi. 2008. Planning Theory: From the Political Debate to the Methodological Reconstruction. Springer-Verlag, Milano.

[4] Frans Berkhout and Julia Hertin. 2004. De-materialising and re-materialising: digital technologies and the environment. *Futures* 36, 8: 903–920.

[5] Gilles Billen, Josette Garnier, and Sabine Barles. 2012. History of the urban environmental imprint: introduction to a multidisciplinary approach to the long-term relationships between Western cities and their hinterland. *Regional Environmental Change* 12, 2: 249–253. https://doi.org/10.1007/s10113-012-0298-1

[6] Neil Brenner. 1997. State territorial restructuring and the production of spatial scale: Urban and regional planning in the Federal Republic of Germany, 1960–1990. *Political Geography* 16, 4: 273–306. https://doi.org/10.1016/S0962-6298(96)00003-0

[7] Perrine Chancerel, Max Marwede, Nils F. Nissen, and Klaus Dieter Lang. 2015. Estimating the quantities of critical metals embedded in ICT and consumer equipment. *Resources, Conservation and Recycling* 98: 9–18. https://doi.org/10.1016/j.resconrec.2015.03.003

[8] Brett Christophers. 2011. Revisiting the Urbanization of Capital. *Annals of the Association of American Geographers* 101, 6: 1347–1364. https://doi.org/10.1080/00045608.2011.583569

[9] Barney Cohen. 2006. Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in society* 28, 1: 63–80.

[10] European Commission. Urban development - Regional Policy - European Commission. Retrieved April 8, 2017 from http://ec.europa.eu/regional_policy/en/policy/themes/urban-development/

[11] European Commission. 2014. Smart Cities and Communities: About the partnership - What is it? Retrieved April 7, 2017 from http://ec.europa.eu/eip/smartcities/about-partnership/what-is-it/index_en.htm

[12] Benjamin W Cramer. 2012. Man's need or man's greed: The human rights ramifications of green ICTs. *Telematics and Informatics* 29: 337–347.

[13] Steven J Davis and Ken Caldeira. 2010. Consumption-based accounting of CO2 emissions. *Proceedings of the National Academy of Sciences of the United States of America* 107, 12: 5687–5692. https://doi.org/10.1073/pnas.0906974107

[14] Richard Dobbs, Jaana Remes, James Manyika, Charles Roxburgh, Sven Smit, and Fabian Schaer. *Urban world: Cities and the rise of the consuming class*. Retrieved from http://www.mckinsey.com/global-themes/urbanization/urban-world-cities-and-the-rise-of-the-consuming-class

[15] Anthony Downs. 2004. Still Stuck in Traffic: Coping with Peak-Hour Traffic Congestion. The Brookings Institution, Washington.

[16] ECF. 2010. Roadmap 2050 A PRACTICAL GUIDE TO A PROSPEROUS, LOW-CARBON EUROPE. Brussels.

[17] Reid Ewing, Gail Meakins, Grace Bjarnson, and Holly Hilton. 2011. Transportation and Land Use. In *Making Healthy Places: Designing and Building for Health, Well-being, and Sustainability*, Andrew L. Dannenberg, Howard Frumkin and Richard J. Jackson (eds.). Island Press/Center for Resource Economics, 149–169.

[18] Susan S. Fainstein. 2008. Mega-projects in New York, London and Amsterdam. *International Journal of Urban and Regional Research* 32, 4: 768–785. https://doi.org/10.1111/j.1468-2427.2008.00826.x

[19] John C Falcocchio and Herbert S Levinson. 2015. *Road Traffic Congestion: A Concise Guide*. Springer, Cham.

[20] Sendy Farag and Glenn Lyons. 2012. To use or not to use? An empirical study of pre-trip public transport information for business and leisure trips and comparison with car travel. *Transport Policy* 20: 82–92.

[21] Rebecca Gasper, Andrew Blohm, and Matthias Ruth. 2011. Social and economic impacts of climate change on the urban environment. *Current Opinion in Environmental Sustainability* 3, 3: 150–157. https://doi.org/10.1016/j.cosust.2010.12.009

[22] Herbert Girardet. 2013. Towards the regenerative city. Expert Commission on Cities and Climate Change of the World Future Council.

[23] Cedric Gossart. 2015. Rebound Effects and ICT: A Review of the Literature. In *ICT innovations for sustainability*, Lorenz M. Hilty and B. Aebischer (eds.). Springer International Publishing, Cham, 435–448. https://doi.org/10.1007/978-3-319-09228-7

[24] A Greenfield. 2013. Against the smart city (The city is here for you to use, part I). Do Projects, New York City.

[25] Sue Grimmond. 2007. Urbanization and global environmental change: local effects of urban warming. *The Geographical Journal* 173, 1: 83–88.

[26] Anders Gullberg. 2015. An Integrated Information and Payment Platform for urban transport. Stockholm.

[27] Stéphane Hallegatte, Nicola Ranger, Olivier Mestre, Patrice Dumas, Jan Corfee-Morlot, Celine Herweijer, and Robert Muir Wood. 2011. Assessing climate change impacts, sea level rise and storm surge risk in port cities: A case study on Copenhagen. *Climatic Change* 104, 1: 113–137. https://doi.org/10.1007/s10584-010-9978-3

[28] Michelle Heacock, Carol Bain Kelly, Kwadwo Ansong Asante, Linda S Birnbaum, Åke Lennart Bergman, Marie-Noel Bruné, Irena Buka, David O Carpenter, Aimin Chen, and Xia Huo. 2016. E-Waste and Harm to Vulnerable Populations: A Growing Global Problem. *Environmental health perspectives* 124, 5: 550–555.

[29] Richard Heinberg. 2010. Peak everything: Waking up to the century of declines. New Society Publishers.

[30] Greger Henriksson. 2008. *Stockholmarnas resvanor - mellan trängselskatt och klimatdebatt*. Ph.D. thesis in Ethnology at Lund University. Published by KTH Royal Institute of Technology, TRITA-INFRA-FMS 2008:5, ISSN 1652-5442 (in Swedish with an extensive summary in English), Stockholm, Sweden.

[31] Lorenz Hilty. 2015. Computing Efficiency, Sufficiency, and Self-sufficiency: A Model for Sustainability? In *Limits 2015*.

[32] Mike Hodson, Simon Marvin, Blake Robinson, and Mark Swilling. 2012. Reshaping Urban Infrastructure: Material Flow Analysis and Transitions Analysis in an Urban Context. *Journal of Industrial Ecology* 16, 6: 789–800. https://doi.org/10.1111/j.1530-9290.2012.00559.x

[33] Robert G. Hollands. 2008. Will the real smart city please stand up? *City* 12, 3: 303–320. https://doi.org/10.1080/13604810802479126
[34] Mattias Höjer, Åsa Moberg, and Greger Henriksson. 2015. *Digitalisering och hållbar konsumtion*. Naturvårdsverket, Stockholm.
[35] Mattias Höjer and Josefin Wangel. 2015. Smart sustainable cities: definition and challenges. In *ICT Innovations for Sustainability*. Springer, 333–349.
[36] IRP. 2013. Urban Resource Flows and the Governance of Infrastructure Transitions. Retrieved from https://www.journals.elsevier.com/environmental-development/news/urban-resource-flows-and-the-governance
[37] ITU. Focus Group on Smart Sustainable Cities. Retrieved April 7, 2017 from http://www.itu.int/en/ITU-T/focusgroups/ssc/Pages/default.aspx
[38] Jane Jacobs. 1961. *The Death and Life of Great American Cities*. Random House, New York.
[39] Robert R Jakubek. 2015. Nonequivalent Quasi-Experimental Study of Wireless Telecommunication Traffic During Severe Winter Storms. *IEEE Access* 3: 1036–1041.
[40] Rob Kitchin. 2014. The real-time city? Big data and smart urbanism. *GeoJournal* 79, 1: 1–14. https://doi.org/10.1007/s10708-013-9516-8
[41] Jacqueline M Klopp and Danielle L Petretta. 2017. The urban sustainable development goal: Indicators, complexity and the politics of measuring cities. *Cities* 63: 92–97. https://doi.org/10.1016/j.cities.2016.12.019
[42] Sekhar N Kondepudi and The International Telecommunication Union (ITU). 2014. *Smart sustainable cities: An analysis of definitions* . ITU-T Focus Group on Smart Sustainable Cities.
[43] Anna Kramers. 2014. Smart Cities and Climate Targets: Reducing cities' energy use with ICT and travel information.
[44] Anna Kramers, Mattias Höjer, Nina Lövehagen, and Josefin Wangel. 2014. Smart sustainable cities–Exploring ICT solutions for reduced energy use in cities. *Environmental Modelling & Software* 56: 52–62.
[45] Alexis Kwasinski. 2013. Effects of hurricanes Isaac and Sandy on data and communications power infrastructure. In *Telecommunications Energy Conference'Smart Power and Efficiency'(INTELEC), Proceedings of 2013 35th International*, 1–6.
[46] Fabio Leccese. 2013. Remote-Control System of High Ef fi ciency and Intelligent Street Lighting Using a ZigBee Network of Devices and Sensors. *Ieee Transactions on Power Delivery* 28, 1: 21–28. https://doi.org/10.1109/TPWRD.2012.2212215
[47] Duncan Maclennan and Julie Miao. 2017. Housing and Capital in the 21st Century. *Housing, Theory and Society* 6096, April: 1–19. https://doi.org/10.1080/14036096.2017.1293378
[48] A. Malm. 2016. Fossil Capital: The Rise of Steam Power and the Roots of Global Warming. Verso Books.
[49] W.J. Mitchell. 1999. *E-topia: "Urban life, Jim – but not as we know it."* MIT Press, Cambridge, Massachusetts.
[50] Lewis Mumford. 2014. Cities and the Crisis of Civilization. In *The Sustainable Urban Reader* (Third), Stephen M Wheeler and Timothy Beatley (eds.). Routledge, New York, 20–23.
[51] Paolo Neirotti, Alberto De Marco, Anna Corinna Cagliano, Giulio Mangano, and Francesco Scorrano. 2014. Current trends in Smart City initiatives: Some stylised facts. *Cities* 38: 25–36.
[52] Åsa Nyblom. 2014. Making travel sustainable with ICT? The social practice of travel planning and travel information use in everyday life. KTH Royal Institute of Technology.
[53] Daniel Pargman, Elina Eriksson, and Adrian Friday. 2016. Limits to the Sharing Economy. *Limits*. https://doi.org/10.1145/2926676.2926683
[54] Daniel Pargman and Barath Raghavan. 2014. Rethinking Sustainability in Computing: From Buzzword to Non-negotiable Limits. In *NordiCHI*, 638–647.
[55] Chris Preist, Dan Schien, and Eli Blevis. 2016. Understanding and Mitigating the Effects of Device and Cloud Service Design Decisions on the Environmental Footprint of Digital Infrastructure. In *CHI 2016, May 7-12*, 1324–1337.
[56] PWC. 2011. Minerals and metals scarcity in manufacturing: the ticking timebomb Sustainable Materials Management. *Pwc*, 24.
[57] Barath Raghavan and Daniel Pargman. 2016. Refactoring Society : Systems Complexity in an Age of Limits. https://doi.org/10.1145/2926676.2926677
[58] Prof K Y Rajput, Gargeyee Khatav, Monica Pujari, and Priyanka Yadav. 2013. Intelligent Street Lighting System Using Gsm. *International Journal of Engineering Science Invention* 2, 3: 60–69.
[59] William Rees and Mathis Wackernagel. 1996. URBAN ECOLOGICAL F O O T P R I N T S : W H Y CITIES CANNOT BE SUSTAINABLE AND WHY THEY. 16: 223–248.
[60] T Ringenson and M Höjer. 2016. Smart City Planning and Environmental Aspects? Ict4s: 159–166. Retrieved from http://www.atlantis-press.com/php/download_paper.php?id=25860379
[61] Miriam Börjesson Rivera, Cecilia Håkansson, Åsa Svenfelt, and Göran Finnveden. 2014. Including second order effects in environmental assessments of ICT. *Environmental Modelling & Software* 56: 105–115.
[62] M Santamouris. 2014. On the energy impact of urban heat island and global warming on buildings. *Energy and Buildings* 82: 100–113.
[63] Saskia Sassen. 2009. Human Settlement Development: The Central Role of Cities in Our Environment's Future - Constraints and Possibilities. *UNESCO EOLSS I*.
[64] David Satterthwaite. 2011. How urban societies can adapt to resource shortage and climate change. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences* 369, 1942: 1762–1783. https://doi.org/10.1098/rsta.2010.0350
[65] Elizabeth Shove and Gordon Walker. 2010. Governing transistions in the sustainability of everyday life. *Research Policy* 39: 471–476.
[66] Vaclav Smil. 2006. 21st century energy: Some sobering thoughts. *OECD Observer*, 258–259: 22–23.
[67] Benjamin K. Sovacool and Marilyn A. Brown. 2010. Twelve metropolitan carbon footprints: A preliminary comparative global assessment. *Energy Policy* 38, 9: 4856–4869. https://doi.org/10.1016/j.enpol.2009.10.001
[68] Yolande Strengers. 2014. Smart energy in everyday life: are you designing for resource man? *interactions* 21, 4: 24–31.
[69] Örjan Svane. 2013. Energy Efficiency in Hammarby Sjöstad , Stockholm through ICT and smarter infrastructure – survey and potentials. *Ict4S 2013*: 190–196.
[70] Joseph A. Tainter. 2011. Energy, complexity, and sustainability: A historical perspective. *Environmental Innovation and Societal Transitions* 1, 1: 89–95. https://doi.org/10.1016/j.eist.2010.12.001
[71] Joel A. Tarr. 2002. The Metabolism of the Industrial City: The Case of Pittsburgh. *Journal of Urban History* 28, 5: 511–545. https://doi.org/10.1177/0096144202028005001
[72] K. T K Toh, P. Nagel, and R. Oakden. 2009. A business and ICT architecture for a logistics city. *International Journal of Production Economics* 122, 1: 216–228. https://doi.org/10.1016/j.ijpe.2009.05.021
[73] Anthony Townsend. 2013. Smart cities - big data, civic hackers and the quest for a New Utopia. Norton & Company, New York.
[74] Sherry Turkle. 2012. Alone together: Why we expect more from technology and less from each other. Basic books.
[75] Shakila Umair, Anna Björklund, and Elisabeth Ekener Petersen. 2015. Social impact assessment of informal recycling of electronic ICT waste in Pakistan using UNEP SETAC guidelines. *Resources, Conservation and Recycling* 95: 46–57.
[76] UN-Habitat. 2016. *Urbanization and Development: Emerging Futures*. Retrieved from https://unhabitat.org/wp-content/uploads/2014/03/WCR- Full-Report-2016.pdf
[77] UNDESA. 2016. *The World's Cities in 2016 – Data Booklet*. Retrieved from http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf
[78] United Nations News Centre. 2016. UN launches campaign to urge "smart" transition to sustainable cities. Retrieved April 7, 2017 from http://www.un.org/apps/news/story.asp?NewsID=54052#.WOdDm_mGO71
[79] Simona Vasilica Oprea. Informatics Solutions for Prosumers connected to Smart Grids. 12–20.
[80] Åsa Waldo. 2002. *Staden och resandet: Mötet mellan planering och vardagsliv*. Sociologiska institutionen, Lunds universitet, Lund.
[81] Alan Wiig and Elvin Wyly. 2016. Introduction: Thinking through the politics of the smart city.
[82] Eric Williams. 2011. Environmental effects of information and communications technologies. *Nature* 479: 354–358. https://doi.org/10.1038/nature10682
[83] World Bank. 2016. World Urbanization Prospect Indicators. Retrieved from http://data.worldbank.org/indicator/SP.URB.TOTL
[84] Patrick A Wäger, Roland Hischier, and Rolf Widmer. 2015. The Material Basis of ICT. In *Advances in Intelligent Systems and Computing*, Lorentz M Hilty and B. Aebischer (eds.). Springer International Publishing, Cham, 209–221. https://doi.org/10.1007/978-3-319-09228-7
[85] Jorge Luis Zapico, Marko Turpeinen, and Nils Brandt. 2009. Climate persuasive services : changing behavior towards low- carbon lifestyles. *Proceedings of the 4th International Conference on Persuasive Technology*: 14:1--14:8. https://doi.org/10.1145/1541948.1541968
[86] Renata Żochowska and Grzegorz Karoń. 2016. ITS Services Packages as a Tool for Managing Traffic Congestion in Cities. In *Intelligent Transportation Systems – Problems and Perspectives*. Springer International Publishing, 81–103. https://doi.org/10.1007/978-3-319-19150-8_3