

Data-driven sector coupling in smart sustainable cities¹

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Smart sustainable cities provide a vast potential for data-driven sector coupling due to the variety of smart network infrastructure and services involved. Digital twin technologies support city planning and city operation activities. However, virtual replicas cannot replace entrepreneurial solutions to governance problems through the organisation of market-driven activities.

Data-driven innovations as drivers of smart sustainable cities

The evolution from dumb to smart networks is data-driven and characterised by real-time adaptive production and consumption decisions based on real-time and geolocational scarcity signals. Smart sustainable cities are emerging as data hubs with a vast potential for big data-driven innovations. Sensor-generated data is increasingly replacing data generated by infrastructure. Data value chains are becoming increasingly relevant in the planning, delivery and management of transport services and infrastructure due to the rapidly decreasing cost of sensors and of the collection, storage and processing of data (OECD, 2015, Chapter 9; OECD/ITF, 2015, 2016).

In recent years, big data combined with modern information and communication technology (ICT) has assumed a pivotal role in the development of smart sustainable cities (ITU 2015; Al Nuami et al., 2015). The Internet of Things (IoT) is becoming increasingly relevant, combining physical network service such as water, electricity, transportation and waste management with complementary virtual networks and thereby exploiting the full potential of ICT with tools such as smart metering, sensor networks, actuators and remote control. Virtual networks incorporate data value chains combining quality of service (QoS) differentiated data transmission with latency guarantees, position accuracy, continuous sharing of position data and big data processing of sensor data in order to fulfil the requirements of IoT applications and related physical network services (Knieps, 2017a, 2019, p. 176).

Different forms of sector coupling in smart sustainable cities building innovative sustainable value chains to provide physical network services may be distinguished. Sector coupling may arise between different sectors. Synergies of urban system integration can be exploited in transport, energy and waste systems, such as by coupling biogas produced in recycling wastewater plants with buses and

taxis designed to utilise this fuel (OECD, 2015, p. 384). Sector coupling may also create new intermodal markets, shifting intramodal transportation markets towards mobility-as-a-service markets and shared mobility projects. Sector coupling is also challenging the conventional value chain of electricity markets. The coupling of generation and consumption in microgrids can be organised via operator platforms. Renewable energy generation can also be coupled with electric vehicle mobility.

Many possibilities of data-driven sector coupling in cities are still unexploited. Physical features may be improved in order to make cities more walkable, focusing on intermodal mobility service platforms. Data-driven routes in cities can be developed, thus improving urban navigation for pedestrians. Embedding smart city solutions will require more data and better algorithms (Castro, 2020).

The complementarity of physical and virtual networks in smart sustainable cities

Various physical network services are of relevance in smart cities, such as smart transportation management, networked vehicle services, microgrids, smart garbage collection, smart water distribution, shared mobility services and city safety (ITU-T 2015a). Smart cities utilise multiple technologies to improve performance in the areas of health, transportation, energy, education and water services. The potential to enhance smart city services is based on big data analytics (Cathelat, 2019). Of particular relevance in the transition of conventional cities into smart sustainable cities is the creation of data value chains enabling the design of virtual networks complementary to the necessities of physical networks in cities. The need for a multiplicity of different virtual networks in smart sustainable cities results from the heterogeneous requirements of different physical networks. The network logistics of heterogeneous virtual networks for smart cities are based on common elements of ICT architecture, particularly sensor networks,

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geopositioning services and the aggregation and processing of big data (Knieps, 2017a).

Different forms of data-driven sector coupling in smart sustainable cities

Data-driven innovations create a vast potential for big data-driven sector coupling in smart network industries, with particular relevance in smart sustainable cities. Cities are not only considered data hubs collecting large volumes of data and offering many chances for data-driven innovation but they also provide a wide range of market coupling opportunities due to the variety of smart network infrastructure and services involved.

Traditional separately organised markets are now converging, resulting in a tremendous potential for sector coupling due to the increasingly blurred boundaries between traditional network industries. Big data-driven market coupling is of particular relevance in the electricity and transportation sectors (OECD, 2015, p. 50). Microgrids can combine the low-voltage generation and consumption of electricity with a focus on renewable energy and coupling customised energy generation and storage with energy consumption (Knieps, 2017b). Multipurpose home networks are coupling the broadband capacities of sensor networks for energy prosumage with communication and entertainment applications such as voice over IP and IPTV (ITU-T, 2016).

Examples of cross-functional applications of ZigBee IP sensor networks in smart sustainable cities are infrastructure maintenance, garbage management and street parking. Electronic devices endowed with smart metering capabilities enable the real-time digital collection of consumption data on network services in urban infrastructure. The remote accessibility of data concerning electricity, heat, gas and water consumption enables not only real-time smart metering and concomitant adaptive energy consumption but also billing, leak detection and peak-load pricing (ITU-T, 2015). ‘Mobility-as-a-Service’ platforms can evolve for intermodal physical transportation services, enabling seamless app-based mobility-as-a-service combining the advantages of sector coupling with different complementary rail- and road-based transportation options (Knieps, 2018). ICT and the digitalisation of urban flows are gaining importance, thus increasing the ability to monitor and manage urban infrastructure in real time (Engin et al., 2019). Smart sustainable cities may also benefit from cross-sector data sharing enabled by ZigBee IP sensor networks and smart metering. Examples can be drawn from electrical, water and waste systems and transport with re-

al-time peak load demand and supply (OECD, 2015, pp. 50, 379-403).

Digital twins and their role for smart sustainable cities

Al Nuami et al. (2015, p. 15) identify the need to develop simulation systems to reduce implementation and testing costs during the various stages of smart city development as an open issue. Based on recent innovations in the fifth generation of mobile technology, 5G, a state-of-the-art simulation and planning tool known as ‘digital twins’ has become relevant. 5G-driven artificial intelligence (AI) along with augmented and virtual reality (AR/VR) technologies enable the construction of virtual replicas through a software representation of the physical city. Digital twins combine virtual replicas of urban infrastructure with real-time sensor-based information about the physical city (Castro, 2019). Members of the Open Mobility Foundation, consisting of 13 U.S. cities (including New York City, Philadelphia, San Francisco and Washington, D.C.), collaborate on creating digital data models of urban mobility (Westrope, 2019). The Open Mobility Foundation White Paper is widely based on the ‘digital twin’ model, specifying that municipalities own and control a digital data model of urban mobility (Open Mobility Foundation, 2019). Virtual Singapore is considered a forerunner project. Singapore’s three-dimensional (3D) city model merges simulations of large-scale automotive IoT deployment (National Research Foundation Singapore, 2018). Cities that have deployed digital twins in the meantime include Newcastle, Rotterdam, Boston, New York, Singapore, Stockholm, Helsinki and Jaipur (Onag, 2019). The planners of the new capital city of Amaravathi in India are using digital twins to help design this greenfield smart city (Jansen, 2019). The number of digital twins is expected to increase significantly in the next decade (Blackman, 2019).

Digital twins versus virtual networks

Digital twin technology is a planning tool enabling users to simulate the impact of exogenous changes to infrastructure, e.g. building an additional bridge, reorganising traffic, extending car-free zones, etc. Digital twins can also be applied to support smart city operation systems. For example, Rotterdam’s digital twin tracks both road and waterway traffic intensity to optimise bridge opening and closing, enhance urban waste collection and link real-time usage data to the digital twin keeping residents informed (EIP-SCC Marketplace, 2019). A digital twin provides a virtual replica of a city without solving the challenging governance problems of contractual relationships among the different actors involved. In contrast, the IoT

requires physical and complementary virtual networks to enable adaptive, real-time and location-differentiated network configurations for smart sustainable cities (Knieps, 2017b). In order to meet the diverse requirements of different physical network infrastructure and network services, different combinations of sensors, cameras, location-based data generation and processing and QoS requirements of data transmission are required.

Although data value chains are pivotal in developing IoT applications in smart sustainable cities, solving the entrepreneurial governance problems in the IoT requires physical networks and complementary virtual networks. The presence of both enables adaptive, real-time and location-differentiated network configurations. Although digital twin technologies may become very beneficial in city planning and city operation activities, virtual replicas cannot replace entrepreneurial solutions to governance problems through the organisation of market-driven activities by the different actors involved, such as platform operators, virtual network providers and all-IP broadband network providers.

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