Big Data, People, and Low-Carbon Cities

Paul Fleming

Abstract Information- and communications-technology systems are now collecting and analysing previously unimaginable amounts of data in cities. Big data and the "internet of things" are allowing communications between city infrastructure (buildings, transport systems, equipment, and appliances) and people. For example, data are collected by a wide range of public and private organizations, and people are sharing their own local weather and local solar-electricity production. This chapter discusses how cities can use the information from this increasing volume of data to decrease their carbon emissions, help create new employment opportunities, facilitate future infrastructure investment, and more effectively engage with their citizens.

Keywords Energy management • Low-carbon city • Future city • Smart grids • Community engagement • Citizen data • Data analysis

Key Terms

Big Data. The large volume of structured and unstructured data that is now available from buildings, transport systems, people, etc. It refers to data that are too big to be analysed using traditional data-processing techniques.

The Internet of Things. The representation of uniquely identifiable objects on the Internet. A medium for transferring data between a data source and the processes that monitor those data sources. Enabling things to communicate with each other.

Virtual power plant. A collection of distributed energy-supply technologies (fossil fuel or renewables) that can be virtually managed as "one single power plant".

Smart grid. An energy network that is able to optimise energy supply with demand by monitoring and controlling energy supply, storage, and demand. It decreases peaks in demand by remotely switching off equipment or shifting the use of that equipment to another time period.

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Smart city. A city that uses information and communication technology to help improve governance, mobility, carbon emissions, and peoples' quality of life. It uses big data and Internet of Things to manage city infrastructure and to provide feedback from, and dialogue with, city stakeholders and citizens.

Digital divide. Inequality between people and cities in terms of their access to, and knowledge of, information and communication technology.

1 Introduction

Cities have been taking action to decrease their greenhouse-gas emissions for many years. Organisations—such as Energy Cities [1], Fedarene [2], ICLEI [3], Climate Alliance [4], the Covenant of Mayors [5], the C40 Cities Climate Leadership Group [6], Eurocities [7], and the OECD [8]—all possess a wealth of information on how to decrease greenhouse-gas emissions at the city scale. Traditionally, local and regional emissions data were derived from annual records of electricity, gas, oil, and solid fuel use, which account for >80 % of emissions [9]. City energy managers then focused on specific programmes to decrease their emissions and estimate the potential reductions [10]. Sub-hourly data from utility meters and building energy-management systems now provide energy-related data almost in real time. Traffic-management systems provide real-time traffic information and make it available on the Internet. The Internet of Things has resulted in many devices being Internet enabled, thus allowing for two-way communications with "things" that are now being controlled rather than just measured. This brings with it the potential for "smart" systems. However, these smart systems must be robust to cope with potential disruptions. For example, they may need to include local data storage to address potential cascading failures when electricity network interruptions disrupt the performance of sensors and communications networks. Such disruptions could undermine the reliable operation of future smart networks as well as that of future smart cities. An example is the city of Lancaster, UK, where flooding caused the electricity system to be unavailable for 4 days resulting in a loss of data communications and problems for people living and working in the city [11].

Future cities will not operate the way cities did in the past, with centralised power supplies. Separate electricity, gas, heat, and transport networks will not deliver ambitious energy- and carbon-reduction measures over the long term. These networks will need to be integrated, expanded, and made part of an effective ICT (Information and Communications Technology) network to collect, share, and analyse data to provide information required to optimise their operation. The networks will also need to have an element of both electrical and thermal storage to cope with "peaks" and "troughs". Information technology can then provide the communication between city energy supply, energy demand, and energy storage, thus enabling intelligent demand-management measures to optimise efficient energy supply, storage, and use [12]. Transport will also be part of this integration, and electric vehicles will have the potential to act as electrical sources for energy storage for powering buildings as well as vehicles. There will be not only individual heat and power generation but also individual energy storage in homes and businesses. Homes and businesses will no longer be just consumers, they will be energy producers as well. The city energy supply will therefore be much different than it has been in the past. Traditional, highly centralised power generation will be replaced with new decentralised systems that will operate at a very local level. These systems will match the intermittent supply to the demand by using demand shifting and storage. Data analysis will be a key part of the successful operation of such decentralised systems. People and businesses should then have greater engagement with heat and power suppliers because they are producers (and generating an income) as well as consumers (consuming at different prices at different times of the day with new tariff structures). Complex control software must be available to optimise such different supply, demand, and storage options at scale. Many local producers are already sharing their data on solar-electricity production on Web sites (e.g., www.pvoutput.org) to share, compare, and monitor live photovoltaic-electricity generation. These new decentralised systems will help overall system resilience; however, many legal, ethical, and operational challenges must be overcome before they will be widely adopted.

In the past, city managers had relatively limited engagement with users of the city's day-to-day services. They had to arrange specific public meetings or surveys to get feedback on how effectively systems were operating as well as any proposals for new city infrastructure. However, we now have cities with dedicated telephone and Web-based "hot lines" and people using social media, again allowing for two-way communications, to tell the world their views on a wide range of things—including low-carbon cities. Cities can now use the data from city infrastructure (buildings, transport, etc.) and data from people (by way of Web sites and social media) to help deliver a low-carbon city. They can more rapidly identify when things are going wrong—such as power outages or internet failures as well as traffic delays—so they can maintain smooth operation of the city.

An integrated, multi-disciplinary approach, in partnership with other stakeholders, is needed to achieve the deep cuts in carbon emissions needed to meet international targets. For example, achieving a 5 % reduction in energy consumption in a building can be delivered through addressing one single technology. Either providing additional thermal insulation, improving heating or cooling systems, or improving building-control systems should result in >5 % savings. However, our challenge is for western cities to achieve savings on the order of 80 % to keep the global temperature increases to <2 °C as agreed at the Paris COP in 2015 [13]. To do this, it is not sufficient to determine a solution from one single technology or discipline. An interdisciplinary approach must be employed using several technologies (thermal insulation, heating and cooling systems, lighting and ventilation systems, and improved controls), and then we must go beyond the technology itself to address how people effectively make use of these technologies in their daily lives. A comprehensive, whole-systems approach to energy and carbon emissions is therefore needed at the city scale.

Information- and communication-technology systems now allow for the collection and analysis of previously unimaginable amounts of both city-infrastructure and people-related data. Data are therefore available to help estimate people's carbon emissions almost in real time. The challenge is how we move from this "big data" to "big knowledge" and how we develop better approaches to data visualisation. This will help cities to share data and compare the performance of different lifestyles, homes, businesses working practices, etc. These data could also help businesses develop new products and services based on more detailed and relevant information about carbon emissions. Services reflecting this concept have been developed, for example, by Uber and BlaBlaCar for mobility services. Overall these data can then be used to manage the "carbon system" of the city. They can be used to enable a city to operate a smart-electricity grid, smart-heat grid, and smart-transport grid as well as help create new employment opportunities and facilitate inward investment and better engagement with, and participation from, the public.

2 What Data Exist

Data are routinely collected regarding energy supply (electricity, heat, and transport) and fuel type (fossil-fuel heat, fossil-fuel electricity, renewable heat, renewable electricity, and transport-related fuels). We can measure this supply by different types in real time. Smart meters are available in people's homes. Data are also collected, by way of automatic meter readings of the energy demand in buildings and industry (electricity and heat in buildings) and transport (electricity and oil). Building energy-management systems (BEMS) collect data on temperature, lighting, ventilation, etc., in different rooms in different buildings. Air quality–monitoring stations collect local weather and air pollution data. Process-control systems record data on industry, and transport-management systems collect data on vehicle movements, passenger loading, congestion, car-park occupancy, electric-vehicle charging points, bus and train times, etc. Car manufacturers collect data on engine performance, speed, location, etc., which can be used to provide feedback to drivers so they change driving styles to decrease emissions. Remote sensing by satellite enables the monitoring of local air pollution in real time, and examples exist of waste being tracked from the recycling point to eventual reuse and disposal.

Geographical Information Systems allow this information to be displayed as maps, and new techniques are being developed to help people visualize these data. People can share information about themselves and their "happiness". All of these data can be collected and analysed. Systems are now moving beyond monitoring and displaying information to also controlling things. Washing machines, cookers, heating systems, and televisions can now be switched on and off remotely by way of mobile phones. Machines can communicate with machines without human intervention. However, gaining access to these data at meaningful geographic and temporal resolutions and ensuring consistent quality can still be a problem.

All of this now makes it possible to better predict energy use in cites and to offer people incentives to both decrease and time-shift their heat, light, and power needs. Cities are installing improved information and communications technologies, and open-source approaches are allowing access to large data sets. They are now using these data to become intelligent future cities and citizens. Communities and individuals are self-reporting and sharing their data. These data can then be analysed to act as a proxy for population density or to highlight future development options for communities. However these data bring ethical, security, and privacy issues. People are become more concerned about how their data are used. Whose owns the data? What is proprietary data, and what is publicly available? Legal, ethical, privacy, and security issues still remain to be overcome.

3 What Data Do Not Exist

Using data that currently exist, it is possible to estimate the annual carbon emissions at a city level, but this cannot yet in be done in real time or in terms of understanding the detail of citizens' behaviours. The challenge is taking these existing data, obtaining further data, and making use of the information provided by these data. We do not yet have the quality and quantity of data to provide a true city-wide picture in real time. Data are not available uniformly; rather, there are concentrations of data. For example, there are substantial energy-related data for buildings as well as transport-related data through traffic-management systems, car parks, and bus and train time information. However, there are still minimal data available on carbon emissions associated, for example, with food procurement and waste. How to deal with the variations in availability and quality of data is a key issue for cities not just to address the digital divide but also for the research community to develop new algorithms to help close the gaps in data and knowledge.

A further key issue is the collection, storage, and processing of these data. Substantial interoperability issues associated with data acquisition still remain. Data are collected in different formats over different time periods at different locations, and they are of varying quantity and quality. For example, whilst common standards for energy-related data exchange have been suggested [14], they have not yet been widely adopted. More data are becoming available all the time with the Internet of Things and open-source approaches. However, the issue is not just the existence of data but the relevance, quality, and usefulness of these data as well as how to address the associated security, privacy, and ethical issues. Maintaining quality of data over time still remains a major issue.

4 What More Is Needed?

First, as we collect increasingly more data, we need better institutions to oversee their collection and management. This is needed not only to ensure quality but also to reassure the public that ethical, privacy, and security issues have been addressed. Second, we need better ways of extracting useful information from these data, information to help city **decision makers** improve the management and future infrastructure of our cities. Finally, additional real-time data are needed to help provide more information about carbon emissions from infrastructure as well as from people. These data will then need to be collected, processed, stored, analysed, and presented to users. Interoperability, ethics, privacy, and security issues must also be resolved. We need infrastructure-related data on buildings, transport, food, and waste as well as people-related data in terms of their attitudes and behaviours. Using these infrastructure and people data, "typical" citizens in different house types—with different jobs and taking part in different leisure and social activities— could be constructed. These virtual citizens could then be compared with people's similar lifestyles and advice and guidance given on how to decrease emissions through making changes in lifestyles. This reduction could then be measured and quantified.

As more data become available, we will need to develop new techniques to analyse them, E.g., new approaches to presenting these data in the most appropriate way to different users including city leaders, city mangers, city businesses, and citizens. For example, city leaders may not have traditionally used this level of data before. They will need to have information derived from the data in different forms than that needed by city managers. They will also be very acutely aware of ethical, privacy, and security issues that can cause significant reputational damage if not addressed effectively from the outset. In addition, we still must overcome the digital divide and address regular public concern over the release of heath and other data to private companies. Ethical, security, and privacy issues will therefore be key issues to address in parallel with other data-quality, -management, and -visualisation issues.

5 How to Use Data

Data visualisation is key to making better sense of data. We must know how to present the most appropriate outcomes from the complex analysis of large data sets to city practitioners and the public so that they are able to use it effectively. This ranges from providing simple smiley faces to represent electricity gas- and water-consumption trends in buildings [15] to city dashboards [16] to complex visualisation of multi-layer urban-data platforms for citizen and policy-maker exchange as in Live Singapore [17] (http://senseable.mit.edu/livesingapore/index.html). The growing areas of data mining and data visualisation will continue to be key future research topics. Such an approach is being adopted by the European Commission's

Collective Awareness Platforms (https://ec.europa.eu/digital-single-market/en/collective-awareness), which are supporting environmentally aware, grassroots processes and practices to share knowledge, achieve changes in lifestyle, production, and consumption patterns, and set up more participatory democratic processes all using city-wide data to engage with different users. An example is the Political and Social Awareness on Water Environmental Challenges (POWER [http://www.power-h2020.eu/overview/]) project, which engages policy-makers, professionals, and citizens in water-related issues identified by the European Innovation Partnership (EIP) Water Action Group City Blueprints, thus improving the implementation capacities of cities and regions (http://www.eip-water.eu/City_Blueprints). This project brings together public bodies, private bodies, and communities to share knowledge and data by way of a digital social platform to address specific local water-related issues through building on the analysis of local city data.

Large amounts of data—including data from both city infrastructure and citizens available in real time—are therefore being collected, stored, analysed, and presented to potential users. The infrastructure, in terms of networks and smart grids (smart heat, smart electricity, smart transport, and smart energy storage), is being expanded. In terms of information from the average citizen, people share about the following:

- where they are, how they travel, and how much electricity, gas, and water they are using in their homes or at work;
- what temperatures they maintain in their home and working environments; and
- what information they are sharing with other people on social media and other Web sites.

In addition, businesses share their energy efficiency and benchmark these data with those of similar businesses in other countries. The information gathered from these data can be used to help deliver and manage a low-carbon action programme. Information from the analysis of these data thus inform the delivery of large-scale low-carbon interventions such as a district-wide or community-wide refurbishment projects, new low-emission vehicle programmes, air-quality action zones, refurbishment of non-domestic buildings, new business opportunities and models, etc. It also allows for the ongoing monitoring of these schemes and provides evidence to convince decision-makers of the business case for further investment.

These data can inform a city-wide carbon-management system that can measure and control the operation of different city infrastructures. Machine-to-machine communication will deal with the control and operation of some systems. It can provide people with real-time feedback on carbon emissions as well as information about emissions from homes, businesses, and modes of transport. Such emissions are related to different peoples' lifestyles. It can form part of a city dashboard by describing current city-wide emissions. It will enable cities to move beyond simple monitoring to introduce control, management, public engagement, and pubic feedback. However, data quality, long-term storage and management, ethics, interoperability, and privacy issues remain to be resolved.

6 Conclusions

Big data and the Internet of Things are now providing the opportunity to help deliver a low-carbon city. The amount of data and the number of things connected to the Internet are increasing. Future cities cannot operate the way they did in the past with separate electricity, gas, heat, and transport networks. These will not deliver the internationally agreed-upon energy- and carbon-reduction targets. The networks will need to be integrated as well as have an element of both electrical and thermal storage with the electrical storage including electric vehicles where the stored electricity is used to power buildings as well as the vehicle. Information technology provides communication between energy supply, energy demand, and energy storage, thus resulting in intelligent supply- and demand-management measures to optimise energy supply, storage, and use. Homes and businesses will be producers as well as consumers of energy. From an energy perspective, we now (in theory) have access to the real-time data to develop a virtual power plant for a city. It is conceivable to link a smart-electricity network with a smart-heat network and a smart-transport network having both electrical as well as thermal demand response and storage.

Analysis of the vast amount of data and the information from this analysis is then used to inform the "management" of the city. Much of this ongoing, daily management is performed automatically, machine to machine, by way of software. Specific fault correction and efficiency improvements are performed by energy-service companies. Information from the analysis of these data will enable cities to better understand the needs of their citizens through a more regular dialogue based on citizens' real-time carbon emissions to move beyond simple monitoring to intelligent control. However, ethical, privacy, and security issues need to be overcome, and the digital divide could prevent some citizens from realising the full benefits of a smart city. The key is ongoing monitoring and evaluation at a city scale. From an energy manager's perspective, this involves moving from monitoring, target setting, and investment in buildings to monitoring, target setting and investment in cities. It means moving toward smart cities.

7 Summary

- Data are available to help estimate and manage carbon emission at the city level. The amount of data is increasing, and the relevant data can be harnessed to decrease carbon emissions in our cities.
- Both data from city's infrastructure—homes, businesses, and transport—and data about people living, working, and studying in cities are available.
- Security, privacy, and ethical issues, as well as the digital divide, must be addressed from the outset.
- Citizens, communities, and businesses are sharing their data.

- Data can help justify low-carbon investment opportunities, and ongoing city management can be delivered through virtual power plants and smart grids with energy supply, storage, and demand management.
- Using these data, it is possible to develop evidence-based policy regarding city efficiency. The main goal is to evaluate a city's performance in decreasing greenhouse-gas emissions and to evaluate citizens' responses to this policy.

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