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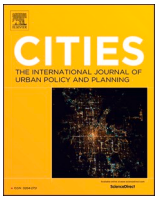

Sustainable open data ecosystems in smart cities: A platform theory-based analysis of 19 European cities

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ABSTRACT

An understanding of how modern Open Data Ecosystems (ODEs) work is critical in the context of current trends towards sustainability and smartness, while is seen to be an asset to support urban governance and development, in coordinating actions, and fostering civic engagement. This paper aims to establish such understanding by analyzing the contextual patterns, platforms, and components shaping sustainable ODEs by employing platform theory. This study explores and compares characteristics, similarities, differences, and best approaches in 19 cities across 8 countries. In this study we (1) identify 50 patterns that influence and shape sustainable ODEs and their platforms, i.e., Open Data Platform Ecosystems (ODPEs); (2) explore the relationships between platforms and other ODPEs components by developing a respective model, and identifying internal platforms and other components; (3) empirically validate the conceptual findings of five types of ODPEs presented in the literature, redefining them from the conceptual to real-life implementation of the respective components in sample cities; (4) considering the experience gained during the study with respect to the ODPEs and external pressures and environments that shape or influence them, we define 12 recommendations for policy planning and urban governance of more sustainable ODEs.

1. Introduction

The growing challenges to be faced by urban areas due to an increasing population and urbanization increase the relevance and the role acquired by Information and Communication Technologies (ICT) in public policies to successfully address these challenges through collective intelligence and its integration into the public administration area. In recent years, there has been an increased need and interest in giving power to citizens, engaging them directly in urban management, obtaining data and information, thinking about and reflecting on the issues of their city's problems, and taking part in shaping the future of their city (Hasegawa et al., 2019). The digital transformation of processes and services, the efforts to ensure transparency and accountability, and the amount of data and information used in the daily

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activities of cities are pushing their representatives to consolidate, organize and orchestrate these pressures (Bagheri et al., 2021; Botequilha-Leitão & Díaz-Varela, 2020; Gupta et al., 2020; Janowski, 2015). This digital transformation towards a sustainable environment in smart cities has demonstrated to be highly dependent on the flow of data and information between stakeholders and other systems' components (Aziz et al., 2022; Caputo et al., 2019; Lnenicka et al., 2022), which requires the design of such inclusive and smart data infrastructures[1] that will enable an efficient data exchange, share, and reuse (Curry & Sheth, 2018), which, in turn, is expected to help address sustainable development needs (Mayaud et al., 2019).

Openness[2] is one of the core concepts underlined in these public sector reforms (Vancauwenberghe et al., 2018), providing complex, innovative, and networking environments using Open Government Data (OGD), performed by and for people. It is of particular importance for urban and smart city development and supporting urban governance, and more importantly, "smart city governance" (Ruhlandt, 2018), coordinating actions, and fostering civic engagement (Ma & Lam, 2019), as well as fostering new digital economy services (Smith, 2016). This makes the ecosystem approach to be an appropriate way to effectively examine components and types of smart cities, Open Data Ecosystems[3] (ODEs) and their main characteristics (Bagheri et al., 2021; Lnenicka et al., 2022; Wessner, 2005). According to Adner (2017), the ecosystem is characterized "*by the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize*" (p. 42). Hence its importance to the value creation process, which can be influenced by the structure of the components and the dynamics of relationships between them. According to Jetzek (2017), this ecosystem is built on a complex network of values created by various stakeholders. Gao and Janssen (2022) reported that formulation of a value proposition from open data involves identifying or defining data users, data providers, and infomediaries, and possibly other partners providing technology or infrastructure support. Modern ICT enable the flows of data and information between stakeholders fostering their participation, interactions, and collaboration to create value (Chokki et al., 2022; Viale Pereira et al., 2017; Zuiderwijk et al., 2014).

Although ODE has been defined in different ways, currently, there is a lack of a clear, commonly accepted definition of it, its characteristics, components, and relationships between them. Its definition tends to vary from a tool for identifying and evaluating strategies that can be adopted to achieve the benefits of open data (Davies, 2011) to "*an actor-network within which data flows are facilitated through an enactment of actors*" (McLeod & McNaughton, 2016, p. 28). Welle Donker and Van Loenen (2017), however, argue that building a well-functioning ODE requires focusing on technical, legal, and organizational perspectives of open data policies to define standards promoting interoperability of data together with a network for data users that is stable and sustainable. In brief, ODEs provide an environment in which OGD initiatives and strategies can be created, promoted, and managed in a sustainable manner.

[1] Smart data infrastructures are infrastructures built in smart cities (or smart regions/smart villages) that are mainly built for data produced by smart cities, i.e., smart data obtained from various sensors and often processed in real-time in the form of data streams. These infrastructures differ from the general concept of data infrastructure in that the characteristics and specific goals of smart cities (smart transport, smart environment etc.) and the data lifecycle of the smart data obtained are considered when building these infrastructures.

[2] Openness – in this study always refers to "as open as possible" principle (Jeffery et al., 2021).

[3] ODEs are built around OGD and other types of open data such as Open Citizen Data (OCD), Open Business Data (OBD), or Open Science Data (OSD) (Lnenicka et al., 2022). Therefore, while other studies refer to this concept as Open Government Data Ecosystem (OGDE), we use the term being a superset of the OGDE, i.e., ODE includes OGDE and other above-mentioned types of open data.

Although these ecosystems are usually formed in the public sector at different administrative levels and can be also created around private organizations or across industrial sectors (Csáki, 2019; Curry & Sheth, 2018; Heimstädt et al., 2014b; Jetzek, 2017; Oliveira et al., 2019; Osorio-Sanabria et al., 2020; Styrin et al., 2017), they are especially relevant to provide an environment and support for data sharing initiatives in smart cities (Oliveira et al., 2019). Indeed, city data ecosystems are not only considered as "*an integrated view of data applications by the various city entities that operate within an institutional environment*" (Gupta et al., 2020, p. 1), but also as elements to provide national data ecosystems with information to make decisions (Reggi & Dawes, 2022). According to Reggi and Dawes (2022), local governments are of much importance in providing an environment for OGD users to share information effectively, facilitating access to open data as well as facilitating and stimulating engagement, collaboration, cooperation, and participation of other stakeholders with the system in use (Clement et al., 2022). Nonetheless, there are different types of data ecosystems in cities based on the infrastructure's deductively derived characteristics and components (Hrustek et al., 2022; Lnenicka et al., 2022), making it important to understand their current state and maturity with the aim of extracting from them requirements for building sustainable ODEs.

To achieve this aim, the platform theory (Gawer & Cusumano, 2002) is a critical component of the implementation of ODEs concerning their governance design constructs and the distinct approaches to be taken in the implementation (Bonina & Eaton, 2020). Indeed, the platform-centric structure of the data ecosystem is one of the types of structures identified by Oliveira et al. (2019). Danneels et al. (2017) defined an OGD platform as "*an architecture of data services together with the governance of access and (re-)use, created for the purpose of allowing third parties to create new value*" (p. 366). Nonetheless, there is a lack of a clear and commonly accepted definition of the Open Data Platform Ecosystem (ODPE) in the platform theory, especially being compliant with current trends, i.e., sustainable and smart, and more importantly, characteristics that this ecosystem should have as well as platforms, components, and relationships between them.

Therefore, based on the platform theory, this paper seeks to fill this research gap, analyzing the platforms, components, and types of ODPEs, comparing characteristics, similarities, differences, and best approaches, as well as acquiring an understanding of experiences and practices that will help in building such sustainable data ecosystems in cities. This analysis could help to understand the (re-)designing of the ODPE and its components (e.g., OGD portal), since the understanding of the ecosystem is crucial to enable its long-term viability (Grabis et al., 2022).

In brief, the ODPEs studied in this paper mainly refer to platform ecosystems and OGD platforms as defined by Danneels et al. (2017). We focus our comparative analyses on the components and characteristics of ODPEs identified by Lnenicka et al. (2022). Thus, in this paper as a component, we understand every element that can be used to describe the context of the ecosystem and/or to affect (influence) the dynamics of the management and development of the data ecosystem, and as a relationship - a connection between elements, the nature of which depends on the elements. Finally, our analysis extends prior research using innovative methods for collecting, interpreting, and assessing information on which components should constitute these types of ecosystems in sustainable smart cities, answering the following Research Questions (RQs):

RQ1. What are the contextual patterns that influence and shape open (government) data efforts in smart cities?

RQ2. What are the relationships between platforms and other components of ODPEs that can be found in smart cities?

RQ3. How do the patterns, platforms, and other components form different types of ODPEs and how do they contribute to the maturity concept of a sustainable ODE?

To answer the RQs, we first developed a protocol covering (1) managerial and organizational, (2) political and institutional, and (3) information and technological contexts to identify relevant patterns. The protocol also covers digital platforms that contribute to transparency, openness, and accountability in which we focused on the internal and external components as well as aimed to explore the position of the ODPEs in the whole data ecosystem. For this purpose, we performed a Delphi method to identify and validate the contexts, platforms, components, and their relationships. We applied a cluster analysis to identify similarities between groups of patterns that influence and shape open (government) data efforts in smart cities. Then, we explored relationships between platforms and other components that form different types of ODPEs. Finally, we used these findings and our experiences gained in this study to discuss their contribution towards the maturity concept of a sustainable ODE.

To meet the objectives of this study, the paper is organized as follows: Section 2 establishes the research background, Section 3 provides the methodology for the research, the findings resulting from the study are described in Section 4, discussion and recommendations are brought forth in Section 5, limitations are presented in Section 6, and the paper concludes in Section 7 highlighting future directions for research and clarifying the primary contributions of this paper.

2. Research background

2.1. Data ecosystems

General types of ecosystems in information systems research were examined by several authors. Benedict (2018) identified seven dominant ecosystem types: (1) business, (2) service, (3) innovation, (4) digital (business), (5) platform, (6) software, and (7) technology. The digital ecosystem includes at least one digitized component, and its architecture is designed to solve complex dynamic problems (Benedict, 2018). It is also one of the most frequent types of ecosystems in current research (Guggenberger et al., 2020). A data ecosystem is one type of a digital ecosystem.

Oliveira and his colleagues collected several definitions of a data ecosystem used in scientific literature over the years. The most complex can be found in Oliveira and Farias Lóscio (2018), according to which data ecosystem is *"a set of networks composed by autonomous actors that directly or indirectly consume, produce, or provide data and other related resources (e.g., software, services, and infrastructure), each actor performs one or more roles and is connected to other actors through relationships, in such a way that actors collaboration and competition promotes data ecosystem self-regulation"* (p. 85). The main constructs of the data ecosystem are actors, roles, relationships, and resources. Their definitions consider social and technical relationships between components and how they interact and collaborate with data resources through their lifecycle to create value (Oliveira et al., 2018; Oliveira et al., 2019). Linåker and Runeson (2021) extended the definition by emphasizing the role of an underpinning technological platform that serves as the foundation for various actors to engage in the processing of data, thus facilitating innovative practices, value creation etc. According to Heimstädt et al. (2014a, 2014b), a data ecosystem can be viewed as an interaction between cooperating and competing actors, which are an interconnected mashup of technologies, people and organizations operating in a systemic reading – constantly communicating with adjacent ecosystems.

Data infrastructure is an important prerequisite for enabling data ecosystems. Indeed, Davies (2011) states that data infrastructure and data ecosystems can be viewed as metaphors deployed in a twin manner. Gelhaar et al. (2021) claim that the data infrastructure is provided by a platform that supports the sharing and usage of data within the ecosystem. A more detailed elaboration of the technological platform in the data ecosystem context is provided by Lnenicka et al. (2022), who reported that it could be represented by data portals and other repositories and data sources providing OGD and other open data (also in line with Ma and Lam (2019)). Curry and Sheth (2018) believe that mass collaboration within the data ecosystem must be accompanied by a proper data governance model which fully considers ethical, legal, and privacy concerns.

2.2. Open data ecosystems

There is currently a lack of a clear, commonly accepted definition of the ODE, its characteristics, components, and relationships between them. Many different definitions and insights can be found in the literature. Davies (2011) defines it as a tool for identifying and evaluating strategies that can be adopted to achieve the benefits of open data. Similarly, Dawes et al. (2016) and Reggi and Dawes (2016) emphasized assessment of existing conditions and relevant policies, strategies, and relationships using the ecosystem approach to plan and design ODEs. To build a well-functioning ODE, Welle Donker and Van Loenen (2017) emphasize focusing on technical, legal, and organizational perspectives of open data policies to define standards facilitating data interoperability and a stable and sustainable network for users of the data. In this network, relationships represent data supplied freely for use and reuse, and utilized for various activities (McLeod & McNaughton, 2016) and flows of information from one actor to another (Reggi & Dawes, 2022). Kapoor (2018) consider a dynamic interaction of a system of record, a system of insight, and a system of engagement as a key requirement for the ODE.

Linåker and Runeson (2022) define the ODE as a *"type of community of actors, openly sharing and evolving data on a technological platform"* (p. 1). In the case of Open Government Data Ecosystems (OGDE), the provider of the technological platform is constituted by a public entity or part of such (Linåker & Runeson, 2021), which acts as a central actor and takes the initiative within the ecosystem to achieve specific goals (Harrison et al., 2012). The OGDE can be seen as a *"collection of nodes (functional systems) connected by complementary infrastructure networks that together organize a foundational data flow"* (Crusoe, 2021, p. 285). It is characterized by interactions between government and innovators from technology sectors, private industry, and academic institutions (Harrison et al., 2012). The OGDE must be valuable or beneficial to other organizational ecosystems and existing environments, such as economic, social, technical, environmental, cultural, or political, that shape the purpose of the ecosystem, the goals it strives to achieve, the ongoing processes within it, and the services provided by it (Lnenicka et al., 2022).

Considering the delimitation of ODEs' components by the platform theory, platform ecosystems and their platform-centric structure (Bonina & Eaton, 2020; Oliveira et al., 2019; Tarkkala et al., 2020), their origin is shaped by pressures of open data initiatives to create new data standards and new components of the data apparatus of the state (Davies, 2011). Different types of technological platforms then create data-centric and data-driven infrastructures (Gelhaar et al., 2021; Linåker & Runeson, 2021; Lnenicka et al., 2022). A digital platform is a concept that covers not only data infrastructures but also other types of platforms that provide digital products and services and support value creation (Hein et al., 2020). In the ODE, digital platforms together form an ODPE and provide open government (data) services.

Thus, the ODE consists of digital platforms and other components that are in relationship with each other. There are multiple definitions of what an ODE component is in the literature. According to Harrison et al. (2012), the components are diverse due to the many actors, tools, and resources that can be connected through ICT. The key components of the ODE identified by Gama and Farias Lóscio (2014) are an IT-based platform and actors. Zuiderwijk et al. (2014) represent an ODE as three interacting parts, namely, data producers, data users, and tools and services such as an OGD portal. Osorio-Sanabria et al. (2020) found from a mapping study of existing literature that an ODE ecosystem has five components at minimum that include (1) a political or legal

framework, (2) actors, (3) a technological infrastructure, (4) data, and (5) standards or tools ensuring easier interoperability. Similarly, Hrustek et al. (2022) identify policy and governance, stakeholders, data, and infrastructure as the four key components of the ODE. In any ODE, these components are in a relationship with each other and are strongly interdependent (Van Loenen et al., 2021). In the ODE, most of the relationships are represented by data activities through which data are disclosed and reused.

The components of the ODE and their relationships are influenced by the context of that ODE. Gil-Garcia and Sayogo (2016) studied government inter-organizational information sharing and stressed that the context is a multidimensional concept, comprising (1) *a managerial and organizational context* (e.g., governance, financial resources), (2) *a political and institutional context* (e.g., enabling legislation), and (3) *an information and technological context* (e.g., technical infrastructure and security standards). Styrin et al. (2017) study the ODE at the country level and identify government policy frameworks and institutional structures, government data management practices, and stakeholders' engagement with open data as contextual dimensions.

These contextual elements are applied in the literature to compute ODE maturity indices and maturity levels (Lee & Kwak, 2012). For example, Danneels et al. (2017) measure the maturity of the ODE by looking at the actors involved with OGD platforms, their relationships, and the types of the OGD platform. Welle Donker and Van Loenen (2017) assess the ODE's maturity from the perspective of open data provision and supply, OGD users' characteristics, and open data governance. More recently, Bonina and Eaton (2020) published the ODE maturity assessment approach based on the enabling actors of the ODE, their interactions, governance intervention, and dynamics over time. However, maturity is not the only aspect that differentiates ODEs. Rather, different types of ODEs exist in smart cities. This makes it interesting to study and understand the current state and level of development of different types of ODEs.

2.3. Sustainable open data ecosystems

The current body of knowledge suggests different definitions of what makes an ODE sustainable. Van Loenen et al. (2021) and Aziz et al. (2022) refer to it as a combination of three pillars, e.g., "user driven", "circular", and "inclusive", where Aziz et al. (2022) see these pillars to be interrelated in a form that user-drivenness of portals contributes to and encourages the circularity and inclusiveness of stakeholders in a fully sustainable ecosystem. Similarly, Van Schalkwyk et al. (2016) report that boosting open data flows will help enhance access to these data and ensure the ecosystem's sustainability of open data supply. Wiener et al. (2016) posited that building a sustainable data ecosystem necessitates the formulation of a flexible design strategy capable of effectively harnessing and interconnecting existing platforms while also defining the protocols for engagement, sharing, discovery, and communication.

Tang et al. (2022) compared the spread of information about the ODE to the spread of a virus. People who are infected (i.e., possess information about the ODE) will spread it for some time. To define the sustainability of the ODE, the authors make the analogy to the basic reproduction number (i.e., the R0) in virus propagation. Therefore, a sustainable ODE needs a sustained diffusion of information about it. Heimstädt et al. (2014a) do not explicitly define sustainability in the context of ODEs but state that data suppliers must be convinced of the usefulness of publishing data for the ODE to be sustainable, otherwise they could stop providing data. Kitsios et al. (2021) state that "*it is necessary to create a model that fosters value and entrepreneurship for the ODE, aiming to develop an economically self-sustained ecosystem*" (p. 1), thus, defining a sustainable ODE as an economically viable one. Van Schalkwyk et al. (2016) also address the sustainability of ODEs from the economic perspective. They state that "*the provision and impact of open data by the intermediary in the ecosystem is therefore not inherently sustainable*" (p. 77), and that sufficient financial resources are necessary.

While there is a lack of a clear definition of sustainability, these papers mostly refer to what Welle Donker and Van Loenen (2017) use as synonymous with a "long-term". They share the vision that a sustainable ODE is an ecosystem that is sustained in time, and they put forward conditions for achieving this, such as continuous diffusion of information about the ecosystem, financial resources, and providers convinced of the value of publishing data. However, while in most cases, current literature views sustainability as a long-term provision of data or information, it should be focused not only on this area, but also consider other levels, such as changes in data structures and information over time to improve the impact of data on making decisions.

In the absence of a commonly accepted definition and associated measures, it is still unknown how the components of an ODE contribute to the sustainability of said ODE. Nonetheless, we believe that the sustainability of an ODE is a largely subjective and relative concept, whose characteristics cannot be expressed in a way that would allow us to measure them quantitatively. Instead, assessing the sustainability of the ODE is possible in a categorical or qualitative manner, where we expect to establish an understanding of current attempts to provide components of ODEs that will contribute to their sustainability.

3. Research methodology

Our study develops a multi-country study using a comparative exploratory research design (Leavy, 2017; Rose & Mackenzie, 1991). Exploratory research is a method of exploring a topic when it is novel or at an early and developing stage. Thus, it can help us to fill identified knowledge gaps in this relatively novel and understudied subject, generating new insights (also in line with Leavy (2017)). Our study analyzes the existing patterns and real implementation of ODPEs in different countries and cities. We considered three views: (1) contextual patterns that influence and shape open (government) data efforts; (2) real implementations and components, and (3) opinions and perceptions (analyzed with qualitative data from the experts). We aimed to identify the patterns, internal and external components, and relationships that together form and shape different types of ODPEs and contribute to a sustainable ODE.

To answer RQ1 - *what are the contextual patterns that influence and shape open (government) data efforts in smart cities* - we extended the list of contexts and corresponding questions introduced by Gil-Garcia and Sayogo (2016) to reflect the topic of open (government) data in smart cities. Thus, in our protocol for collecting data (Appendix A.A), we focused on (1) *managerial and organizational*, (2) *political and institutional*, and (3) *information and technological contexts* to identify relevant patterns.

To answer RQ2 - *what are the platforms and other components of ODPEs and their relationships* - we used the classification of platforms at the smart city level found by Lnenicka et al. (2022) as a baseline. However, we aimed to get more information about components that result from opinions and perceptions of experts, i.e., *what digital platforms that contribute to transparency, openness, and accountability by providing access to open data and other openly available information and city-related datasets have been implemented in smart cities and their* ODPEs. We focused on the internal and external components as well as aimed to explore the position of the ODPEs in the whole data ecosystem.

To answer RQ3 - *how the patterns and components form different types of* ODPEs *and how they contribute to the maturity concept of a sustainable ODE* - we utilized the types of ecosystems identified by Lnenicka et al. (2022) and redefined and enhanced them in the context of their real-life implementations to discuss their contribution towards the maturity concept of a sustainable ODE.

3.1. Methodological steps of the study

To answer our RQs, we followed the methodological steps presented

in Fig. 1. First, we developed a protocol for collecting data to provide a more comprehensive view and involve all the components and relationships relevant to the sustainable development of ODEs (Appendix A.A). We then defined criteria and processes for the selection of sample countries and respective cities (Section 3.3). The study was conducted by experts representing each selected country, who were involved in the Delphi process to obtain relevant data. A three-round Delphi method was applied for this study (Section 3.4).

Data were collected for each city using the protocol (Section 3.2). These data were collected through desk research, searching for the required information in respective documents such as OGD and ICT/digital strategies (if they exist), general information about the city, its ICT-, transparency- and openness-oriented development, searching for specific types of the ODPE, and examining the found platforms in detail according to a predefined protocol. Then, the results of this step were analyzed and the patterns for each were determined by analyzing these protocols. According to Liu et al. (2006), we define a pattern as "*an activity, resource or tool that was identified by at least in one city and has an influence on the formation and development of the city's ODE*". This constituted the first Delphi round. The second Delphi round consisted of validating the original list of determined patterns. In the third Delphi round, new and updated patterns were validated again by the same group of experts, and agreement was reached on a final list of patterns. Finally, based on the findings, recommendations were derived for further actions to be taken to promote the sustainability of the ODE.

To sum up, for the identification of patterns, i.e., contextual patterns, OGD strategies, and internal and external components and their relationships, we used the protocol. To identify relationships and similarities between contextual patterns, we applied cluster analysis. For the clarification of types of ODPEs, including the most representative platforms, we synthesized and contextualized our findings about the components and their relationships observed in the cities. For recommendations towards the sustainable development of the ODE we merged contexts, OGD strategies, components, and external pressures.

3.2. Protocol development

To develop our protocol (Appendix A.A), we used the concepts that are frequently employed in studies of ODEs, i.e., smart cities' contexts, public sector information, open government (data) characteristics, including approaches and tools to disclose open datasets, and especially the platform theory (Bonina & Eaton, 2020; Dawes et al., 2016; Gil-Garcia & Sayogo, 2016; Lnenicka et al., 2022; Van Loenen et al., 2021). As reported by Styrin et al. (2017), although other criteria could be certainly relevant, we restricted our comparison to these concepts, which we see as fundamental to the description of ODEs. Therefore, we collected data on:

(1) the city such as population, population density, area, Gross domestic product (GDP) nominal/per capita at current market prices by NUTS 3 regions;
(2) characteristics of the ODE with reference to:
  (a) managerial and organizational context (7 questions);
  (b) political and institutional context (5 questions);
  (c) information and technological context (6 questions);
(3) the ODE of the city considering:
  (a) OGD strategies in the strategic urban planning of the city;
  (b) platforms providing access to open (government) data;
  (c) external pressures and environments which affect the ODE;
(4) expert comments, which are relevant to understanding the ODE and its components and characteristics in the city and future efforts in this area.

We used the model developed by Gil-Garcia and Sayogo (2016) to analyze the characteristics of the ODE, including the contexts and the ODE of the city in terms of the OGD strategy in the strategic planning of the city that can potentially affect ODEs of cities. Then, focusing on the ODPE, we referred to Lnenicka et al. (2022), who conceptualized ODPEs in the context of smart cities, identifying five types of existing ecosystems to understand what different platforms are observed in different types of ODPEs. This is expected to contribute to the understanding of current best practices as well as to the identification of the maturity of the ODPEs.

Finally, we consider the external pressures and environments that may affect a city's ODE without strict specification of its type, which may differ from one city and/or country to another, thus, here we expect to establish a common understanding of the various forms of these pressures and environments, which are then explored in more detail in the

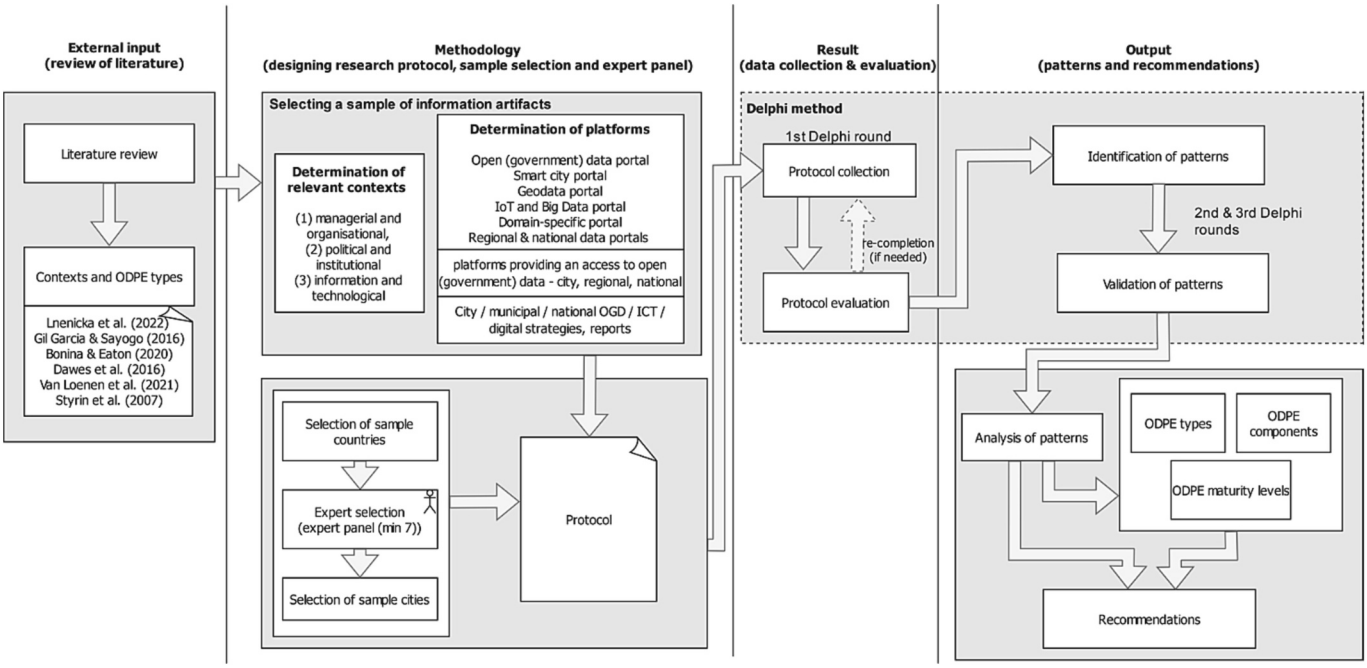

Fig. 1. Methodological steps of the study.

context of the common understanding we get from analyzing multiple ODEs of different cities and countries within the European Union (EU). However, some guidelines we have set to navigate the experts are based on the previous literature review, namely: (1) city-level (data) platforms other than those defined in (Lnenicka et al., 2022) that are not necessarily focused on open data (i.e., OGD, OBD, OCD, OSD) but support transparency, participation, collaboration, cooperation, and communication processes, e.g., transparency portals; (2) regional (data) platforms (OGD portals, smart cities platforms etc. that provide services for more cities), including exploring whether there is any link between the city's ODE and these platforms (e.g., is the city forced/recommended to publish data in them), (3) national (data) platforms (e.g., national OGD portal and a section for the city on this portal), including exploring whether there is any link between the city's ODE and these platforms, and (4) other pressures outside the city that can affect the development of the city's ODE (organizational, social, environmental, economic, spatial, administrative, technological). This was followed by an open-ended question (long-answer) as regards other potential external pressures that remained unnoticed within the previous aspects.

3.3. Sample cities selection

Prior research has determined that organizational change (Jacobs et al., 2013) and technology implementation, especially open data initiatives, is content-dependent (Sayogo & Pardo, 2012; Zuiderwijk et al., 2015). Therefore, considering the complexity of the topic under study and the developed protocol, an in-depth analysis of cities under consideration is expected with reference to the structured protocol on the city's ODE, as well as factors that may affect it, but not necessarily directly related to them, i.e., cultural, political, economic and/or historical specificity, along with the external pressures and environments, and potential effects of the above. Such a wide range of knowledge and depth of research implies not only the determination of the patterns we are looking for but also, possibly, the limitation of the set of these factors to be studied in the future when replicating or reproducing the study or maintaining its results. Thus, it seems reasonable to study a subset of countries and cities to refine the protocol, validate it, and then draw the results regarding patterns.

To this end, we have adapted the approach used by Breaugh et al. (2023) to select representative countries and then consider several cities representing the country under consideration. A multi-country comparative study methodology is expected to allow us to dive deeper into individual services (Mergel et al., 2019, p. 12) without losing sight of the bigger picture (Lijphart, 1971). A total of 8 countries and 19 cities were selected based on several criteria. The primary criterion was the country's ranking in the Open Data Maturity Report (ODMR) 2022 (Carsaniga et al., 2022). To diversify the list and avoid sampling only the most competitive countries according to this report (and thus not allowing us to consider the pitfalls faced by less competitive countries), we have selected countries that represent all the groups defined in the ODMR: trend-setters, fast-trackers, followers, and beginners (see Table 1). Most of our sample countries belong to the followers, as representatives from those countries are the main target audience of this research, considering our goal to provide a list of recommendations.

Additionally, we made sure that all the countries we selected were member states of the EU, reflect different administrative traditions, geographical areas, and include unitary and federal states. Based on the above steps, 8 countries made up our sample. Two states were selected from Northern Europe, namely Sweden (decentralized unitary state) and Latvia (unitary parliamentary republics), Eastern Europe is represented by Poland and the Czech Republic (both unitary parliamentary republics), Southern Europe is represented by Croatia (a parliamentary republic), and Western Europe is represented by Austria (a federal state), Belgium (with an originally Napoleonic character and federal structure), and Germany (a federal parliamentary republic).[4]

Table 1
The ODMR 2022 ranking.

Category (maturity)	List of countries[a]
Trend-setters (91 %–97 %)	Cyprus, Estonia, Spain, France, Ireland, Italy, **Poland**, *Ukraine*[*]
Fast-trackers (87 %–90 %)	**Czech Republic**, Denmark, Lithuania, Slovenia, *Norway*[*]
Followers (66 %–82 %)	**Austria**, **Belgium**, Bulgaria, **Croatia**, Finland, **Germany**, Hungary, Luxembourg, the Netherlands, Portugal, Romania, **Sweden**, *Switzerland*[*], *Serbia*[*]
Beginners (18 %–63 %)	Greece, **Latvia**, Malta, Slovakia, Iceland, *Albania*[*], *Bosnia and Herzegovina*[*], *Montenegro*[*]

[*] Countries marked with an asterisk and written in Italics are represented in the ODMR but are not part of the EU and thereby cannot be included in our sample.
[a] Countries in bold represent selected countries from which a sample of cities was chosen.

Then, for each selected country a sample of cities was chosen. In line with the definition of the European Commission, smart cities are context-dependent, which means that each one of them must face different challenges and, therefore, different initiatives are undertaken in each one of them. Nonetheless, all of them have a common pillar, the use of intensive ICT to face these challenges. Thus, cities were selected based on their appearance in widely-accepted smart cities indices, such as the Cities in Motion Index, the Cities of the Future Index, and Rudolf Giffinger and his colleagues' European smart cities benchmark, and smart projects of a single city or a group of cities undertaken and funded by the EU, such as CEKOM - Competence Centre for Smart Cities or Next Generation Micro Cities of Europe. The rankings are widely supported by prior research (Alderete, 2020; Lnenicka et al., 2022; Patrão et al., 2020). Open (government) data and transparency are essential as objectives of these projects. To sum up, cities are labeled as smart by these indices and by the fact that smart initiatives are undertaken under the grants of EU projects.

The selection of these cities was made by experts, i.e., by a person representing the country in question - the expert's country of origin or the country in which the expert is employed and is involved in the open data initiative. These experts selected cities that comply with the above, and that can be characterized as more interesting/subject-compliant considering their specificities, i.e., what makes it special and different from other cities in the country, such as a special or specific focus on technological, social, socio-technical, and environmental development. In other words, we did not set very strict restrictions on neither cities in terms of their size nor other factors that give the expert freedom to choose the most relevant cities, considering their expert knowledge of the country and the cities under consideration. We have not determined the number of cities expected to be covered, that early determination could artificially increase or decrease the sample size to pursue a threshold instead of covering the most appropriate cities. This led us to a sample of 19 cities provided in Table 2 (for general data about sample cities see Appendix A.B, Table B.1).

All in all, our study employs a comparative methodology (Rose & Mackenzie, 1991) that entails the application of a standardized framework of fundamental concepts across a targeted assemblage of countries to examine and contrast their similarities and dissimilarities. The methodology of comparative research involves the grouping of various phenomena that demonstrate a variance across diverse countries and languages, utilizing concepts or shared points of reference. The pursuit

[4] Geographic area definition from United Nations Statistic Division (UNSD), M49 Standard, https://unstats.un.org/unsd/methodology/m49/.

Table 2
Sample cities.

Country	City
Austria	Graz, Vienna
Belgium	Brussels, Namur
Croatia	Rijeka, Zagreb
Czech Republic	Brno, Pilsen, Prague
Germany	Berlin, Munich
Latvia	Cesis, Riga, Valmiera
Poland	Katowice, Warsaw
Sweden	Gothenburg, Malmo, Stockholm

of pertinent artifacts was directed by a set of concepts, reference points, or criteria that are commonly utilized in investigations of the assessments of the government's open data, as well as by empirical analyses of ODEs (Dawes et al., 2016; Styrin et al., 2017).

3.4. Delphi method and experts' panel

An expert panel was established, consisting of experts representing each country in the sample. By the term "expert" we mean a person dealing with the topic of open (government) data and/or smart city development in the respective country and its cities, thus possessing both in-depth knowledge of the subject and the context associated with the specifics of a particular country and its cities that might affect the results. The general profile of the expert is a person that has at least a Master's degree in OGD-related fields (e.g., business and management, political sciences, computer sciences etc.), whose research and practical experience is related to open (government) data and smart city projects and/or OGD initiatives in public administration of the country in question. The process of creating an expert panel included the identification of researchers who correspond to the expert profile we have defined. Once potential candidates were identified, the authors contacted them directly with an invitation to participate. Once a sufficient number of experts was obtained to ensure an adequate research sample size, a panel was formed, and the study began. Thereby these cases were analyzed at the deepest level, being familiar with the context of the specificities of the country and, more importantly, cities (economic, technological, environmental, and cultural), as well as being involved in or related to these initiatives.

We then applied the Delphi method as proposed by Linstone (1985). First, eight experts were selected, and the expert panel was formed. The selected experts hold a PhD degree, are employed in universities as teaching and/or research staff, work for State Governments or consulting firms, and have more than 3 years of work experience in this role (mainly over 8 years). Our panel size of eight experts is compliant with Linstone (1985), according to whom "*a suitable minimum panel size is seven with accuracy deteriorating rapidly with smaller sizes and improving more slowly with large number*" (Mullen, 2003, p. 41). The protocol was then developed and the proper wording (vagueness, redundancies etc.) was tested by two authors. One of them had previously acted as a facilitator of the Delphi process.

In the next step, i.e., the first round of data collection took place for each city using the protocol (Appendix A.A). As mentioned above, desk research was used for this purpose, i.e., a process of obtaining information and insights through the analysis and synthesis of existing data and sources. We were interested in data that are available online on the city's website and/or data platforms, or can be found via a web search engine, especially in cases where the information is related to the national level. Otherwise, we did not limit ourselves to one or several platforms, when studying a particular aspect and expanded the scope of search. We tried to find as many other platforms providing access to data and information that could affect the city's ODE as possible. We used this information for clarification of contextual patterns, their relationships, components, and types of ODPEs that can affect the ecosystem and should be considered by city's representatives. This task was done between December 2022 and January 2023. The next step was the analysis of the first round of responses. This task was done in January 2023.

The second Delphi round consisted of validating the original list of determined patterns, i.e., *whether the pattern is observed in a particular city*. This was done by all experts, with each expert also being asked (1) to add new patterns relevant to his/her city, or (2) to clarify, or reformulate, or (3) merge a pattern with another, or split a pattern into multiple patterns. In the third round, new and updated patterns were validated again, and agreement was reached on a final list of patterns (Appendix A.C). This task was done in March 2023. The response rate was 100 % for all three rounds of the Delphi process, there were no dropouts of experts. The last step of the Delphi process included the preparation of the list of patterns for the cluster analysis, i.e., their coding and formatting.

The last step of our approach, the analysis of patterns, involved clustering patterns based on the similarities of patterns observed for each context. With this, we aimed to understand whether it is possible to determine clusters based on prevailing common patterns. This would allow us to identify similarities between patterns and their contribution towards the maturity concept of a sustainable ODE.

4. Multi-country comparative study - summary and findings

We performed three rounds of the Delphi method to get information that helped us to identify the key components of the ODEs in selected cities and clarify patterns that affect the growth of these ecosystems towards their sustainability goals. In the first round, we collected qualitative data for each context and corresponding questions. We further obtained the data about the OGD strategies in the strategic planning of the city and components of its ODE, i.e., digital platforms that provide open data and information contributing to transparency, openness, and accountability. After processing data collected following the above process, we formulated the list of 56 patterns for contexts, OGD strategies (OS), and internal (ICO) and external (ECO) components of the ODE. They were evaluated by all experts for each city as a Boolean value, i.e., YES - the pattern is relevant for the city under consideration or NO - the pattern is not relevant (1/0). Each pattern could be also clarified, refined, reformulated, or merged with another, or split into multiple patterns. In this round, 18 patterns were reformulated, and 6 patterns were removed from the list. These changes were validated and approved in the third round. The total number of 50 patterns was obtained that can be found in Appendix A.C.

4.1. Characteristics and contexts of open data ecosystems in smart cities

4.1.1. Managerial and organizational context

Managerial and organizational context (MOC) context included 7 questions, from which 15 patterns emerged. It was found that only 3 cities have an office responsible for open (government) data, while in other cities, this topic is under the responsibility of the ICT department, and in 7 cities, the hierarchy of departments is not available online or does not exist. On the other hand, in 11 cities there is a project manager, or at least a staff member or a city council member, responsible for the OGD/ODE. In terms of providing open data training for public and government officials/civil servants, 11 cities have their own online platform (e-learning system) or internal/in-house training opportunities or use regional or national e-learning platforms that provide open data training.

We were also interested in how many years OGD had been used in the city. The average number of years of use of OGD in the city was found to be 8 years. Berlin, Graz, Stockholm, and Vienna were among the first cities to start building their ODEs in 2011. About a third of the sample cities started with OGD at a time when this topic was being addressed at the national level. Only three Swedish cities among 19 sample cities have the financial resources (budget) specifically

dedicated to open data. In other cities, the budget for open data is included in all IT/ICT services, or only the budget for the entire ICT department is available, or it is included in the budget of an external company that manages IT/ICT. About half of the cities check data to prevent fake data before disclosing it to data portals, and this process and its respective steps are available online in a transparent manner, i.e., including for external parties.

4.1.2. Political and institutional context

For *political and institutional context* (PIC) context, 5 questions were defined, from which 6 patterns were identified. All cities have enabling legislation, regulatory framework, executive involvement, or legislature support (national, regional, or local) that enforce them to undertake the ODE projects.[5] This is due to EU directives (PSI/Open Data Directive) and national Freedom of Information (FOI) laws. There is support (legislative) for goals of sustainable development in a total of 15 of 19 cities, usually an ongoing/active smart city strategy (domain such as smart living etc.) or related goals found in many types of documents, including but not limited to strategies (e.g., development strategy). A question that attempted to be answered as to which ruling political party was pushing the OGD/ODE project in the respective city did not yield any pattern. We can assume that it depends on several people in the city administration who support open data efforts, and it is also highly influenced by the national and EU's legislation.

If there is no legislation or regulatory framework for undertaking ODE projects, there are at least some guiding principles to follow on their creation in the 11 of 19 cities. Finally, we found that there were no certification services for ODE projects in the sample cities. The reason for this may be that this information is not monitored. This is one of the problems that are faced by current ODEs because while this information is important for ODE sustainability most OGD strategies lack the long-term monitoring and evaluation of ODE projects.

4.1.3. Information and technological context

Information and technological context (ITC) context included 6 questions from which 9 patterns emerged. The first question was focused on the key digital and e-government services, and IT infrastructures in the city. We found that in all cities citizens can use digital public services provided by the city's online services portal. The range and quality of these services vary across the sample cities. These services can be considered as support for the ODE as digital services and OGD usually use the same data infrastructure and ICT resources. A total of 14 cities has city-level ICT/digital strategies, in which emerging ICT such as big data, cloud computing, artificial intelligence, etc. are mentioned. Another question explored the existence of interoperable standards or information security strategies in the city. It was found that 11 cities have an information/data (cyber)security strategy and/or an interoperability strategy, or this topic is included in the (cyber)security strategy. The existence, and especially the interconnectedness, of these strategies are important for ODEs as they support their resilience to changes resulting from electoral cycles and emerging ICT. We found that for only one city, information is available online on the share of the budget spent on both maintenance and investment in the implementation of new technologies. The question that attempted to get an answer on the technological projects for which the city is known and/or are supported/preferred by representatives of the city, revealed that for each city, corresponding projects can be found. Most of them belong to the category of digitalization and the provision of new services for citizens.

We further explored whether the city is included in any ranking concerning the technological context and position in the ranking. The most suitable for this were (1) the *IESE Cities in Motion Index 2022*, and its technology dimension (see Table 3), which covers 183 cities, and (2) the *Smart City Index 2021*, and its technology category (AAA is the best and D is the worst category in Table 3), which includes 118 cities. The first index assessed 10 sample cities, and the second - 8 cities. While several cities have a very high overall score in the *IESE Cities in Motion Index 2022*, e.g., rank 5 for Berlin, rank 11 for Munich, or rank 15 for Vienna, their technology dimension is weak, e.g., rank 39 for Berlin, rank 42 for Munich, or rank 87 for Vienna. Only the Swedish cities, Gothenburg, and Stockholm, score higher in the technology dimension than the overall scores. Also, most of the cities are covered by the Cities of the Future Index and Rudolf Giffinger and his colleagues' European smart cities benchmark.

By checking the structure of dimensions and categories for each index, we can state that cities in which they do not sufficiently support the building of infrastructure and the effective use of available technologies cannot achieve the full sustainability of their ODE, since it can be assumed that ODEs will develop towards data-intense services and cities may not have sufficient IT/ICT capacity to do so. Finally, it was found that other indices that provide some feedback on the development of the city and its comparison with others are available for Brno (*Innovation Cities™ Index 2019* by 2THINKNOW[6]), covering European cities, where Brno is ranked 320th, Berlin and Munich (rank 11 and 2, respectively, in the *das Digitalranking der deutschen Großstädte*), Cēsis (rank 2 in the *Integrated monitoring of the provision of public services and the needs of end users,* 2021 by *Ministry of Environmental Protection and Regional Development of the Republic of Latvia*[7]), and Katowice (*Electromobile Cities Ranking,* 2023 by Polityka Insight[8]), which are local indices.

4.1.4. Contextual patterns affecting maturity of open data ecosystems

We explored the similarities between the identified patterns (cases) and smart cities (variables) based on their contexts using the cluster analysis method. For this, the STATISTICA 12.0 analytics tool module containing clustering methods was used. First, the data were standardized, and then cluster analysis was performed. A non-hierarchical K-means clustering method and hierarchical algorithms were applied. Initial tuning/setup of cluster centers was performed using a hierarchical single linkage algorithm and Ward's minimum variance method. By checking the dendrograms for both methods, we can get information about how the clusters are formed. Thus, the non-hierarchical clustering was carried out using the K-means algorithm for 4 and 5 clusters. Of the given numbers, 4 clusters provide the highest quality clustering (e.g.,

Table 3
Occurrence of sample cities in selected indices focused on the city level.

Index	IESE Cities in Motion Index 2022		Smart City Index 2021	
	Overall rank	Technology rank	Overall rank	Technology category
Vienna	15	87	11	BB
Brussels	67	94	52	BBB
Zagreb	101	115	N/A	N/A
Prague	43	30	78	CCC
Berlin	5	39	50	BB
Munich	11	42	14	BBB
Riga	94	128	N/A	N/A
Warsaw	62	76	75	CCC
Gothenburg	53	41	46	BBB
Stockholm	25	16	25	BBB

[5] Projects focused on the development of applications, showcases, reuses, and other types of outputs that reuse open datasets.

[6] https://innovation-cities.com/europe-cities-ranking-2019-innovation-cities/18839/.

[7] https://www.varam.gov.lv/lv/media/30167/download.

[8] https://content.knightfrank.com/research/2298/documents/en/katowice-city-attractiveness-and-office-market-q1-2023-10212.pdf.

intra-cluster and inter-cluster distances, no empty cluster, no cluster with a single member etc.). This number has been selected for further processing. We applied an approach in which each pattern is exclusive and belongs to only one cluster. The patterns in each cluster are shown in Table 4.

Cluster 1 is characterized by positive answers to questions. The patterns in this cluster suggest that, if there is a department that is responsible for ICT and (open) data management/analytics tasks, then a budget for open data is specified, and/or there is a budget for a data portal provider, who manages the entire process of OGD. The city also provides open data training for public and government officials and has its own online portal (e-learning) or internal capacities training for stakeholders involved in the OGD process. The topics of interoperability, data security, and/or information security are included in the city's ICT and digital strategies. We can assume that the ODEs of cities in this cluster are **mature**, since there are clear responsibilities for open data initiatives, including budget, cities actively support improving competences and advanced training in working with open data, and finally, the sustainability of ODE is ensured by incorporating other relevant components that support goals of sustainable development and emerging trends in ICT that can contribute to building and maintaining more sustainable ecosystems. This cluster includes *Brno*, *Malmo*, *Munich*, *Riga*, and *Warsaw*.

Another cluster that includes patterns that suggest that open data efforts are supported by the city is *cluster 4*. All patterns in this cluster are positively answered. There is a project manager, who is responsible for the OGD/ODE. Data are checked to prevent fake data prior to disclosure on the portal, and the data checking process prior to disclosure to the OGD/ODE is usually the result of city, regional or national strategy and/or legislation. There are some guidelines on how to undertake ODE projects. There is support (legislative) for goals of sustainable development in the city, usually an ongoing/active smart city strategy (domain such as smart living etc.) or related goals that can be found in many types of documents, such as strategies (e.g., development strategy). There are also city-level ICT/digital strategies that mention emerging ICT. There is an information/data (cyber)security strategy and/or an interoperability strategy, or the topic is included in the (cyber)security strategy. Cities in this cluster are included in at least one ranking concerning its technological context. We can conclude that the patterns in this cluster characterize **a very mature ODE**, in which open data initiatives are properly managed, linked to other ICT and digital strategies, and benchmarked by related indices. *Berlin*, *Gothenburg*, *Prague*, *Stockholm*, and *Vienna* are representatives of this cluster.

The list of patterns in *cluster 2* suggests that if the city has an office in charge of open data and is interested in platforms that provide open data training for public and government officials/civil servants (does not have its own portal, but uses other relevant platforms for this purpose) then we did not find any documents that support (legislative) goals of sustainable development in the city, no strategies relying on emerging ICT at the city level, and no interoperable standards or strategies for information security at the city level. There is also no ranking in which the city is included. We can assume that the ODE of the city is focused not only on open data, i.e., is at **an early stage of development**, so the city is now concentrating on building this ecosystem, and in later stages will link it with other ICT (digital) components that will have a synergistic effect on its sustainability. It is also possible that the city has these documents, and they are not available online or the document is in progress. This cluster includes *Graz, Namur, Rijeka, Pilsen, Cesis,* and *Valmiera.*

Cluster 3 can be characterized as a group of patterns with negative answers. It can be assumed that the ODEs represented by these patterns are **very immature**, since the topic of open data is not considered as a priority, and the ODE of the city is formed and shaped only by legislation, the regulatory framework, the executive involvement, or legislative support provided by local authorities to undertake the ODEs projects, usually due to the EU (PSI/Open Data Directives) and national FOI laws. The city does not undertake activities to support the development of the ODE, or information about these activities is not available online. This cluster includes *Brussels*, *Zagreb*, and *Katowice*.

Table 4
A list of patterns in each cluster with respect to their relevance in selected cities.

cluster1	MOC02, **MOC03**, MOC07, MOC10, ITC04, ITC08
cluster2	MOC01, **MOC08**, PIC03, ITC02, ITC05, ITC07
cluster3	MOC04, MOC06, **MOC09**, MOC11, MOC13, MOC15, PIC01, PIC05, PIC06, ITC09
cluster4	MOC05, MOC12, MOC14, PIC02, PIC04, ITC01, **ITC03**, **ITC06**

Bold style is used to indicate a pattern with the largest distance from the center for every cluster.
MOCx, PICx, ITCx is the pattern identifier, where {MOC, PIC, ITC} stands for the context (MOC - managerial and organizational context, PIC - political and institutional context, ITC - information and technological context), and x is the pattern number (see the list of patterns in Appendix A.C).

4.2. Platforms, components, and types of ecosystems

4.2.1. OGD strategies in the strategic planning of the city

The most important documents shaping the city's ODE are OGD strategies that guide/define how city and urban data are collected, stored, published, and reused. We have found four approaches to consider the topic of OGD in the strategic planning of the city:

(1) **there exists a city-level open (government) data strategy**, usually also including the topic of open government and/or some other data types such as big data, linked data, geodata[9] etc. This approach is represented by *Berlin*, *Cesis*, and *Graz*;
(2) **the open (government) data strategy does not exist, but there is a strategy, in which open (government) data are one of the key topics**, usually as a separate section in the document, e.g., a general data or information strategy, an open government or openness or transparency or accountability strategy etc. This type of strategy was found in *Stockholm*;
(3) t**he open (government) data strategy does not exist, but there is a strategy, usually a digital or ICT, or smart or sustainable city strategy, in which open (government) data or open government or openness or transparency or accountability is only mentioned** in the text and/or are one of the goals/plans. This approach was found in most of the sample cities, i.e., *Brno*, *Brussels*, *Gothenburg*, *Munich*, *Namur*, *Pilsen*, *Prague*, *Riga*, *Vienna*, *Zagreb*, *Valmiera*, *Warsaw*;
(4) **strategy does not exist or was not found**. This was the case for *Katowice*, *Malmo*, and *Rijeka*.

We then performed the cluster analysis, in which we added these four patterns to the patterns identified for the three analyzed contexts - *Managerial and organizational, Political and institutional, and Information and technological contexts*. We expected to find similarities between patterns for contexts and patterns for OGD strategies. However, this analysis did not show any significant relationships between these patterns.

4.2.2. Platforms and other components of open data platform ecosystems

Using the revealed information about components and their relationships, we redefine the categorization and the model of the ODPE introduced in Lnenicka et al. (2022). The authors only considered platforms that provide access to any open data but did not deal with

[9] Also "geospatial data" or "geographic big data" or "geospatial big data" also known as location-based big data (LocBigData) that predominantly refers to big earth observation data, but can also include big human behaviour data (social sensing) (Huang et al., 2021).

other platforms beyond transparency that provide openly available information and city-related datasets and help to build ODPE.

As part of the Delphi method, together with experts we explored existing digital platforms (over 100 in total) in sample cities through which the cities provide open data and information, contributing to transparency, openness, and accountability. We have found that some platforms are focused not on the instrument (tool) used to disclose information, but on the subject (smart service and smart projects), the format of the information (geodata), or content (domain-specific portals) that is being disclosed. At the same time, data and information flows are enabled by data infrastructures that provide resources for platforms. These infrastructures are usually built and managed by public sector agencies and institutions, and users use the Internet to access them and search for data and information.

The platforms at all levels are shaped by interactions in which stakeholders perform data- and information-related activities. The intensity of these activities, as well as the maturity of the ODPE, i.e., how supportive the environment is in terms of legislative, administrative, and regulatory aspects and what financial, technological, and human resources are allocated for the ODPE, are crucial for its sustainable development. Therefore, we define the ODPE in the platform theory as *"a set of digital platforms that contribute to transparency, openness, and accountability by providing access to open data and other openly available public information and city-related datasets*." Our new classification is based on the model of the ODPE below, see Fig. 2.

At the city level, we identified several internal platforms and other components that we classified into four categories.

1. Data and information disclosure platforms such as open data portals, transparency portals, and official city websites. These are the contexts in which the information is disclosed regardless of the content and/or format of the information disclosed. It is relevant for stakeholders to have a general understanding of government transparency and the reliability of government information, as they know where all the information is officially located.

The open data platform is the central point for disclosing datasets in open formats and under open licenses, including the provision of features to work with these datasets and support their reuse and value creation. This platform was found in a total of 16 out of 19 sample cities and is the most common approach to providing city and urban data online. These portals were developed (most of them between 2011 and 2015) to meet the characteristics and requirements of open (government) data, such as a set of 8[10] or 14[11] OGD principles and then city or national legislation. We found that there are at least three evolutionary stages or generations for these platforms. The first portals launched after 2010 used the open-source CKAN (Comprehensive Knowledge Archive Network) and DKAN (Drupal-based open data portal based on CKAN) systems, and they were not always the city's official portals (powered by NGOs or enthusiasts). The second generation of portals (most launched between 2015 and 2020) have already been built by the cities to meet the requirements arising from the legislation, and at the same time provide features to work with OGD. The third generation that is emerging in some countries is the centralization and modernization/upgrade of the national OGD platform, combined with the discontinuation and/or closure of most city's open data platforms.

The transparency platform is usually a portal that provides information and documents. These platforms existed in many cities before the topic of open data became relevant due to public access laws. They do not always meet the principles and characteristics of open data and provide only basic search and filter features, but not other features to work with data. Finally, official city's websites, typically older than open data platforms, can provide openly available information and city-related datasets. Both transparency platforms and city's official websites can only be considered as supporting resources that, for example, direct potential users to the right platform, or introduce them to the benefits of OGD.

2. Thematic city development platforms is a category that refers to platforms that are focused on the subject of the information, i.e., the topic of the OGD is not always a key one for these platforms, but they usually provide their subject-specific datasets or are designed to collect data and information that can be further transformed into OGD. We found the following platforms in the sample cities: (1) *smart city* and *smart projects platforms*, (2) *a participation platform* that includes opinions, discussions, projects and voting, including a participatory budget, (3) *a citizen reporting or accountability platform*, which collects reports/data about critical issues, e.g., damages, fireplaces, wastes, crime, (4) *a crowdfunding platform* for local projects, (5) *a startup platform* focused on smart solutions, data reuse, data for urban governance, and (6) *a digital services platform* that is more general and deals with all digital technologies. This list is not exhaustive and other platforms may exist in other cities.

3. Specific data format platforms, where geodata platforms are the main representatives of this category. In many cities, these platforms were launched before open data (some cities launched them in the late 1990s). They provide datasets in a specific format, as well as maps and other visualizations that are easier to consume by users (partly due to the greater complexity of the data). The first generation provided maps and basic features to work with them, but in the interim period (2010–2015), when open data were already being promoted, but open data platforms were not yet so common, data that met the principles and characteristics of open data were published here (as required by legislation/law). For the second generation, i.e., recently launched, or new versions of portals, open data has become the standard, and these portals provide interactive maps and related services, as well as provide features for searching, filtering, downloading etc. open data. In some cases, the created visualizations can also be downloaded (e.g., maps) or at least embedded links can be obtained for sharing them. Therefore, this component is an important part of the city's ODPE. Other examples of this category include platforms devoted to the topics of climate change, meteorology, natural hazards, or food safety.

4. Content of information focused platforms, i.e., domain-specific platforms that are focused on data visualizations and storytelling, which include but are not limited to *smart data portals*, *Internet of Things (IoT) and big data portals*, *domain-specific web/mobile apps* (usually as dashboards). The main purpose is to visualize data (usually open data reuses) and support transparency, participation, smart living, and other reuses of these data (data can be downloaded or APIs for data streams/raw data are provided). Cities are generally aiming to engage more users into the ODPE, i.e., a citizen-centric city, and cities also position themselves as "doing something for citizens" having a focus on transparency, efficiency, smartness, digitization etc. *An open budget platform* that provides open data about the city's budget is one of the examples. This category represents an internal part of the ODPE that helps to present the outputs that can be obtained by reusing OGD, thereby demonstrating the actual value of the data and their potential to create an impact.

We also found that the city's ODPE is affected by platforms that are operated by cities' districts. The municipal districts also have their own visions, websites and platforms dedicated to transparency, participation, collaboration etc. The platforms tend to be oriented towards participation processes because the questions/issues to which answers are sought, including but not limited to urban challenges, are closer to citizens in their place of residence. However, some of the cities prefer centralized solutions and platforms, in which each district has its own section.

The administrative division of the country and the respective units are also important in understanding what other platforms may externally influence the ODPE. If the city is the center of the region or the largest city, there is usually a *regional open data platform* and *geodata platform* that provide access to data from more cities. Since most

[10] https://opengovdata.org/.
[11] https://opengovdata.io/2014/principles/.

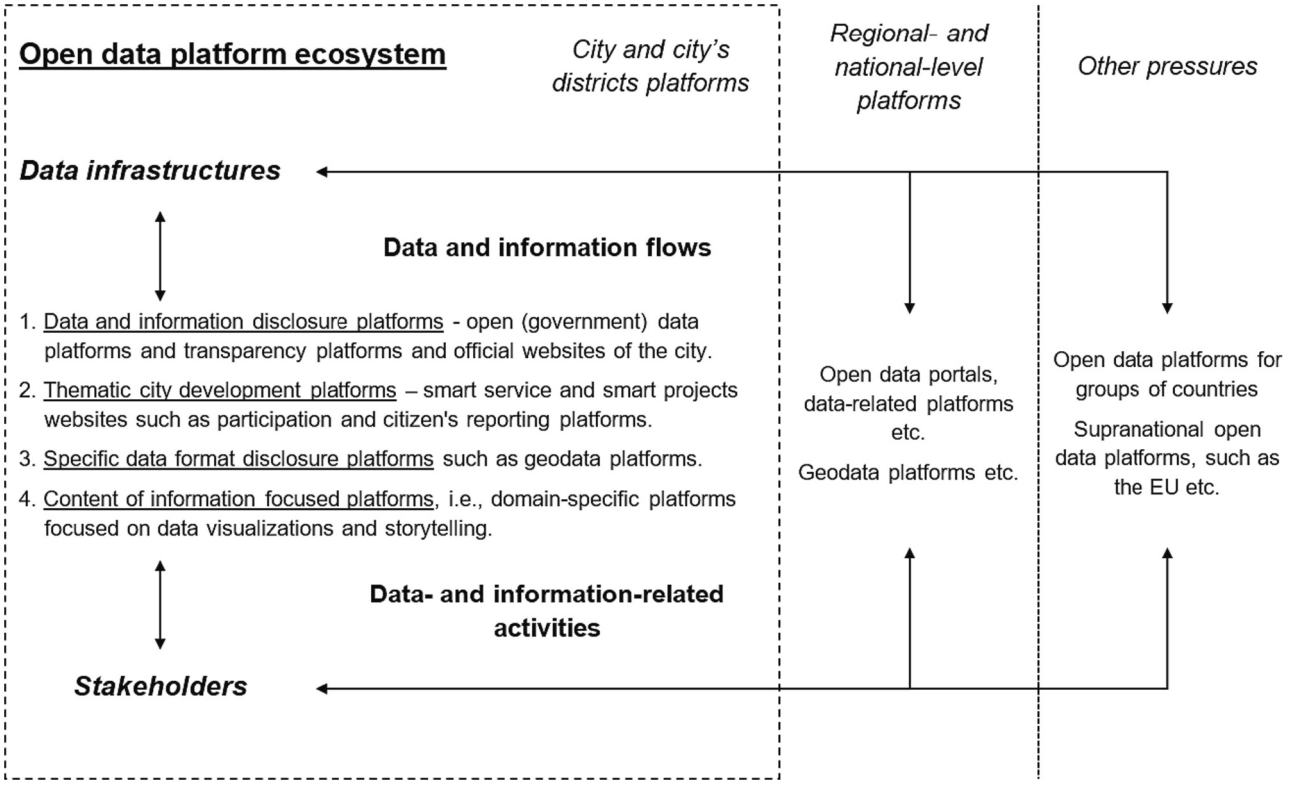

Fig. 2. Relationships between platforms and other components of the city's ODPE.

national open data portals harvest datasets from a city open data portal, the city's ODPE is also affected by the existence of that portal and the quality of features it provides to work with datasets. On the other hand, we found that in several cities there is no open data portal and there is only one official national platform through which open data of all administrative units are disclosed. The national geodata platform is also one of the city's geodata sources.

Finally, among other sources of open data and city-related datasets, there are supranational platforms that harvest information about open data platforms and/or datasets from cities that are from culturally and historically related countries, such as Open Data Atlas for German-speaking countries, or platforms at the EU level, such innovation projects – typically, the city will publish datasets as a consequence of participation in such projects.

4.2.3. *Towards clarification of types of open data platform ecosystems*

We used the list of contextual patterns and our classification of platforms and other components of the city's ODPE to update and enhance the types of ODPE developed by Lnenicka et al. (2022). The following types of ODPE are described based on prevailing contextual patterns and relationships between platforms and other components. This means that the ODPE of the concrete smart city can slightly differ because the boundaries of these types of ODPEs are not always clear, primarily due to other platforms and pressures that may shape the ecosystem. Our aim was to empirically validate the conceptual findings of Lnenicka et al. (2022) and track the progress from this conceptualization to real-life implementation of respective platforms and other components in sample cities. More precisely, we used five types of ODPEs defined by Lnenicka et al. (2022), who introduced a list of these types. We confronted their findings with real-life implementations of ODPEs in selected cities, for which a heuristic approach based on exploratory qualitative data analysis was utilized. We not only provided a detailed description but included maturity development levels for each type. We also identified several subtypes for each type to distinguish between different characteristics of real-life implementations of ODPEs.

Type 1. The ODPE is centered around the OGD platform through which the datasets are published. The focus is on datasets that meet open data principles, including FAIR principles (findable, accessible, interoperable, and reusable), metadata and API and SPARQL endpoints and emerging approaches for OGD processing and reuse such as artificial intelligence, machine learning, virtual reality, IoT etc. The platform provides features to work with datasets, reuse them, request those unavailable, and make all data requests transparent in one place. We found that OGD platforms in this type of ecosystem are constantly improved to meet the requirements set by new technologies to support OGD reuse and value creation. As regards contextual patterns, this type is characterized by an active support of cities towards management and organization of OGD efforts, especially their interest in development of the ODPEs both in the aspects of new technologies and needs, competencies, and advanced training of stakeholders.

The maturity of this type of the ODPE can vary between mature and very mature development levels depending on how the concept of open government (data) is perceived/defined by representatives of the city. We found two main approaches (subtypes of this ODPE) in our study: (1) a wide definition in which data- and information-related activities in the city are supported through the OGD platform, the transparency platform and other official city websites (Berlin, Munich, Prague, Warsaw etc.) and (2) a narrow definition that includes only the OGD platform but other data and information platforms that do not meet the principles of OGD are not considered as a part of the ODPE or do not exist in the city (Gothenburg, Graz etc.). It should be also noted that maturity is affected by how long OGD have been used in the city.

Type 2. It is crucial for the city to **provide access to OGD through all available content of information focused platforms of the city to maximize reach and potential (re)users**. There is usually the OGD platform as the central point but there are also other platforms focusing on different dimensions such as public transport, waste collection, energy, health, safety etc., are important components of this ecosystem. Datasets are published in open formats, under open license and with appropriate metadata but the platform on which these data can be found

is not the key characteristics of the ODPE. This type is not centralized but rather focuses on concrete dimensions in which the users are interested in. For the contextual patterns, the findings show that this ODPE is characterized by advanced digital strategies, which cover all the key components of this ecosystem (development of data infrastructures, (cyber)security and tools, digital public services with respect to data- and information-related activities etc.), managers and clear responsibilities for the development of the ODPE, and emphasis on skills, competencies, and advanced training of stakeholders (e-learning platforms and courses).

The maturity of this type of the ODPE can vary between mature and very mature development levels because cities that prefer this type of ecosystem require that all datasets published by the city and its departments and organizations must meet the principles of open data, usually defined in respective city strategies. This type of the ODPE supports the access to these data for users based on their preferences and needs as well as provides more options with respect to their different levels of skills and competencies because they can find data on platforms with which they are familiar. We found two subtypes of this ODPE that characterize it most: (1) focused on platforms that provide primarily dashboards, data visualizations, and storytelling, i.e., target less skilled users for which these forms of data presentation are more user friendly (Brno, Namur, Katowice etc.) and (2) focused on open datasets publication through smart data, IoT, big data and other platforms, i.e., target more skilled users which will rather work with and reuse these data (Brussels, Stockholm etc.). Some of the cities use both approaches to some degree.

Type 3. This type of ecosystem cannot be considered as the ODPE but rather as **a public data ecosystem in which the focus is not centered around open (government) data principles and characteristics only but also consists of other data and information platforms that provide datasets for specific purposes** such data streams or unstructured data for machine learning, raw data from sensors, specific data formats for different analysis tools etc. Specific data format disclosure platforms such as geodata platforms are important components of this ecosystem. While it may be beneficial for cities not to focus on just one type of data and invest resources in ensuring that all datasets meet the requirements of OGD, this type of ecosystem can be also more difficult to manage and usable for stakeholders. Similarities for contextual patterns can be found in the category of digital strategies, i.e., those that were introduced in the last few years and their emphasis is not only on open (government) data (Malmo, Pilsen, Zagreb etc.) but also other types of data that contribute to building sustainable and smart public data ecosystems. In addition, platforms that were implemented in this period are already adapted to this and we can assume that more cities will shift towards this type of ecosystem.

In the context of the ODPE's maturity, this type is usually immature or medium mature because open (government) data principles are not the key topic. However, the whole public data ecosystem can be very mature. Two subtypes of this ecosystem can be identified: (1) **closely connected**, in which there are several platforms, but the datasets are not duplicated, i.e., it is clearly defined what can be found where and at the same time these platforms provide services corresponding to the typology of their users, i.e., their preferences, needs and level of skills and competencies, and (2) **loosely connected**, multiple data platforms exist, but the range of available datasets and services overlaps, partly because this ecosystem is not effectively managed and lacks links to related digital strategies.

Type 4. This type of the **ODPE is only a part of the ecosystem that is focused on smart projects and services**. There may not even be the OGD platform. This ecosystem consists of domain-specific and specific data format disclosure platforms. However, providing open datasets and the features to work with and reuse them is not a top priority for them. These platforms are focused on data visualization, storytelling, and specific data formats and are characterized by the involvement of multiple stakeholders that develop web and mobile services and applications. They are usually created by businesses, research institutions, or enthusiasts and provided to citizens. The city can serve here only as a subject that provides guidelines, checks data to prevent fake data, maintains data infrastructure, provides funding and other resources etc. The maturity of this type of the ODPE depends on the importance of OGD for the city's representatives. We can assume that if OGD prove their contributions to meeting the strategic goals of the city, the maturity level of the ODPE can increase. Rijeka and Riga can be included in this type of the ODPE.

Based on the extent to which the stakeholders are involved in data visualization and storytelling platforms and services' development we can identify these subtypes: (1) most of the platforms and services are developed by the city and its departments and organizations and this type of ecosystem does not actively support other stakeholders to participate in the ecosystem's development, and (2) involvement and engagement of other stakeholders, i.e., NGOs, research institutions, businesses etc., in data- and information-related activities are supported by the city and open government processes are specific for this type of the ODPE.

Type 5. This type of the ODPE can be defined as **an open government centric with an emphasis on processes supporting these efforts and respective platforms that enable the realization of these goals in practice**. The role of the OGD platform is equal to other thematic city development platforms that support participation, collaboration, and cooperation of stakeholders. We found that the existence of these platforms is affected by the development of civil society and democracy. Therefore, these platforms occur most in countries such as Belgium, Germany, or Sweden. This type of the ODPE is characterized by contextual patterns that rely on active involvement of stakeholders: (1) OGD and other related digital strategies include citizen-centric approaches and relationships between supply and demand sides, (2) guidelines, courses, trainings, and other opportunities to improve skills and competencies are provided by the city, and (3) hackathons and datathons are organized by the city or its departments or organizations. It should be also noted that this type of the ecosystem overlaps with other types and can be seen as their extension. Berlin, Brussels, or Munich can be included in this type of the ODPE.

Several subtypes can be identified for this type of the ODPE based on the mix of platforms that support open government efforts. We found that each city has its own priorities, usually given in a concrete smart city or digital strategy, and these types of platforms can differ from crowdfunding and startup platforms (Berlin, Namur, Munich, Vienna etc.) to platforms focused on subsidy titles (Brno, Katowice, Pilsen etc.).

5. Discussion and recommendations

Within the study, we not only focused on the ODEs and ODPEs-specific aspects of the sample cities, but also collected general data about these cities (see Appendix A.B, Table B.1) to explore whether they influence how the ODE is formed and what services are provided. Further data analysis demonstrated that our assumption is valid and there are several other aspects that affect urban development, as well as several urban development-aspects that can affect ODEs and ODPEs. More precisely, mainly the population of the city and financial indicators such as the city's budget, including funding opportunities, wealth of its inhabitants, or the GDP of NUTS 3 regions must be considered by city's representatives in building and developing the ecosystem. These urban development characteristics can also affect the types of data that are collected, the methods used to collect them, and the ways in which they are processed and made publicly available. For example, for Latvia, we found that there are no city open data platforms, only a national open data portal (with city geodata portal being now launched). However, Vienna and Berlin that have those platforms, have more inhabitants compared to Latvia, so we can assume that the number of potential users affects the existence of data- and information- related platforms of the city.

Furthermore, a city's political, cultural, and social contexts in both national and urban settings can influence the level of citizens' collaboration and participation in data reuse and the degree to which data are shared with the public (Clement et al., 2022; Corbett et al., 2020; Macke et al., 2019; Viale Pereira et al., 2017). The smart city ecosystem conceptualized by Clement et al. (2022) is highly collaborative and requires consideration of the factors that affect the intensity of collaboration. Although more collaboration leads to a higher operational performance, indicating a positive size effect (Janssen & Estevez, 2013), the current research suggests that limited resources for managing ecosystems can make local government to increase collaboration only up to a certain point (Botequilha-Leitão & Díaz-Varela, 2020).

While we have only focused on a general description of maturity levels for ODPEs in this study, the maturity can be assessed using a variety of frameworks, tools, and other metrics/indicators such as a number of visits of the platform (as the ODMR does), other web analytics tools, features that a platform should provide to support data and information flows in the ODPEs, usability metrics, etc. (Çaldağ & Gökalp, 2022; Neves et al., 2020; Welle Donker & Van Loenen, 2017). Another increasingly popular and timely way to assess the ODEs can be their compliance with the Sustainable Development Goals (SDGs). For example, Giuliodori et al. (2023) explored factors influencing the SDGs agenda and emphasized the importance of high-quality governance. The implementation of such practices has the potential to foster a culture of reflexivity and facilitate the generation of novel forms of knowledge that align with the SDGs.

Assessing the level of maturity, evolution or development of the data ecosystem and the respective analysis of such, however, contribute to and even spur its further development by identifying the current state, gaps, best practices and setting the agenda (Grabis et al., 2022). It is expected that the results of this assessment will contribute to the diversity, efficiency, adaptability, and cohesion of data ecosystems. As reported by Aaen et al. (2022), managers and policymakers should carefully coordinate their activities, stakeholders, and data, considering both the positive benefits and the negative dangers/hazards posed by developing data ecosystems.

Many public sector agencies and institutions still refuse or fail to share their data and thus cannot utilize the offerings of ODEs. The actual data sharing can also be costly in terms of effort and time. The development of trust among the various actors involved in the ecosystem plays a critical role. An issue of concern pertains to the task of elucidating to all stakeholders the advantages they stand to gain through active involvement in the data ecosystem, and the associated exchange of their data (Gelhaar & Otto, 2020), and trying to capture how different stakeholders interact regarding their interests in the ODE (Najafabadi & Luna-Reyes, 2017). Public entities can operate/function very independently of each other, creating, consuming, and curating data in a variety of ways, with little motivation to coordinate technological techniques or exchange data, depending on the city's administrative and legal framework. Consequently, more attention needs to be paid to the territorial politics of the metropolitan development (Kitchin & Moore-Cherry, 2021).

During investigation, it was found that while open government and OGD are commonly seen as an important and multi-perspective concept, the perception tends to vary from what we see as “wide” and “narrow” understanding of such. Narrow definition rather treats the OGD as a stand-alone topic, where the central point is the OGD platform of national and city level, which is also covered specifically and separately by the respective documents, e.g., OGD strategy, which further is framed into the ODE. Broader definition, however, treats it rather as a culture and philosophy followed at many levels and covered by several portals seeking for an increased transparency, openness and participation as the pillars derived from the OGD concept but not necessarily followed in the establishing and maintaining the OGD portal, but rather building a more complicated and mature ecosystem consisting of multi-purposive platforms, including but not limited to smart city, participation etc., which we rather see as a public data ecosystem instead of ODE since for non-purely OGD-related platforms some OGD principles are not followed in full, and it is rather a part of strategy other than OGD, e.g., digital strategy or sustainable development strategy.

Finally, there are still debates on what cities should be called smart cities. Lnenicka et al. (2022), whose research we relied our study on, considered cities to be smart if they are covered by one or more smart city indices. At the same time, nowadays, most cities in developed and developing countries have a strategy labeled as smart, thus the cities do not have to necessarily be included in smart cities indices and rankings. Most cities have in their agenda strategies, urban policies, or tasks defined as a plan towards smartification of the city, while both the level of maturity and even the definition of this smartness tend to differ. The definition chosen may influence the results, which may differ if the study is replicated using a different definition.

Finally, best practices or “pain points” of ODEs (Appendix A.A, last two sections of the protocol), obtained from experts while exploring the ODEs in the sample cities with reference to both the ODE itself and external pressures and environments that shape or influence them, resulted in 12 recommendations for policy planning and urban governance summarized in Fig. 3 (for a detailed description of these recommendations, see Appendix A.D).

6. Limitations

This study has several limitations, some of which, in turn, define the future research agenda. First, this is a multi-country comparative study that examined a limited number of cities (19) representing eight countries. While we used a well-defined sampling approach to cover a diverse set of cities, which made the results more generalizable, the diversity of ODEs and ODPEs we revealed in the examined cities suggests that a wider coverage of preferably all EU countries would be beneficial in terms of generalizability of the results, in particular clustering. This constitutes a future research agenda, i.e., to expand the scope and instead of a sample of countries to cover all EU countries and their cities. However, it must be recognized that covering all EU countries will not completely eliminate the above, since even if all countries are covered, coverage of all cities within these countries is likely to be impossible (i.e., infeasible). Hence the complexity (theoretical and practical) of the topic covered.

Second, the examination of the ODEs of the cities in question considers experts' perspective, which, although considered an appropriate approach, still has its own issues. In other words, it does not consider the perspective of either users or public servants, which, when combined can provide the greatest value. However, this paper is primarily focused on identifying contextual patterns, platforms, and other components of existing ecosystems, where users' involvement is not expected, where their participation may be useful at later stages of the research, when user expectations and needs may shape requirements, characteristics, and features of ecosystems, which they are expected to have with a particular focus on their sustainability. Interviews with representatives of cities as owners/providers of these ODEs can provide more clarity on the current level of maturity and justify the choice of a specific type of ecosystem. Additionally, considering that initially each country was covered by one expert representing the country in question, the involvement of city representatives could serve as a validation of the data, if a particular platform was not found by the expert, but in fact it exists (but its findability is an issue). This, i.e., a data collection process on a country by a single expert forms yet another limitation we acknowledge, which, in turn, defines another future research line, where interviews with city representatives are expected to be conducted to examine the covered countries and cities in more detail. Then, the users' perspective will be included.

Third, we mostly focus on the platforms and other components that constitute the ODPEs and their characteristics. However, the ODPE in general also includes other elements that shape the ODE's development.

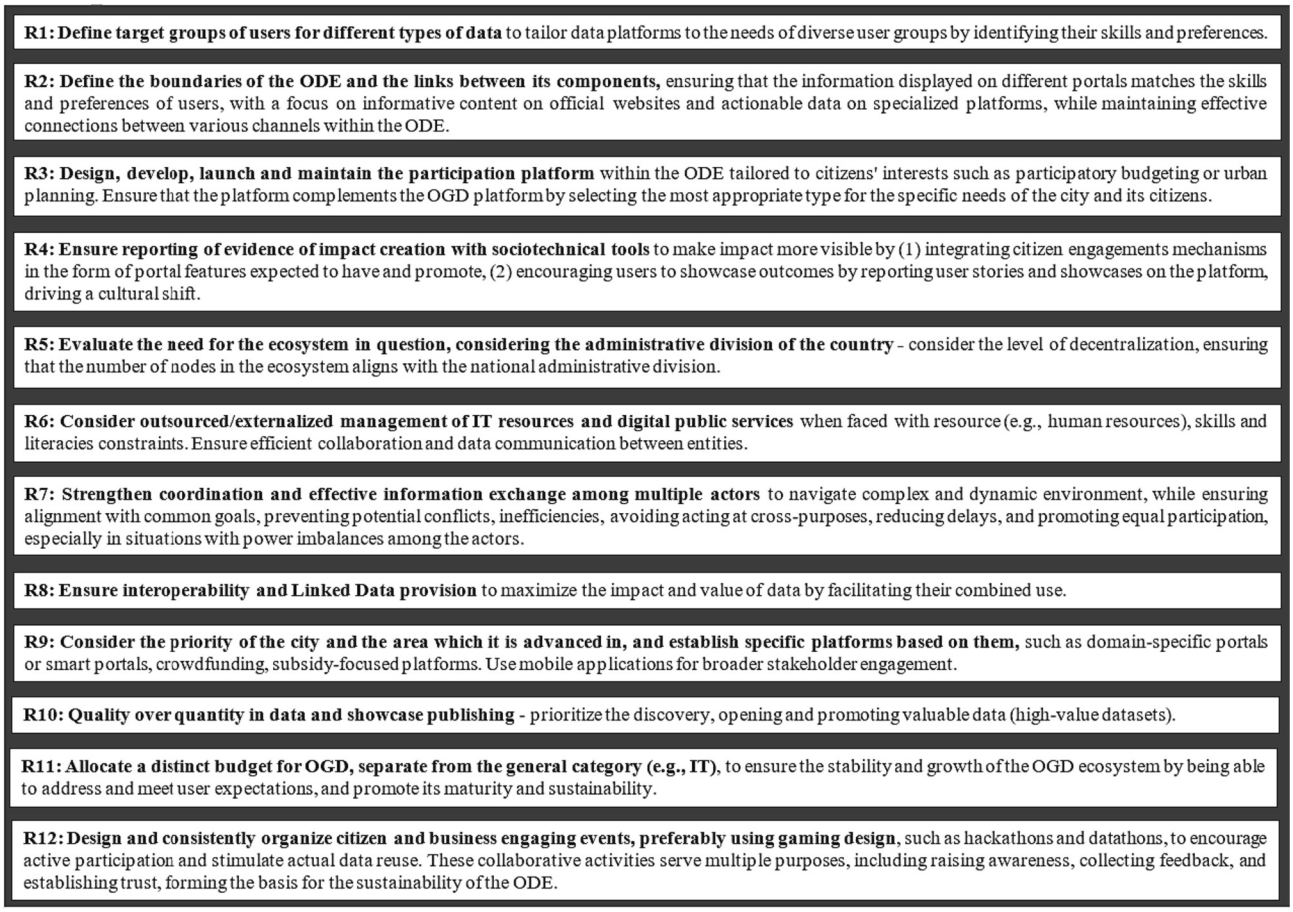

Fig. 3. Recommendations for policy planning and urban governance.

Platforms, however, form the prerequisite for an ecosystem as a point through which interactions take place between stakeholders and their roles (actors), data and information flows and system, system and another system, and different actors of the same and different types. This also applies to the context that we have identified and studied along with additional factors that may influence the ODE, as well as to form the list of recommendations. While we have considered (1) *managerial and organizational, (2) political and institutional, and (3) information and technological contexts*, considering (4) the *social context*, which may include data reuse dynamics, more attention to platform interactivity and off-line activities, and a greater focus on the target audience or objectives of data opening, and probably their dynamism, may reveal additional valuable insights.

Fourth, there is a limitation regarding the applied k-means clustering algorithm, which is sensitive to scaling. Since the found patterns were evaluated by experts for each city as a Boolean value, i.e., YES - the pattern is relevant for the city under consideration or NO - the pattern is not relevant (1/0), the similarities between groups of patterns can be affected by this limitation. Since this study is exploratory in nature, the results require further validation, where fulfillment levels at some multidimensional scales are determined for each pattern. Another limitation is related to the exclusivity of patterns in clusters. In this regard, several overlapping clustering methods can be applied to ensure that one pattern can belong to more than one cluster (N'Cir et al., 2015).

Finally, the topic under discussion is dynamic in its nature. First, this applies to the ODEs we studied - this study is devoted only to the analysis of currently implemented ODEs. However, information or data may be published within different areas of the city, i.e., various stand-alone websites, or may not be available online at all and/or kept in secret for various reasons, and they are not published on any online platforms of the ODPE. In this regard, disclosure of information is not included in our research. In addition, some data may become outdated or lack up-to-date information, potentially altering the relevance and applicability of the findings. Additionally, the dynamism of the topic makes it difficult to predict or forecast what the next generations of ODEs will be like, especially after we have found that there exist public data ecosystems and other subtypes of ecosystems, and thereby ensure their sustainability. While we have defined both the maturity and the types of ODPEs and the characteristics they are expected to have, along with the recommendations, it is likely that with years considering a full focus towards digitization, smartification, Society 5.0 and Industry 5.0, this list and the highest level of maturity should be revisited. Similarly, the results for cities in question are subject to changes with modifications of the current ecosystems.

7. Conclusions

Smart cities are designed to improve the quality of life of citizens, enhance urban services, and promote sustainable development, while previous research has shown that open data is a catalyst for the sustainable development of smart cities and their governance (Neves et al., 2020). Thus, we aimed to identify and analyze contextual patterns, platforms, and other components that shape these efforts. In today's digital age, cities are generating a vast amount of data that can be used to improve the quality of life for citizens, reduce carbon emissions, and create more sustainable cities. However, to fully realize the potential of these data, it is important to have an open data ecosystem that enables data sharing and collaboration among various stakeholders.

One of the most critical components of a sustainable smart city's ODE is the platform. The platform is a digital infrastructure that allows for the

collection, storage, processing, publishing, reusing, and sharing data. An effective platform must be able to integrate with different data sources and provide features to support decision-making processes. Platforms should be easily findable, accessible, and usable for all stakeholders. Contextual patterns are another important aspect of cities' ODEs. These patterns are the underlying structures and relationships that influence the work with data. Contextual patterns can be shaped by various factors, including social, economic, and environmental factors. For instance, in a city with a high population density, traffic data may be more critical than in a less dense city. Thus, understanding the contextual patterns of a city is crucial in developing effective ODEs.

To ensure the sustainability of ODEs, it is necessary to consider the interplay between these contextual patterns, platforms, and components. For example, a city with a high level of citizen engagement may require different platforms than a city with low levels of citizen participation. Similarly, a city with a high level of data security may require different communication networks than a city with lower levels of security. A comprehensive understanding of these factors can help city planners, policymakers, and technologists to design and implement effective ODEs that support the needs of citizens and promote sustainable urban development.

To this end, in this paper we raised and answered three RQs. First, we examined *what are the contextual patterns that influence and shape open (government) data efforts in smart cities.* Within the study 50 contextual patterns were derived from the analysis of 19 cities and their data platforms. RQ2 aimed to understand *what the relationships between platforms and other components of ODPEs that can be found in smart cities was answered by presenting the respective model.* More important, we identified several internal platforms and other components that we classified into four categories, namely, (1) **data and information disclosure platforms** such as open data portals, transparency portals, and official city websites, (2) **thematic city development platforms** focused on the subject of information such as smart city and smart projects platforms, participation platforms, citizen reporting or accountability platforms, crowdfunding platforms for local projects, startup platforms, etc., (3) **specific data format disclosure platforms**, and (4) **content of information focused platforms**, i.e., domain-specific platforms focused on data visualizations and storytelling, which include but are not limited to smart data portals, IoT and big data portals etc.

We then redefined types of smart cities' ODPEs presented in Lnenicka et al. (2022) with further description of how they contribute to the maturity concept of a sustainable ODE and respective platforms thereby answering RQ3. Finally, the experience gained during the study with reference to both the ODE itself and external pressures and environments that shape or influence them allowed us to define 12 recommendations for policy planning based predominantly on best practices or pain points for ODEs in the sampled smart cities.

This study contributes to existing literature by analyzing the contextual patterns, platforms, and components shaping sustainable smart cities' ODEs. To the best of our knowledge this study is the first, which empirically validates the conceptual findings of Lnenicka et al. (2022) and tracks the progress from this conceptualization to real-life implementation of respective platforms and other components in sample cities. Clarification of the elements and their relationships into several types of ODPEs contributes to the platform theory by concerning their design constructs and the distinct approaches to be considered in the implementation. Our study offers evidence suggesting that two key components of the ODPE are the OGD platform and open government platform around which the ecosystem is built. Therefore, our findings contribute to research on policy planning and urban governance with respect to information and e-government systems design and are in line with previous works, e.g., Martin et al. (2021).

In future research we will focus our attention on the deficiencies found on the components and on the differences and design a questionnaire to gather the opinion of the responsible persons of the ODE to know their opinions concerning the deficiencies found on their ODEs and the urban public policies to be taken for improving the ODEs. It is also expected to expand this study by conducting interviews with representatives of these cities, where the findings of this study expect to shape the scope of the interviews.

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CRediT authorship contribution statement

Martin Lnenicka: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Anastasija Nikiforova:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antoine Clarinval:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Mariusz Luterek:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Daniel Rudmark:** Writing – original draft, Investigation. **Sebastian Neumaier:** Writing – original draft, Investigation. **Karlo Kević:** Writing – original draft, Investigation. **Manuel Pedro Rodríguez Bolívar:** Writing – review & editing, Validation, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2024.104851.

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