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Energy savings from Smart Cities: A critical analysis

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Abstract

The world's cities are responsible for some three-quarters of global energy use and energy- and industry-related greenhouse gas emissions. Global climate change mitigation, and ecological sustainability in general, therefore crucially depend on the sustainability practices of urban residents. Present climate change policies are not working, as annual emissions are still growing. Clearly, new approaches are needed. One possible new approach is to implement *smart city* policies. In this paper, the potential for smart city policies to help make significant energy (and related greenhouse gas) savings in urban transport and building construction and operation is investigated. The main findings are that although significant potential exists, it will not be realised unless supporting policies are in place. Furthermore, support for smart city innovation will be weakened unless the challenges of data privacy, security and reliability can be overcome.

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Keywords:, air pollution; greenhouse gases; internet of things; smart cities; urban energy use; urban transport

1. Introduction

More than half the 2018 global population of about 7.5 billion already live in cities, a proportion that can be expected to increase, at least in the short term. When a full accounting of both energy and greenhouse gas (GHG) emissions is done, it is estimated that cities globally are responsible for roughly 75% of both energy and energy- and industry-related GHGs [1,2]. The energy that is directly consumed in cities, such as in urban vehicles, households and factories, is a major contributor to both urban air pollution and the urban heat island (UHI) effect. (In cities showing the UHI effect, various factors including heat release, reduced evaporative surfaces and urban form combine to raise temperatures above that of the surrounding countryside [3].) But the reach of cities is far greater

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than these direct effects, since they draw in raw materials, food, water, and energy, including electricity, from more distant, even global, locations. The energy and GHG costs of these imports must also be attributed to cities.

Given this dominant position for urban energy and GHGs, it follows that there can be no ecological sustainability, no global climate change mitigation, if cities themselves are not sustainable in this wider sense. This is increasingly recognised by urban governments worldwide: over one thousand local governments have joined the International Council for Local Environmental Initiatives (ICLEI) [4]. Urgent action and new ideas are needed, since present climate change policies are not working. According to a recent study by Peters and colleagues [5], global carbon dioxide (CO_2) emissions from energy/industry, after stagnating from 2014 to 2016, were expected to rise 2% in 2017, and to total 37 gigatonne (Gt). Since cities account for 75% of this total, it is clear than urban GHG reduction policies are not working either. In this paper, only the energy- and GHG-related aspects of urban sustainability will be examined. The paper looks at the possible role for *smart cities* (SCs) in reducing urban energy use, and also urban GHG and air pollution emissions.

Nomenclature

BD	big data
CBD	central business district
CHP	combined heat and power
CO_2	carbon dioxide
EJ	exajoule (10^{18} joule)
ES	environmental sustainability
GHG	greenhouse gas
Gt	gigatonne
ICLEI	International Council for Local Environmental Initiatives
ICT	Information and Communications Technology
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
MJ	megajoule (10^6 joule)
PTA	Personal Travel Assistant
PV	photovoltaic
RE	renewable energy
SC	smart city
UHI	urban heat island

2. Smart cities, the internet of things and big data

Reductions in urban energy use, along with urban GHG and air pollution emissions are important aims in what are variously described as *green cities*, *eco-cities* and *smart cities* (smart cities are also called *intelligent cities*). Several self-described eco-cities have been planned, a number of cities in the world already call themselves smart cities and publications on SCs show an exponential growth pattern [6]. However, in all cases, the cities concerned have only made a start on implementing policies that would make them ecologically sustainable. As Glasmeier and Nebiolo [7] have stressed, SCs are an 'idea that promises a great deal, but so far has delivered modest results.' Marks [8] has even commented bluntly that the hype about SCs is now reaching 'fever pitch'. On the other hand, the use of big data is already well established in some areas of science (eg high energy physics, astronomy) and in commerce (eg the retail sector).

Where SCs differ from green/eco-cities is their heavy stress on using the new Information and Communications Technology (ICT) to accomplish urban environmental sustainability, as well as better, more citizen-responsive, urban governance. Baig and colleagues [9] define a smart city as having six categories: 'smart environment, smart mobility, smart economy, smart governance, smart people and smart living; with IoT as the enabling technology.' The present paper is only concerned with the first two items on this list. The Internet of Things (IoT) can itself be defined as ‘the network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators, and connectivity which enables these objects to connect and exchange data’ [10] The global number of such on-line capable devices is rising rapidly, and is forecast to increase from 8.4 billion in 2017 to 30 billion by 2020.[10].

SCs can only be an innovative solution to urban sustainability if two conditions are met: (a) SC applications can cheaply and reliably provide large volumes of timely, relevant and useable data, and (b) a relative lack of information is presently at least one of the important barriers to attaining ES in cities. See [2] for arguments supporting these two propositions.

2.1. Present and potential examples of SC initiatives in urban transport

A number of cities around the globe have implemented one or more SC policies relevant to urban environmental sustainability [11]. Urban planners have long realised that road traffic needs to be treated as an interconnected system. For decades, well before the idea of smart cities was considered, cities have been using computers and traffic sensors to monitor real-time traffic flows on their network, adjusting lane directions, traffic light timings and speed limits to achieve maximum efficiency from the road network. More recently, in Spain, the city of Santander has instituted a smart parking scheme that monitors parking spots and gives real time information on availability to motorists [11]. Boston, USA, installed sensors at hundreds of downtown parking spots. Planning officials used the occupancy data collected to change time limits, reducing those for spots in heavy demand, and increasing them for more lightly used parking spots. Uber, the transport company, is now sharing its ride data with Boston city planners, which will give them access to origin and destination and time of travel for all Uber trips [12].

Public transport has also benefited from big data applications, and any shift from private to public transport modes has urban ES benefits, since such modes are generally several times more energy and GHG efficient (in terms of passenger-km per megajoule or kg CO_2) than the car [13]. Smart cards for use on public transport systems are now used in a number of cities. Apart from traveller convenience—important for any modal shift from cars—these smart cards, like London’s Oyster Card, provide vast amounts of data on trip volumes, destinations and times, which can be used for transport planning. Smart phone apps are now available for a number of cities, helping intending travellers plan their trips and giving dynamic information on the time of the next public transport service at their pickup location. In Seoul, Republic of Korea, planners have developed a Personal Travel Assistant (PTA) which allows travellers to select a mode and route giving the shortest travel time, the cheapest travel costs, or the lowest GHG emissions [14].

For the city of Barcelona, Spain, Bassolas and colleagues [15] constructed resident activity diaries using information gathered from mobile phones, then used these to build a transport MATSim model for that city. Such activity-based models are superior to the traditional trip-based four-stage models (trip generation, trip distribution, mode choice and route assignment), but their use so far has been restricted because of their heavy data needs [15]. Such an approach, based on how residents go about their daily out-of-home activities, can help urban planners better understand existing urban travel patterns, a necessary step toward steering them in a more sustainable direction.

It is unlikely that merely substituting more public transport travel for car travel will in itself reduce urban transport energy enough. Nor will feasible higher vehicle energy efficiencies or occupancy rates. Instead, large reductions in vehicular travel itself are needed, which will involve reframing the urban transport problem as one of *accessibility*, not *mobility* [13]. What people want from transport is the ability to access out of home activities—workplaces, shops, schools. Implementation of supporting policies which discourage urban car travel—such as speed limit and parking space reductions, priority for alternative transport modes, pedestrian-only precincts and carbon taxes—could benefit from SC initiatives. Increasing both the monetary *and* time costs of car travel with these policies will significantly change travel patterns as residents adjust to the new transport realities. Residents can respond in the short term by choosing closer destinations for discretionary trips such as shopping, coupled with more use of non-motorised modes. Other trips types can be combined, rather than made separately [16]. Smartphone PTA apps could help here; urban residents could input the time and location of their non-discretionary trips (eg work trips) as constraints. The PTA could then calculate how other trips could be fitted around these constraints so as to minimise travel energy or GHGs [2].

Another means by which ICTs could reduce urban travel is by *direct substitution* of trips such as those for work, business, shopping, education or health reasons [17]. However, as Gössling [18] has stressed when discussing the general impact of ICTs on transport, ICT can presently have both positive and negative impacts on levels of personal travel. Hence a further vital requirement for SC success is supporting transport and energy policies that can encourage sustainable practices, which might for instance include city-wide traffic speed reductions, restrictions on parking, traffic-free CBDs, and priority for more environmentally friendly modes [13]. Implementation of carbon taxes would likewise favour less vehicular trips and a shift to more energy and carbon efficient modes.

2.2. Present and potential examples of SC initiatives in urban energy

Along with private transport fuel use, domestic energy use—mainly reticulated natural gas and electricity in OECD countries—is under the direct control of the urban householder. Householders have for many decades received overall energy consumption information in the form of their periodical household electricity and gas energy bills. *Smart meters* are now being trialled in a number of countries, but so far this more detailed data on energy use available to consumers has had little impact on their domestic energy consumption [19]. As we saw with transport and ICTs, smart meters also presently have mixed effects on domestic energy use. But this could change in future, because of the urgent necessity to raise the share of electricity derived from renewable energy (RE) sources to combat climate change. Although the global technical potential for RE may be large, most of this potential is for two intermittent sources, wind and solar energy [20].

If RE is to eventually produce the major share of both electrical and non-electrical energy globally, it will be thus necessary to institute both energy storage and *load shifting*—shifting electricity use away from periods of low intermittent wind and solar energy generation. The shift to RE will bring about several major changes in householders' perceptions of energy use and its costs. First, with the advent of domestic rooftop photovoltaic cell (PV) arrays, particularly in Germany, households (and non-energy businesses) are turning into *prosumers*—they both consume and produce electricity. Further, a major shift to RE electricity will tend to increase energy prices, because lower quality resources will need to be progressively tapped and energy storage will be increasingly needed, necessitating conversion of excess primary RE electricity into hydrogen or chemical energy in batteries and later reconversion back into electricity. Storage will thus involve substantial energy losses and hence rising costs [20]. A carbon tax will be needed to encourage the shift away from fossil fuels.

The real cost of domestic energy will vary with the minute-to-minute variations in RE output. Householders will become much more aware of these energy prices, and the hourly energy costs of their appliances. They will use weather forecasts (predicted wind speeds, insolation)—or more likely, smartphone apps giving predictions of energy costs based on weather forecasts, to decide when to use major amounts of domestic energy. Some activities like clothes washing and drying and carpet vacuuming can be shifted several days or more to take advantage of lower prices. Some continuously operated thermal appliances like refrigerators, freezers and water heaters can be automatically turned off or turned up for short periods when intermittent energy production is low or high respectively [2]. By reducing the need for energy storage, overall energy and costs are saved. Smart grids will be a necessary part of this transition to intermittent energy sources [21].

Further future energy savings can be realised by viewing urban energy use in its entirety. This might entail keeping track of the location and magnitude of urban waste heat sources, whether from vehicles, factories, buildings or power stations. This data could be integrated with detailed data on temperature, wind speeds etc over the city area. The data could then be used to plan how waste heat could be used for district heating schemes, where parks should be located for maximum cooling effect in warmer cities, or what would be the optimum location for major waste heat sources [2].

3. Challenges for smart cities

3.1. Privacy and security

Privacy is the recognition that individuals should be able to keep some personal information a secret from others, and is the basis for the various privacy laws. However the rise of the internet and big data has forced a continuous revaluation of the concept and its meaning [2]. Fortunately, privacy concerns are likely of less importance for urban environmental sustainability than they are for urban health, for example, where much information of a personal nature must necessarily be collected for use by health practitioners and planners. Certainly, data from urban pollution level sensors, or from infrastructure monitoring devices should have few privacy implications, but detailed transport data from smart phones has implications for privacy.

Security could be a much more serious problem for SCs [9]. As control over transport and traffic operations, power grids and other infrastructure are increasingly automated, the danger from malacious cyber attacks rises. So far, SC software package vendors, in their rush to get the product to market, have not given security priority [22]. As Colding and Barthel [6] have argued: ‘By interconnecting systems that serve totally different purposes (e.g., traffic control and energy management), creating a “system of systems”, the complexity of such collaborating systems increases exponentially. As a result, the number of vulnerabilities in a Smart City system will be significantly higher than that of each of its sub-systems [23]. Hence, cyber security is one of the biggest challenges facing smart city development.’ Care will need to be taken to ensure that the benefits exceed the costs, which may not be the case for some proposed ‘smart home’ applications.

3.2. Other challenges for SCs

SC applications also face *reliability* problems. These can arise from use of the data trail from social media for urban research, where it is known that deliberate manipulation of data occurs to promote commercial or political gains. Technical problems still remain, even in technologically sophisticated countries. Apart from the problem of providing power sources to perhaps billions of sensors, the use of BD in general is still hampered by lack of storage capacity, computational power and even skilled personnel. Job loss could also occur for some job types [2].

Some of the present energy-related SC applications may have unintended consequences, with adverse urban sustainability implications. These often arise because of the failure to adopt a *systems* approach to urban energy use. For example, smart parking and smart traffic management might reduce the energy and GHG emissions for a particular car trip, but if total car trips consequently rise because of this better management, travel by alternative modes—non-motorised and public transport—will fall. The result will be increases in both urban transport energy use and GHG emissions. Likewise, a PTA might give information on the shortest journey time, energy/GHG emissions, or monetary cost for a given trip. However, the route and mode giving the shortest travel time will often conflict with those giving the lowest environmental cost, because the slower modes are usually more energy-efficient [13]. Without supporting policies, travellers, especially those on higher incomes, could well prefer to save time over money or environment.

4. Discussion and conclusions

Large cities today need very large amounts of timely data for their efficient operation, and if cities are to become more environmentally sustainable, this need can only rise in future [2]. As detailed in Section 2 for domestic energy and urban transport, Smart City applications have much potential for reducing urban energy use/GHGs, and so producing a better urban environment as well as helping mitigate global warming [24].

But several conditions must be met before SCs can realise their energy-saving potential. There are some risks to privacy with data collected from, for example, social media, or from personal transport data. As the number of internet-connected sensors rapidly expands, the opportunity for security breaches likewise increases. Social data use can also lead to reliability problems. Unless these concerns are properly addressed, and security built into the software, SCs will not be able to realise their urban sustainability potential. Even if these various SC difficulties can all be overcome, a variety of supporting policies will also need to be introduced to support SC initiatives. These most likely include a general carbon tax, which should both reduce energy use and help the shift away from fossil fuels. For urban transport, additional policies much encourage a reduction in urban motorised transport overall, and a focus on access over mobility. For the remaining passenger transport, priorities need to shift toward non-motorised and public transport modes. Such a shift will probable need to include pedestrian only precincts, road closures, city-wide speed limit reductions and greater parking restrictions.

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