European Planning Studies

ISSN: 0965-4313 (Print) 1469-5944 (Online) Journal homepage: http://www.tandfonline.com/loi/ceps20

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To cite this article: Sarah Giest (2017) Big data analytics for mitigating carbon emissions in smart cities: opportunities and challenges, European Planning Studies, 25:6, 941-957, DOI: 10.1080/09654313.2017.1294149

To link to this article: https://doi.org/10.1080/09654313.2017.1294149

Published online: 28 Feb 2017.

EUROPEAN PLANNING STUDIES, 2017
VOL. 25, NO. 6, 941–957
http://dx.doi.org/10.1080/09654313.2017.1294149

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Big data analytics for mitigating carbon emissions in smart cities: opportunities and challenges

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ABSTRACT

The paper addresses the growing scepticism around big data use in the context of smart cities. Big data is said to transform city governments into being more efficient, effective and evidence-based. However, critics point towards the limited capacity of government to overcome the siloed structure of data storage and manage the diverse stakeholders involved in setting up a data ecosystem. On the basis of this, the paper investigates the challenges city governments face when dealing with big data in the context of carbon emission reduction. Through the lens of the evidence-based policy and policy capacity literature, the cities of Copenhagen (Denmark), London (UK), Malmö (Sweden), Oxford (UK) and Vienna (Austria) are analysed. The cases reveal that the institutional complexity underlying big data integration limits local government capacity to set up data management structures that would allow further utilization of big data and that current solutions focus on local pilot sites and outsourcing of data analytics.

ARTICLE HISTORY
Received 4 February 2016
Revised 1 December 2016
Accepted 8 February 2017

KEYWORDS
Big data; smart cities; policy capacity; institutional complexity; evidence-based policy

1. Introduction

In recent years, big data and smart cities have become buzzwords for the use of new data methods to provide robust, empirical evidence for urban policy-making. Big data can refer to different aspects. It can describe the characteristics of the data (massive, rapid, complex, unstructured, etc.), the technological needs behind processing large amounts of data as well as the impact of it on society and politics. The smart city concept (Caragliu, Del Bo, & Nijkamp, 2011) is connected to big data in that some argue it has been revived by the data movement (Bright, 2015; Kitchin, 2014). It further has expanded over time to include optimal delivery of public services and processes for citizen engagement and civic participation on top of finding 'smart' solutions for urban areas. The synergy of both is the idea that data can be used to make cities smarter over different spatial and temporal scales (Batty et al., 2012). This is also referred to as 'policy-making 2.0', an umbrella term for the interplay between a number of technologies that are applied in order to achieve more participative, evidence-based governance. This conceptualization of

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policy-making encompasses all phases of the policy cycle that utilize open and big data (Misuraca, Mureddu, & Osimo, 2014; Mureddu, Osimo, Misuraca, & Armenia, 2012).

In addition, there is wide-ranging support for the fact that local governments play an increasingly important role in addressing global problems, especially in the area of social and environmental sustainability (Caragliu et al., 2011; Hordijk & Baud, 2006; Mitlin, 2004). In combination with new technology, such as sensors, cities have the ability to measure, for example, detailed carbon emission levels connected to traffic congestion or buildings. The expectation is that, compared to current data collection, cities become less dependent on other data sources. However, while the technical tools are advancing, obstacles within governments remain. Recent examples show that local governments struggle with the integration of data knowledge, because of their dependence on additional data from other government levels or departments and outside stakeholders. The discrepancies of how data are collected at different levels and the legal framework for private companies compiling and analysing city data pose some of these challenges (Höchtl, Parycek, & Schöllhammer, 2016; Letouzé & Jütting, 2014). So far, there is however limited research on the intended use of big data in urban governments for specific goals, such as carbon emission reduction and the actual implementation of a data-based structure.

Connected to sustainability goals, the role of big data is most visible in the field of energy. The energy sector is facing efficiency and environmental challenges linked to the reduction of carbon emissions (Zhou, Fu, & Yang, 2016). The exploitation of renewable and distributed energy generation is in fact a critical element in reducing CO_2 emissions since the power grid operations are responsible for one-fourth of global emissions (Bayram, Shakir, Abdallah, & Qaraqe, 2014). Energy data analytics provide opportunities to tackle these issues by providing 'effective and efficient decision support for all the producers, operators, customers and regulators' (Zhou et al., 2016, p. 216). Most of the data come from sensors in urban areas that track transportation, energy, water and waste. And the smart cities community has become increasingly involved with these sensor systems, particularly with their integration and performance enhancement possibilities (Thakuriah, Tilahun, & Zellner, 2015). In carbon emission reduction there are further different and not always compatible inventories. These are used as planning tools for identifying and measuring effectiveness of measures within cities (Romero-Lankao, 2012).

Based on this, the transition towards using big data in the city context is treated in this research as a policy choice that is critically dependent on the local institutional and governance context. To conceptualize the local institutional and governance context, the paper uses the evidence-based policy (Best and Holmes, 2010; Nutley, Walter, & Davies, 2007) and policy analytical capacity literature (Howlett, 2009, 2015; Pawson, 2006; Sanderson, 2006) to identify how data-based information enters the policy process and what the obstacles are to integrating this evidence into policy-making.

1.1. Methodology

The selected cases are frontrunners in applying data-based solutions for carbon emission reduction and have the potential of highlighting aspects that other cities might face in the future. Two-thirds of smart city projects throughout the EU remain in the planning or pilot testing phase; this means that the number of mature initiatives remains relatively low (Manville et al., 2014). The selected cities are from a pool of mature smart cities that have implemented or piloted initiatives. The literature further suggests that city size may play a role in how data information is integrated and linked to the number of institutional players involved in the process (Manville et al., 2014). The cities chosen thus vary in their population size from small (Oxford and Malmö), medium (Copenhagen) to large (London and Vienna). Two of them, Copenhagen and Vienna, are identified as the most successful cities for boosting smart city initiatives (Manville et al., 2014). All of them have dedicated smart city and big data strategies with special focus on 'smart environment'. Smart environment includes 'renewables, ICT-enabled energy grids, metering, pollution control and monitoring, renovation of buildings and amenities, green buildings, green urban planning, as well as resource use efficiency, reuse and resource substitution' (Manville et al., 2014, p. 28). In short, the set of cases is diverse in terms of size and country location, but they all share a smart environment or smart energy strategy that goes beyond the pilot stage. Table 1 gives an overview of the cases and their characteristics. The cases are being assessed based on the capacity and evidence-based policy framework, looking specifically at the challenge involved in incorporating big data in the carbon emission field linked to the government departments and non-governmental stakeholders. Government (evaluation) reports and newspaper articles serve as the basis for identifying issues that local governments experience.

The following section highlights current literature on data-based policy-making and links it to evidence-based policy and policy capacity research. Section 3 outlines the four cases and Section 4 analyses them in light of their information management and institutional structure. The final section concludes the paper.

2. Data-based policy-making

In their effort to utilize big data, city governments largely focus on one of two strategies: They strive to put all data into one compatible base, which is done through cloud-based computing or they tap into existing databases for pieces of information. From a structural perspective, this translates into choosing between centralized or decentralized data storage and management. Current research suggests that the two models consist of either a centralized structure where a city data centre is established or a decentralized model in which data scientists are integrated into different city departments who then compile data from various sources (Courmont, 2015; Goldsmith & Crawford, 2014). Copeland (2015) however raises the concern that under time pressure, these structures are short term and end up enforcing the existing silos of people, IT and data. They further lead to an overemphasis on technological aspects of big data integration (websites, apps, hardware, software) rather than a more profound local government reform addressing the collection and

Table 1. Case characteristics (based on Manville et al., 2014).

City	Country	Population/size	Smart city projects	Smart Environment
Copenhagen	Denmark	541,989/M	5	x
London	UK	8,308,000/L	2	x
Malmö	Sweden	278,523/S	1	x
Oxford	UK	150,200/S	1	x
Vienna	Austria	1,714,142/L	2	x

use of big data (Kitchin, 2014). The focus on technology also pulls resources from setting up a potential information management system that specifically addresses the ways in which the data are integrated into decision-making. In short, adjusting government structure to accommodate a big data element increasingly challenges the policy-making process connected to evidence-based decision-making and capacity within government (Peled, 2014).

The integration of different types of evidence has been widely discussed in the literature. Data are one type of evidence that are being incorporated into the policy-making process. The evidence-based policy-making research largely evolves around the receptiveness of the policy development 'cycle' towards such input and there is a debate about where and how evidence-based contributions can add value to the process (Head, 2008). Two aspects that are particularly relevant for the integration of big data are the institutional context and the capacity of individuals or government entities to being able to find and utilize data-based information. Both are connected in that limited capacity available within government can lead to the involvement of additional actors, which ultimately increases the level of institutional complexity.

There is concern that policy-makers may not have the 'policy analytical capacity' to analyse and understand such evidence (Howlett, 2009; Nutley et al., 2007; Pawson, 2006; Sanderson, 2006). When governments experience low levels of policy analytical capacity they risk incorporating scientific knowledge ineffectively into the decision-making process (Howlett, 2009). Limited capacity to draw relevant knowledge from data also leads, according to Hsu (2015), to the introduction of new actors. These include public and (semi)-private stakeholders, such as NGOs and businesses. For policy areas that cut across several departments, as environmental issues do, Howlett, Migone, and Tan (2014) observe a free-floating set of highly skilled analysts that operate across units. Introducing additional actors into the policy-making process however also increases the levels of institutional complexity. This is thus connected to the second aspect, the institutional context that can potentially limit the use of evidence in the policy process.

Big data forces city governments to include additional stakeholders into the decision-making process. This has to do with the technical capacities of data collection and analysis as well as the ownership of data. The use of big data analytics requires more privatization and contracting out of government linked to accessing, combining and making sense of data as well as collaboration across departments and within communities (Bătăgan, 2011; Meijer & Bolivar, 2015). Often times, public officials have had no experience with these players (Radin, 2003), which leads to difficulties in solving specific issues. There is further evidence that such differentiation and specialization aggravate coordination issues in government (Wollmann, 2002). This idea is represented in the systems model brought forward by Best and Holmes (2010) who argue that the institutional context shapes the way policy and evidence interact and that coordination across several departments, for example, increases the complexity and possible ineffective inclusion of evidence. Kauffman (1995) and Rescher (1998) further suggest that as complexity grows, more trial-and-error efforts and localized experimentation are implemented. It also slows down policy processes, because beyond purely technical input, other information sources are consulted (Sanderson, 2006). Several scholars suggest that compromises among political and technocratic elements are made in this process, where the rational idea of using robust evidence is mixed with political ideology and other 'non-evidence-based' ideas (Best and Holmes, 2010; Howlett, 2009).

Looking at environmental policy in particular, regulators have linked enforcement systems with information programmes to uncover levels of environmental performance of polluters (Foulon, Lanoie, & Laplante, 2002; Hsu, 2015; Wang et al., 2004). Based on big data, more sophisticated climate change models have been developed to reduce the uncertainty surrounding decisions linked to mitigating and adapting to environmental changes (Larson, White, Gober, & Wutich, 2015). But the models also add information that might expose policy-makers to largely irrelevant information or contradictory aspects and result in prolonged decision-making processes (Höchtl et al., 2016; Trenberth, 2010). Beyond data-based information, there are further multiple forms of policy-relevant knowledge that is vital to understanding climate change issues, and thus several evidence bases need consideration (Davies, 2004; Head, 2008; Pawson, Boaz, Grayson, Long, & Barnes, 2003; Schorr, 2003).

This complex structure is reinforced by the wide span of the climate change problem and the uncertainty and ambiguity as to how improvements can be made. Specifically for energy policy, research points towards an intertwined institutional setting where many policy instruments directly or indirectly interact with each other and under international, EU climate and energy policies as well as national measures (Chang & Martens, 2010; Oikonomou, Flamos, & Grafakos, 2010). More specifically, standardization of calculation methods, the inclusion of various actors from the market and the interaction of policy instruments are cited as challenges in the field.

Based on the two themes emerging from the literature, the policy capacity to understand and integrate big data information and the institutional set-up connected to this, the paper brings forward the following hypothesis: Limited capacity to utilize big data and the institutional set-up connected to data-based evidence and the environmental sector lead to:

- The involvement of additional stakeholders
- Increased interconnectedness among government departments and government levels
- Trial and error/local experiments.

3. Big data on carbon emissions in cities: opportunities and challenges

In cities, the amount of data being collected is rapidly increasing, as local governments gather location-specific material, residential records, citizen knowledge and historical data digitally (Wammes, 2015). The obstacles that urban policy-makers encounter largely do not lie in the technology itself, but rather in the information and knowledge management of the data being collected on an hourly or even second basis (Flowers, 2013). Studies show that advances in technology have led to the collection of various data on the environment. Much of these data are collected for specific projects or initiatives that take place at national, sub-national or local level. Merging the data is hereby impeded by incompatibilities in formats, standards, access and organizational structures. Within these projects, government subdivisions further develop their own hardware, software and data applications. Ultimately, without proper data integration and analysis, the collected information cannot be translated into knowledge suitable for decisionmakers (Copeland, 2014; Falke, 2002; Kaylor, 2005). This requires a data ecosystem able to capture, store, process, manage, transmit and share the data (Gant, 2015), but also, from a government perspective, ways to understand, transfer and utilize the knowledge that stems from big data.

These changes in expertise required in many sectors have spiked demand across a range of occupations for data experts. 'There was a 123.6% jump in demand for Information Technology Project Managers with big data expertise, and an 89.8% increase for Computer Systems Analysts' (Columbus, 2014). Most of these are hired by private companies. The demand was the highest in industries-connected technical services (27.14%) and in sixth place for the sector of sustainability, waste management and remediation services (8.2%). This has to do with the fact that large companies see power and utilities sectors as the ones with the highest potential for big data use, since, for example, 'smart metering enables a dramatic increase of data collection frequency for companies in this industry' (EY, 2013, p. 21). It is no surprise that parallel to this, the demand for government in outsourcing or hiring external stakeholders for big data expertise has gone up. A study by Ernst & Young (2013) finds that in Northern Europe (Sweden, Norway and the UK), access to specific knowledge, expertise and tools are now key drivers for outsourcing rather than cost-efficiency. This is often a symbiotic relationship where companies validate and test micro infrastructures while gaining access to the public sphere in order to commercialize their products and services (Manville et al., 2014).

The following frontrunner cases will emphasize challenges connected to data knowledge. The main focus is on data collection in the areas of energy as well as commercial and residential buildings, since these pose the biggest emitting sectors and are areas in which local governments have the authority to mitigate (Romero-Lankao, 2012).

3.1. Copenhagen, Denmark

In 2012, the Copenhagen City Council adopted the CPH 2025 Climate Plan. Reinforcing this plan, smart city solutions have the dedicated purpose of making Copenhagen carbon-neutral by 2025. In junction with deciding to use data as a tool to reduce energy consumption, Copenhagen joined the IBM Smarter Cities Challenge to utilize the data for policy-making (IBM, 2013). Following this, the city partnered with IBM to gather energy data for cutting CO_2 emissions. IBM is currently collecting and channelling relevant data into a so-called 'open data hub'. 'The idea is that the hub will connect data providers and consumers, as well as entrepreneurs and programmers, so they can use the data to find ways to help the city reduce its energy use' (Online Post, 2013).

This collaboration is part of a larger push for collecting data within the city. According to the Smart City Plan (2015), sensors connected to parking spots, traffic flow, garbage bins and water distribution will collect data to make decisions in real-time. The sensor data is connected to a system that can triangulate with Wi-Fi devices to provide, for example, information on movements, cars, bikes etc. in real time and aggregated over time (City of Copenhagen, 2015). These technological advancements translate into several city initiatives focusing on transportation integration and using ICT to improve cycling lanes and discouraging individual car use. Further, in one part of the city, Nordhavn, energy-efficient buildings are being developed with the goal of making them carbon-neutral in the future (Manville et al., 2014). The City is also working with Hitachi

Consulting to build a 'City Data Exchange' Hub, where data information can be stored to be accessed by the public or bought by other businesses. 'The platform is anticipated to enable advanced analytics to support city functions like green infrastructure planning, traffic management and energy usage, by integrating data from multiple sources' (Hitachi Consulting, 2015).

These and other smart city projects are implemented by Danish municipalities and receive up to 50% national funding. A recent report commissioned by the Ministry of Foreign Affairs (2016) finds that of those municipalities that have carried out smart city projects, about half 'lack skills, knowledge, and cross-departmental organisation' to carry them out and that 'municipalities are unclear about which smart city solution to buy, which vendors to buy them from, how to buy them in a way that avoids risks like technology redundancy' (Doody, Walt, Dimireva, & Nørskov, 2016, p. 6). Thereby, most municipalities have open data portals in line with a long tradition of publishing data for public consumption in Denmark. With the rise of smart city initiatives however, 'valuable city data is locked up within private and public organisations where the case for its release has not been made or heard' (Doody et al., 2016, pp. 6–7). In the same way, organizations are developing smart city systems that are not compatible with those of the municipality or other stakeholders, limiting their use.

3.2. Malmö, Sweden

Sweden's goal to have 40% less GHG emissions by 2020 and to own a vehicle fleet completely rid of fossil fuels by 2030 are stepping stones to the overarching goal of a society with no net GHG emissions by the year 2050. Throughout Sweden, 25% of all municipalities have further adopted a common set of sustainability principles (Eco-Municipality Education & Assistance, 2016). However, while emissions of major air pollutants have fallen significantly, 'air concentrations of particulate matter, such as soot, often exceed accepted health standards in some cities' (OECD, 2014, p. 5). This has led selected cities to facilitate climate change initiatives in the area of carbon emissions with data efforts.

Malmö's smart city strategy specifically targets sustainability by calling itself 'the Green Digital City'. The environmental programme includes the goal of being Sweden's most climate smart city, a sustainable management of resources and creating an urban environment that makes it easy to be sustainable (Malmö Stad, 2011). Similar to Copenhagen, Malmö aims to combine a variety of data sources in order to develop targeted policies within the city. The municipality recently updated its online portal Miljöbarometern (Environmental Barometer), which monitors the progress of all environmental indicators. While creating and updating the online database, Malmö however encountered data silo problems as well as limited access to information collected by private companies (Dowding-Smith, 2013).

The city further uses the municipality of Hyllie as a test-site for many of the technologies collecting the data. 'In 2011, the City signed an agreement with VA Syd, Malmö's waste management company, and the utility service provider E.ON to make Hyllie one of the most climate-smart districts in the region' (Guevara-Stone, 2014). The initiative includes smart grids and smart transportation with the goal of reducing emissions and making Hyllie completely sustained by renewable or recycled energy. The data architecture and data models to process the information are still under development. Currently the projects calculate CO_2 emissions in relation to time and outdoor temperatures based on historical data. External companies, such as E.ON and RWTH, are closely linked to the development of these systems (Diekerhof, Lillienberg, & Monti, 2014).

3.3. United Kingdom

The Climate Change Act established a target for the UK to reduce its emissions by at least 80% from 1990 levels by 2050. The Act also created a system of five-yearly carbon budgets, to serve as stepping stones along the way with the second carbon budget period being underway (2013–2017). A recent Committee on Climate Change (CCC, 2016) report however warns that current UK policies fall short of the fifth carbon budget by 100 million tonnes, 'meaning there is a policy gap where new measures are required to deliver at least half of the necessary emissions reductions' (CCC, 2016). This gap is attributed to the fact that carbon emissions reductions are largely linked to the production of renewable energy and limits on coal usage, but existing problems, such as the heating of buildings, are not being tackled. Matthew Bell, CCC chief executive, highlights that 'in those other areas, policy has either not changed or gone backwards' (Carrington, 2016). Based on this, the government has committed itself to using big data to 'meet environmental and sustainability targets' (Her Majesty's Government [HM Government], 2013, p. 33).

Connected to big data use, the UK has identified a capacity gap concerning data analytics skills. Evidence collected by Deloitte shows that there is a lack of the necessary skills within government to combine and manipulate big data and linked data (Deloitte, 2013). Further, this skill deficiency was cited as the most common barrier by local authorities (27%). This leads, according to the study, to public sector information remaining locked up. Further, government units complain about the quality, format and consistency of public sector data and the limited provision of metadata (Deloitte, 2013). The strategy tackling this gap 'Seizing the data opportunity, A strategy for UK data capability' (2013) highlights several potential solutions. Most of them include connecting and networking with other stakeholders, such as establishing working groups with businesses and universities or the development of an open data forum (HM Government, 2013).

At local level, UK municipalities participated in the Department of Energy and Climate Change's (DECC) Local Carbon Framework (LCF) programme. The goal of the LCF was for municipalities and the DECC to learn how councils can integrate measures to combat climate change into their core business. These lessons provide a basis for the development of a new Council Framework for Climate Change. This Framework will eventually serve as a local action plan on delivering carbon emissions, encapsulating the varying portfolios of carbon reduction measures relevant to individual or grouped councils (Gray et al., 2011). The evaluation of data issues reveals that the pilot sites ran into quite a few issues. The biggest issue seemed to be data availability. The Dorset Energy Group points towards 'limitations of national data' while the Manchester group highlights the 'lack of national consistency and standardization' and Bristol talks about data that were 'out of date' (Gray et al., 2011, pp. 203–204). Given that buildings are one of the major obstacles to carbon emission reduction, a report by Preston, White, Thumim, Bridgeman, and Brand (2013) highlights that 'it seems surprising that the government has not commissioned the collation and management of data that captures the full distribution of carbon emissions from householders' (Preston et al., 2013, p. 7). In a separate report focusing on smart meter data in the context of local governments, Britton (2016) finds that 'the access and use of smart meter data present a number of challenges for these sub-national public interest uses', which are identified as the complexity, costs and uncertainty relating to DCC and SEC arrangements and issues relating to data sharing, aggregation and disaggregation of data at a local scale (Ibid, 6).

3.4. London

'Data for London' aims to use data for identifying environmental impacts within the Greater London area. This plan is linked to the 'London Energy Plan' to track and ultimately reduce carbon emissions in the city (Greater London Authority, 2016). While the plan itself is in its infancy when it comes to implementation, it becomes clear which challenges lay ahead and the type of partners the Greater London Authority needs to collect and combine the data. For the latter, a London Borough Data Partnership has been formed to share data and overcome governmental boundaries within the region. Beyond inner-governmental links, the Greater London Authority (2016) points towards a wide range of partners involved in setting up the data for the plan. Those include:

- *Structural partners*: those who actively promote the strategy and the impacts of the city data infrastructure and exploitation. This group includes the GLA, London public services, private sector representatives, the Open Data Institute, Tech City UK, the London Grid for Learning, academia, a Council for Data Ethics, and regulatory and standards bodies.
- *Supporting partners*: the providers of services, tools and data, individuals and organizations involved in defining market needs and the early stages delivery of city data infrastructure, and validators of the wider strategy. This group includes open and proprietary data publishers, such as utilities (water, waste & energy).
- *Contributing partners*: also potentially including the first two groups, these are the direct users of the data infrastructure, creators of business cases, providers of feedback, and creators of knowledge and insights from city data. This group includes:
  - *Data enrichers*: who cleanse, maintain, augment and manage data.
  - *Data integrators*: who access, integrate, analyse and publish data.
  - *Data consumers*: who use, reuse and exploit the full value of data. (Greater London Authority, 2016, pp. 11–12)

The plan further points to other hurdles setting up an integrated data plan in the city. The report highlights the need for widely accepted standards (e.g. for expressing the syntax and semantics of city data) and a lack of understanding within government related to the technological requirements.

3.5. Oxford

Oxford is currently working on an integrated emissions data base to tackle possible fractured data sets and measure the impact of emission-reduction initiatives. The plan is to use a combination of data from the national and the local levels, since national data sets provide an overall inventory of CO_2 emissions from Oxford city by sector, but do not identify which particular areas within a sector need attention. In undertaking these emission reduction efforts, the city of Oxford identified governmental and linked to that data silos and the combination of national and local data as a challenge (Margetts, 2016).

In addition, Oxford launched the Low Carbon Oxford initiative in 2010. This is a city-wide programme of collaboration among private, public and non-profit organizations with the aim of making Oxford a sustainable, low-carbon city. In contrast to some of the other cities, the initiative worked with individual Pathfinders to gather data about which emissions really occur rather than using national datasets. The Pathfinders comprise 29 organizations representing a large proportion of Oxford City's carbon emitters. Based on this model, the city receives information on large carbon emitters and in turn helps them to become best practice examples in their field. In addition, emission calculations in the domestic sector are carried out at national level (Low Carbon Oxford, 2012). This is complemented by a network of companies, branches, businesses, public bodies, from a city council to a university, a hospital, a bus company, a car manufacturer and case studies of some of the Pathfinders.

LOC is also part of an umbrella initiative called 'Smart Oxford', which includes a project targeting the collection, analysis and utilization of data ('UrbanData2decide'). In this project, Oxford City Council and the Oxford Internet Institute work with city partners in the UK and Europe to develop tools to support local government, including the 'potential for tools by designing an integrated and multi-dimensional model combining diverse open data and social media sources' (Smart Oxford, 2015).

3.6. Vienna, Austria

In March 2011, the Mayor of Vienna announced the initiative 'Smart City Wien', which includes increased emission reductions by utilizing data. In the planning document (2012), the City lays out the following goals:

- Development of a smart grid, smart metering and central data network collecting data on energy consumption;
- Set-up and testing of new data storage technology and additional storage capacity.

The plan further states that both the City of Vienna and energy providers have data material on household consumption, but that the data lack a structure to link them to each other and as a result the data are only partially available and used. As a solution, the report suggests to integrate the energy field into the transport masterplan, which could result in close collaboration of the public utility department with experts from the energy and climate change sectors. Another goal presented in the report is to assess the data available in order to evaluate whether data sets can be combined (Smart City Wien, 2012).

Similar to Oxford, the government in Vienna also calls for the merging of relevant data in the energy sector. For example, 'the data from the municipal administration and the different energy supply companies needs to be linked and more cooperation should take place' (Hartman et al., 2015, p. 46). A recent report finds that the data available are of high quality, but that analysis so far has been limited due to missing data descriptions and a lack of harmonization of data collection within the city. The report also points out that compiling data was a bigger issue in the energy and emissions field than expected due to one-off sharing linked to specific questions rather than combining data sets long term (Hartman et al., 2015).

Like Malmö and Copenhagen, Vienna also has a test site for various emission-tracking technologies and data collection. A former airfield on the north-eastern outskirts of Vienna, Aspern, is used to run technologies for power management in smart buildings and solutions managing big data that include the establishment of a City Data Centre. This is done in collaboration with the City of Vienna, the city's utility companies (Wien Energie and Wiener Netze) and Siemens. In its current form, data collection and analysis is at an early stage. Researchers are evaluating the data that has been collected so far with the goal of developing specialized algorithms capable of making sense of the new data (Pease, 2015).

4. Discussion

Even though the cases differ in their integration of data-oriented measures, size and maturity of smart city initiatives, the policy and strategy documents reveal that they face similar challenges and share several characteristics. Along the lines of the dimensions identified in the literature, the discussion focuses on three aspects: the number of stakeholders, their interconnectedness and trial and error or localized experimentation.

For the first aspect, the number of stakeholders, all four cases show that in connection to data, additional actors are added by hiring companies like IBM, Hitachi Consulting or Siemens and the cities further set up projects with energy companies that can collect and process the data. When it comes to their interconnectedness, it is less the connection to private stakeholders that poses an issue, even if some municipalities report struggles to make decisions on which services to buy and finding the right fit, but largely the documents point towards missing cross-departmental and cross-level links. For example, Copenhagen, Malmö and London report limited inter-departmental links that constrain the exchange of data and also create compatibility issues across datasets. The standardization of data collection is further connected to national level regulation, which seems to be in the process of catching up with the more localized experimentation that has been going on in all of these countries. British and Swedish municipalities in particular highlight their dependency on the national level for data information and criticize out-of-date or limited data, a lack of national consistency and standardization. Local governments in the cases further struggle with the dependency on other government departments to fully utilize data. This is facilitated by a decentralized structure in many countries. For example, data collected at the London borough level require further collaborative efforts as well as streamlining data formats. Similarly, Sweden's municipalities have a strong self-governing principle and have had limited collaboration efforts in the past. Thus, they are reliant upon the creation of open data systems for tapping into each other's data pools on specific topics. In addition, in all the cities under consideration, private stakeholders support officials in collecting and analysing data due to limited expertise within government.

Finally, there are a number of local experiments in the form of pilot sites in Copenhagen (Nordhavn), Vienna (Aspern) and Malmö (Hyllie) for data collection in the area of energy usage. The UK also has several pilot sites located in municipalities around the country. These projects enable cities to share their experience in one sector with other city governments and possibly gain insight into best practices (Manville et al., 2014).

The strong focus on the gathering and archiving of data has however limiting effects on building policy capacity. The various initiatives cite data management issues linked to carbon emission reduction as the main obstacles to fully implement and integrate most of the initiatives. Once the data architecture is set up, it alone cannot overcome emission problems. It requires regulatory and behavioural changes by consumers to reduce emissions with the help of data analytics. Big data has furthermore a short-term immediacy, which makes it compelling for real-time applications, such as traffic patterns or parking spot finders, but difficult to manoeuvre in long-term planning scenarios, since this would require further integration and merging of various data – something that has shown to be difficult in the cases (French, Barchers, & Zhang, 2015). Finally, the frontrunner cities use data technology to solve particular problems or a set of problems that are clearly defined, but less to unravel some of the complexities of carbon emissions in the climate change context.

The cases display a rather narrow scope in applying data analytics largely for functionalist aspects of emission reduction. This is further facilitated by outsourcing parts of the data efforts to private stakeholders on a project basis. The technicalities of open data hubs and sensor technology for building emissions and traffic patterns currently dominate the discussion. This is further motivated by attracting businesses to the city and potential branding efforts. Beyond the current hype around big data, researchers increasingly warn policy-makers to build capacity in connection to big data analytics beyond the skill-based outsourcing to private companies and pay close attention to selection bias while maintaining a balanced view on data-driven inferences (Yiu, 2012). This involves not losing the connection with the public and including information on how problems and challenges play out in the real world.

5. Concluding remarks

Within the next 20 years, most information to understand and govern cities will come from digital sensors and will be available in data-form, which poses new challenges for policy-makers. Especially so-called ‘smart cities’ use a combination of technology and data with the goal of providing better public services. So far, however, little is known about how city governments use und integrate this new information and what kind of challenges they face. Analysing frontrunners in the field of using data for emission reduction goals, the cases of Copenhagen, London, Malmö, Oxford and Vienna show that integrating big data at local level is so far limited to local experiments and challenged by the dependence on other governmental entities. The reliance upon datasets that are being collected and stored at different government levels, separate departments or are owned by private companies pose a challenge for policy-makers. Further, these complexities require cities to focus on setting up partnerships with said stakeholders and integrating data infrastructures, paying limited attention to the capacity to utilize the data within government.

As a result, utilizing big data in urban policy-making is still ‘work in progress’. Many planning and framework strategies issued in the last five years focus heavily on the technological side of big data and less on the capabilities to transform the data information into knowledge relevant for cities. At the same time, city governments are dependent on private stakeholders to make sense of the data, since data analytics capacities within government remain rather low. This leads to outsourcing much of what is going on in the big data field with little internal governmental knowledge of what the data can and cannot provide in the context of cities and more specifically for environmental measures.

These findings stem from the policy field of energy and more specifically carbon emission reduction; however data integration in ongoing policy processes poses similar challenges in other sectors. Even if the inter-departmental ties are less complex, local governments still struggle with the skill set they have and the buying of services compensating for limited capacity connected to data. Data standardization and the combination of national-level and local-level data are also something that other policy sectors, such as the transport, health or finance sector, are currently facing. Looking ahead, additional research is required to analyse which effect the integration of big data has on policy-making once these local experiments have been completed and initiatives are rolled out systematically across cities.

Disclosure statement

No potential conflict of interest was reported by the author.

References

Bătăgan, L. (2011). Smart cities and sustainability models. *Informatica Economică*, *15*(3), 80–87.

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., & Portugali, Y. (2012). Smart cities of the future. *European Physical Journal*, *214*, 481–518.

Bayram, S., Shakir, M. Z., Abdallah, M., & Qaraqe, K. (2014). A Survey on Energy Trading in Smart Grid. Conference paper for IEEE GlobalSIP, Atlanta, USA.

Best, A., & Holmes, B. (2010). Systems thinking, knowledge and action: Towards better models and methods. *Evidence and Policy*, *6*(2), 145–159.

Bright, J. (2015, July 23). How big data is breathing new life into the smart cities concept. The Policy and Internet Blog, Understanding public policy online. Retrieved December 14, 2015, from http://blogs.oii.ox.ac.uk/policy/how-big-data-is-breathing-new-life-into-the-smart-cities-concept/

Britton, J. (2016). Smart meter data and public interest issues - The sub-national perspective. Transforming energy demand through Digital innovation network report, Discussion Paper 2. Retrieved December 14, 2016, from https://www.cse.org.uk/downloads/file/teddinet-paper-jess%20-britton.pdf

Caragliu, A., Del Bo, C., & Nijkamp, P. (2011). Smart cities in Europe. *Journal of Urban Technology*, *18*(2), 65–82. doi:10.1080/10630732.2011.601117

Carrington, D. (2016, June 30). UK lacks policies to meet more than half its carbon emissions cuts – report. *The Guardian*. Retrieved from https://www.theguardian.com/environment/2016/jun/30/uk-lacks-policies-to-meet-more-than-half-its-carbon-emissions-cuts-report

Chang, C. T., & Martens, P. (2010). *The social and behavioural aspects of climate change: Linking vulnerability, adaptation and mitigation*. Sheffield: Greenleaf.

City of Copenhagen. (2015). Copenhagen Smart City. Retrieved August 8, 2016, from http://www.almanac-project.eu/downloads/M2M_Workshop_Presentations/Session%204/Mia_Copenhagen_smart_city_2015.pdf

Columbus, L. (2014, December 29). Where big data jobs will be in 2015. *Forbes*. Retrieved from http://www.forbes.com/sites/louiscolumbus/2014/12/29/where-big-data-jobs-will-be-in-2015/#341ada85404a

Committee on Climate Change. (2016). Meeting carbon budgets – 2016 progress report to parliament. Retrieved from https://www.theccc.org.uk/publication/meeting-carbon-budgets-2016-progress-report-to-parliament/

Copeland, E. (2014). Small pieces loosely joined, how smarter use of technology and data can deliver real reform of local government. Policy Exchange, January 26, 2015. Retrieved December 14, 2016, from http://www.policyexchange.org.uk/publications/category/item/small-pieces-loosely-joined-how-smarter-use-of-technology-and-data-can-deliver-real-reform-of-local-government

Copeland, E. (2015). Big data in the big apple, The lessons London can learn from New York's data-driven approach to smart cities. Capital City Foundation Report. Retrieved December 14, 2016, from http://www.spatialcomplexity.info/files/2015/06/Big-Data-in-the-Big-Apple.pdf

Courmont, A. (2015, July). Making the data-driven city. How does the socio-technical shaping of data analytics change the government of the city? Paper prepared for the International Conference on Public Policy, Milan.

Davies, P. (2004). *Is evidence-based policy possible? The Jerry Lee lecture*. Washington: Campbell Collaboration Colloquium.

Deloitte. (2013). *Market assessment of public sector information*. A report by Deloitte for the UK Department for Business, Innovation and Skills.

Diekerhof, M., Lillienberg, D., & Monti, A. (2014, July 30). Advanced ICT solutions for Smart Cities. IEE Power & Energy Society Presentation. Retrieved December 14, 2016, from http://www.ieee-pes.org/presentations/gm2014/PESGM2014P-002748.pdf

Doody, L., Walt, N., Dimireva, I., & Nørskov, A. (2016). Growing Smart Cities in Denmark, digital technology for urban improvement and national prosperity. Research commissioned by the Ministry of Foreign Affairs of Denmark. Retrieved August 8, 2016, from http://www.investindk.com/~/media/Files/Reports/Growing_Smart_Cities_in_Denmark.ashx

Dowding-Smith, E. (2013). City in Focus: Malmö, Sweden, integrating ambitious renewable energy targets in city planning. Retrieved December 14, 2016, from https://www.irena.org/Publications/RE_Policy_Cities_CaseStudies/IRENA%20cities%20case%207%20Malmö.pdf

Eco-Municipality Education & Assistance. (2016). Eco-municipalities: Sweden and the United States – a systems approach to creating sustainable communities. Retrieved from http://www.instituteforecomunicipalities.org/Eco-municipalities.html

Ernst & Young (EY) (2013). Outsourcing in Europe: An in-depth review of drivers, risks and trends in the European outsourcing market.

Falke, S. R. (2002). Environmental data: Finding it, sharing it and using it. *Journal of Urban Technology*, *9*(2), 111–124. doi:10.1080/1063073022000016504

Flowers, M. (2013). Beyond open data: The data-driven city. Data-smart city solutions: An initiative by the Ash Centre at Harvard Kennedy School and powered by Bloomberg Philanthropies. Retrieved December 12, 2015, from http://datasmart.ash.harvard.edu/news/article/beyond-open-data-the-data-driven-city-325

Foulon, J., Lanoie, P., & Laplante, B. (2002). Incentives for pollution control: Regulation or information? *Journal of Environmental Economics and Management*, *44*(1), 169–187. doi:10.1006/jeem.2001.1196

French, S., Barchers, C., & Zhang, W. (2015). Moving beyond operations: Leveraging big data for urban planning decisions. CUPUM paper. Retrieved December 12, 2015, from http://web.mit.edu/cron/project/CUPUM2015/proceedings/Content/pss/194_french_h.pdf

Gant, J. (2015). Smart Cities, Data Warehouses, Data Lakes and the Information Management Challenge. LG CNS Blog. Retrieved from http://www.lgcnsblog.com/inside-it/smart-cities-data-warehouses-data-lakes-and-the-information-management-challenge

Goldsmith, S., & Crawford, S. (2014). *The responsive city: Engaging communities through data-smart governance*. San Francisco, CA: Jossey-Bass.

Gray, D., Couper, G., Jones, E., Wade, J., Pilling, A., Machin, N., & Matthews, P. (2011). Evaluation of the *local carbon framework pilots*. A report by CAG Consultants in association with Impetus Consulting and Dr Joanne Wade, Commissioned by the Local Government Association and the Department for Energy and Climate Change. Retrieved August 8, 2016, from http://www.local.

gov.uk/c/document_library/get_file?uuid=5c86ec51-3e42-4efc-bce4-35cfa7f0b9ac&groupId=10180

Greater London Authority. (2016). *Data for London: A city data strategy*. City Hall: Greater London Authority.

Guevara-Stone, L. (2014, September 23). From a decaying industrial area to an eco-friendly city: Malmö, Sweden is leading the way. Rocky Mountain Institute. Retrieved December 12, 2016, from http://blog.rmi.org/bog_2014_09_23_from_a_decaying_industrial_area_to_ecofriendly_city_Malmö_sweden

Hartman, S., Hlava, P., Tiede, L., Kintisch, M., Mollay, U., & Schremmer, C. (2015). Transformation agenda Vienna. Final report. Retrieved December 12, 2016, from http://www.transformyourcity.eu/resources/TRANSFORMATION_AGENDA_Vienna_150dpi.pdf

Head, B. W. (2008). Three lenses of evidence-based policy. *The Australian Journal of Public Administration*, *67*(1), 1–11. doi:10.1111/j.1467-8500.2007.00564.x

Her Majesty's Government. (2013). *Seizing the data opportunity: A strategy for UK data capability*. Crown Report for the Department for Business, Innovation and Skills.

Hitachi Consulting. (2015). Hitachi Consulting awarded the opportunity to build big data platform for Copenhagen. Retrieved December 12, 2016, from http://www.hitachiconsulting.com/pages/Description.aspx?artcileid=5

Höchtl, J., Parycek, P., & Schöllhammer, R. (2016). Big data in the policy cycle: Policy decision making in the digital era. *Journal of Organizational Computing and Electronic Commerce*, *26*(1–2), 147–169. doi:10.1080/10919392.2015.1125187

Hordijk, M., & Baud, I. (2006). The role of research and knowledge generation in collective action and urban governance: How can researchers act as catalysts? *Habitat International*, *30*, 668–689. doi:10.1016/j.habitatint.2005.04.002

Howlett, M. (2009). Policy analytical capacity and evidence-based policy-making: Lessons from Canada. *Canadian Public Administration*, *52*(2), 153–175. doi:10.1111/j.1754-7121.2009.00070_1.x

Howlett, M. (2015). Policy analytical capacity: The supply and demand for policy analysis in government. *Policy and Society*, *34*, 173–182. doi:10.1016/j.polsoc.2015.09.002

Howlett, M., Migone, A., & Tan, S. L. (2014). Duplicative or complementary? The relationship between policy consulting and internal policy analysis in Canadian government. *Canadian Journal of Political Science*, *47*(1), 1–22.

Hsu, A. (2015). Measuring policy analytical capacity for the environment: A case for engaging new actors. *Policy and Society*, *34*, 197–208. doi:10.1016/j.polsoc.2015.09.003

IBM. (2013). *IBM's smarter cities challenge*. Copenhagen Report. Retrieved January 9, 2016, from http://smartercitieschallenge.org/scc/executive_reports/SCC-Copenhagen-Report.pdf

Kauffman, J. M. (1995). Why we must celebrate a diversity of restrictive environments. *Learning Disabilities Research and Practice*, *10*, 225–232.

Kaylor, C. H. (2005). The next wave of e-government: The challenges of data architecture. *Bulleting of the American Society for Information Science and Technology*, *31*(2), 18–22.

Kitchin, R. (2014). The real-time city? Big data and smart urbanism. *GeoJournal*, *79*(1), 1–14. doi:10.1007/s10708-013-9516-8

Larson, K., White, D., Gober, P., & Wutich, A. (2015). Decision-making under uncertainty for water sustainability and urban climate change adaptation. *Sustainability*, *7*, 14761–14784. doi:10.3390/su71114761

Letouzé, E., and Jütting, J. (2014). Officials statistics, big data and human development: Towards a new conceptual and operational approach. Data-Pop Alliance White Papers Series, 17.

Low Carbon Oxford. (2012). *Building momentum, measuring, monitoring and reporting*. Report commissioned by Oxford City Council. Retrieved January 2, 2016, from http://oxfordsmartcity.uk/Low%20Carbon%20Oxford%20Building%20Momentum%20Report.pdf

Malmö Stad. (2011). *Malmö – the Green Digital City*. Retrieved February 2, 2016, from http://ec.europa.eu/information_society/activities/sustainable_growth/docs/smart-cities/malmo.pdf

Manville, C., Cochrane, G., Cave, J., Millard, J., Pederson, J. K., Thaarup, R. K., … Kotterink, B. (2014). Mapping smart cities in the EU. Directorate General for Internal Policies, Policy

Department A: Economic and Scientific Policy. IP/A/ITRE/ST/2013-02, PE 507.480, European Parliament's Committee on Industry, Research and Energy.
Margetts, H. (2016, August 10). Back to the bad old days, as civil service infighting threatens UK's only hope for digital government. The Policy and Internet Blog, Understanding public policy online. Retrieved December 14, 2016, from http://blogs.oii.ox.ac.uk/policy/back-to-the-bad-old-days-as-civil-service-infighting-threatens-uks-only-hope-for-digital-government/
Meijer, A., & Bolivar, M. (2015). Governing the smart city: A review of the literature on smart urban governance. *International Review of Administrative Sciences*, *82*(2), 392–408.
Misuraca, G., Mureddu, F., & Osimo, D. (2014). Policy-making 2.0: Unleashing the power of big data for public governance. *Opportunities and Challenges for Public Governance*, 171–188.
Mitlin, D. (2004). Reshaping local democracy. *Environment and Urbanization*, *16*(1), 3–8. doi:10.1177/095624780401600102
Mureddu, F., Osimo, D., Misuraca, G., & Armenia, S. (2012). A new roadmap for next generation policy making. In D. Ferriero, T. A. Pardo, & H. Qian (Eds.), *Proceedings of the 6th international conference on theory and practice of electronic governance (ICEGOV2012)* (pp. 62–66). Albany: ACM Press.
Nutley, S. M., Walter, I., & Davies, H. T. O. (2007). *Using evidence: How research can inform public services*. Bristol: Policy Press.
OECD. (2014). Environmental performance reviews, Sweden. Retrieved September 8, 2016, from https://www.oecd.org/environment/country-reviews/Sweden%20Highlights%20web%20pages2.pdf
Oikonomou, V., Flamos, A., & Grafakos, S. (2010). Is blending of energy and climate policy instruments always desirable? *Energy Policy*, *38*(8), 4186–4195. doi:10.1016/j.enpol.2010.03.046
Online Post. (2013, May 20). City turns to data to meet climate ambitions. Retrieved December 12, 2016, from http://cphpost.dk/news14/national-news14/city-turns-to-data-to-meet-climate-ambitions.html
Pawson, R. (2006). *Evidence-based policy, A realist perspective*. London: Sage.
Pawson, R., Boaz, A., Grayson, L., Long, A., & Barnes, C. (2003). *Types and quality of knowledge in social care*. Knowledge Review 3, Social Care Institute for Excellence. Bristol: Policy Press.
Pease, A. (2015). From big data to smart data, Aspern: The city next door. Siemens, Pictures of the future. Retrieved December 17, 2016, from http://www.siemens.com/innovation/en/home/pictures-of-the-future/digitalization-and-software/from-big-data-to-smart-data-aspern-city-research-project.html
Peled, A. (2014). *Traversing digital babel: Information, e-government, and exchange*. Boston, MA: MIT Press.
Preston, I., White, V., Thumim, J., Bridgeman, T., & Brand, C. (2013). *Distribution of carbon emissions in the UK: Implications for domestic energy policy*. Cambridge: Centre for Sustainable Energy. Retrieved from https://www.jrf.org.uk/sites/default/files/jrf/migrated/files/carbon-emissions-energy-policy-full.pdf
Radin, B. (2003). The instruments of intergovernmental management. In P. Guy & J. Pierre (Eds.), *Handbook of public administration* (pp. 606–618). London: Sage.
Rescher, N. (1998). *Complexity: A philosophical overview*. New Brunswick: Transaction.
Romero-Lankao, P. (2012). Governing carbon and climate in the cities: An overview of policy and planning challenges and options. *European Planning Studies*, *20*(1), 7–26. doi:10.1080/09654313.2011.638496
Sanderson, I. (2006). Complexity, 'practical rationality' and evidence-based policy making. *Policy & Politics*, *34*(1), 115–132. doi:10.1332/030557306775212188
Schorr, L. B. (2003). *Determining 'what works' in social programs and social policies: Towards a more inclusive knowledge base*. Washington, DC: Brookings Institute.
Smart City Wien. (2012). Smart City Wien, Framework strategy. Retrieved January 2, 2015, from https://smartcity.wien.gv.at/site/files/2014/09/SmartCityWien_FrameworkStrategy_english_doublepage.pdf
Smart Oxford. (2015). Urbandata2decide – urban decision making. Retrieved January 2, 2015, from http://oxfordsmartcity.uk/cgi-bin/ud2d.pl

Thakuriah, P., Tilahun, N., & Zellner, M. (2015). Big data and urban informatics: Innovations and challenges to urban planning and knowledge discovery. In Proceedings of NSF Workshop on Big Data and Urban Informatics, 4–32.

Trenberth, K. (2010). More knowledge, less certainty. *Nature Reports Climate Change*, *4*, 20–21. doi:10.1038/climate.2010.06

Wammes, H. (2015). How spatial big data underpins smart cities. GIS Lounge. Retrieved January 2, 2015, from http://www.gislounge.com/how-spatial-big-data-underpins-smart-cities

Wang, H., Bi, J., Wheeler, D., Wang, J., Cao, D., & Lu, G. (2004). Environmental performance rating and disclosure: China's greenwatch program. *Journal of Environmental Management*, *71*, 123–133. doi:10.1016/j.jenvman.2004.01.007

Wollmann, H. (2002). Recent democratic and administrative reforms in Germany's local government: Persistence and change. In Janice/Larsen Caulfield & O. Helge (Eds.), *Local government at the millenium* (pp. 63–89). Wiesbaden: VS Verlag für Sozialwissenschaften.

Yiu, C. (2012). *The big data opportunity: Making government faster, smarter and more personal*. Policy Exchange Report, UK digital government unit, London.

Zhou, K., Fu, C., & Yang, S. (2016). Big data driven smart energy management: From big data to big insights. *Renewable and Sustainable Energy Reviews*, *56*, 215–225. doi:10.1016/j.rser.2015.11.050