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Application Programming Interfaces in Governments: Why, what and how

Channelling government digital transformation through APIs

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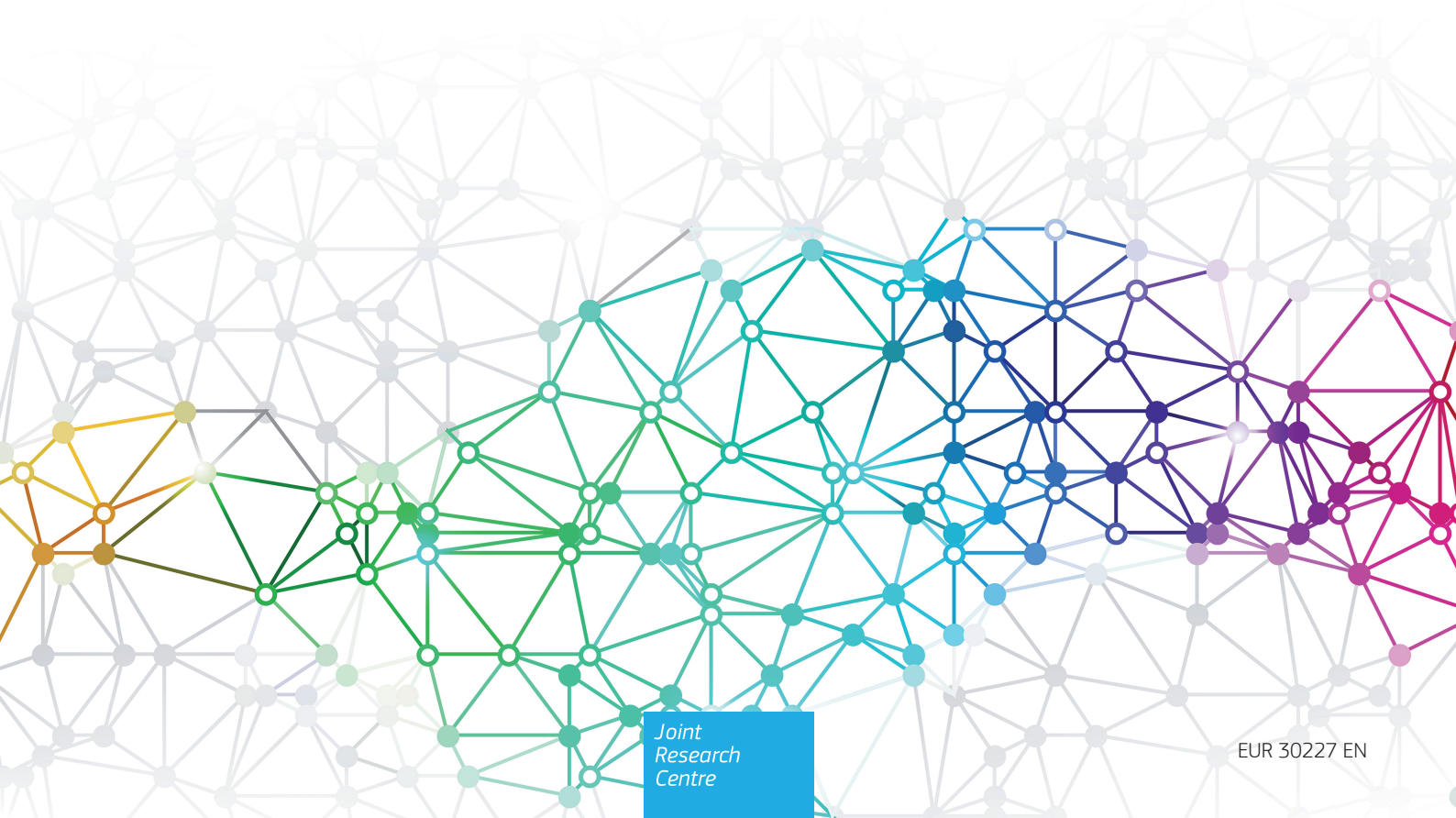

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APPLICATION PROGRAMMING INTERFACES IN GOVERNMENTS: WHY, WHAT AND HOW

Channelling government digital transformation through APIs

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All errors remain the sole responsibility of the authors.

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Abstract

Application programming interfaces (APIs) are a 50-year-old technology that can be applied to many fields and that, for some years, the public sector has used to implement its digital transformation (e.g. for the publication of public-sector information and for public service provision in different areas), although this technology is not yet fully used to support government policies. Recently, the European Commission has produced a series of policy instruments that require or suggest the adoption of APIs in governments and in some specific areas in particular. These initiatives include the Open Data EU Directive 2019/1024, which requires the use of APIs for 'high-value' and dynamic datasets and the European Commission 'European strategy for data' Communication COM/2020/66 that reports on future investment in 'the establishment of EU-wide common, interoperable data spaces'.

The goal of this report is to present the main results of a 2-year study on the adoption of APIs in governments, which also supports the adoption of the abovementioned policy instruments. Even though the cohesive and coordinated adoption of APIs in the public sector is still in its early stages, the results of this study demonstrate that APIs present many benefits for the public sector, including fostering innovation in governments and related public services, improving efficiency, improving access to government open data, increasing economic opportunities for private companies using government APIs and enabling the creation and facilitation of interactions between governments (G2G) and between governments and businesses (G2B) in relation to digital ecosystems. However, these benefits also carry technical and organisational costs.

In adopting APIs, governments can also encounter risks and challenges. These include cybersecurity issues, missing API governance structures, the difficulty in adopting proper legal instruments to adhere to current regulation, the lack of an API culture and the need for agile platforms to adapt digital public services provision to a rapidly evolving society. To tackle these issues, this study has developed a basic API framework for governments. It provides a cohesive, coordinated approach to APIs that deals with the problems and complexity that result from ad hoc implementation of APIs. It frames existing efforts within a more coordinated suite of activities including (i) the alignment of API adoption with policy goals, (ii) the creation of platforms and ecosystems based on APIs, (iii) the organisation of teams and the development of an API culture and (iv) designing processes based on API best practices.

The recommendations and actions outlined in this framework, to be performed in policy priority areas, should also be followed. APIs need to be explicitly adopted to support the new Commission priorities and EU and Member State policies; this adoption should be accompanied by the creation of shared best practices and guidelines to implement an API culture in governments. In addition, the proposed framework should be adopted, further validated and continuously refined to guide government API strategies and digital government strategies, and governments should be more digital-ecosystems aware, engaging multiple stakeholders to co-create and co-design API-based systems.

Preface

Digitalisation is transforming public administration across Europe. Technologies such as artificial intelligence, the internet of things and cloud computing are, undeniably, key elements of this transformation, facilitating public administrations' decision-making process, from policy design to service delivery. Soon enough public administrations will be expected to learn how to exploit and interact with digital twins, informed by thousands of data sources. Governments already not only utilise their own available data to create data ecosystems spanning both the public and the private sectors, but also use the power of data to offer entirely new services (e.g. location-based information for investors, gleaned from digitising thousands of government documents).

Undoubtedly, all this will not happen by itself. The public sector at all levels has to take decisive steps to keep up with the digital transformation of society. In this respect, this joint report of the Directorate-General for Communications Networks, Content and Technology and the Joint Research Centre is timely.

If networks are the motorways of the digital age, application programming interfaces (APIs) are the interchange nodes and connections at which data arrive in containers and then are repacked from one container to another and shipped in trucks to the destination points (i.e. heterogeneous information technology (IT) systems of public and private organisations). Connecting to API interchange nodes lets these organisations build innovative digital public services and modern applications for citizens and businesses.

While other technologies have enjoyed the limelight, APIs have revolutionised the way 'digital is done' in the private sector. The public sector cannot fall behind. APIs will be essential for a number of initiatives at the European level, from the publication of high-value datasets in compliance with the Open Data Directive to the creation of European data spaces and the access of public administration to artificial intelligence and high-speed computing.

This study will support policymakers who would like to understand the benefits and challenges of API adoption, IT leaders and other innovators eager to speed up digitalisation in their remit, and managers willing to assess the API maturity of their organisation, as well as the technical staff in charge of the implementation of API policy.

Following the new Commission strategy on Europe's digital future, the discussion on how key innovative technologies can advance the digital transformation of public administration throughout Europe is in full swing. This study aims to make a significant contribution to this debate. We invite you to take advantage of its findings.

Executive summary

Application programming interfaces (APIs) have long been a foundational part of information and communications technology (ICT) architectures; nonetheless, their role became highly relevant in the light of the digital transformation of society. This relevance stems from the fact that APIs are the connective nodes of modern digital architectures in all sectors of the global digital economy and society. Owing to this connective capability, APIs play an important role as technical and organisational enablers of digitalisation.

The digital transformation of society is also putting pressure on governments to adapt to the digital era. The goal of digital government is twofold. On one side, governments need to transform into a robust digital ecosystem that is flexible, can adapt to advances in technology and is able to 'rewire' the interactions between societal actors. On the other side, governments need to oversee the behaviour of digital environments and ensure societal well-being and stability (e.g. by counteracting technology-driven monopolistic behaviour, controlling the abuse of power due to information asymmetries or ensuring the robustness of critical infrastructure). APIs can play a role in this government transformation by enhancing governments' processes, providing new means for governments to interact with citizens and other societal actors, and fostering innovation in public service delivery.

The purpose of this report is to assess the relevance of APIs in the context of the digital transformation of government. Specifically, the report (i) evaluates the current status of API adoption in governments, (ii) analyses the value, opportunities and challenges that the adoption of APIs brings to government and (iii) proposes a potential roadmap for a coordinated adoption of APIs in government structures distilled from the thorough analysis of extensive literature on current practices. The report aims to support policymakers in understanding the value and implications of API adoption in governments. It also targets governments' information technology (IT) leaders and decision-makers.

Main findings

The study concludes that APIs are essential enablers of the transformation towards digital governments. This conclusion is rooted in three main characteristics of API solutions, namely that they are modular, reusable and easily scalable (near-zero marginal cost solutions). These characteristics endow digital environments with high flexibility both technically and organisationally. Technically, APIs underpin the creation of digital ecosystems and add agility to innovative processes in organisations. Organisationally, API solutions facilitate governments' digital interactions with actors and systems both internally (G2G) and externally (with businesses (G2B) and citizens (G2C)). Moreover, APIs are interfaces in which the relationships between digital actors are defined, namely who can access what and under what circumstances. This has implications for the governance perspective of digital environments. In this regard, APIs technically enable the control and monitoring of the dynamics between actors and systems.

Based on these enabling characteristics, the main findings of the study can be summarised as follows:

APIs are a foundational technological solution that requires attention in digital government agendas. APIs are a necessary component in the digitalisation of government operations and processes. The technical and organisational flexibility that APIs grant to organisations could be used to streamline information flows to all phases of policymaking. A coordinated approach to API adoption is also necessary to harness the transformative potential derived from cross-fertilisation opportunities. This coordination is crucial to also mitigate risks derived from the increased vulnerability that loosely coupled API systems may confer.

APIs can assist governments in steering the organisational change management of digitalisation. The analysis of the usage of APIs can provide relevant information on the exchange of resources, on the actors and dynamics of digital interactions and on processes' performance and, ultimately, can support budget allocation decision-making. This information is key to design the transformational roadmap and improve government efficiency by means of (i) increasing the innovative potential of public service provision and (ii) enhancing policymaking by

facilitating access to virtually any relevant information required in all phases of the policy cycle (policy design, implementation and monitoring).

APIs foster innovation in public administration processes and public service provision. API solutions are intrinsically modular and reusable. This results in API-enabled digital environments having a high degree of flexibility (innovative potential) and virtually unlimited access to digital assets (digital ecosystem enabler). Moreover, APIs can assist governments in drawing on data from multiple sources, working across government departmental siloes, collaborating with industry, research and non-profit sectors, and reusing government assets to achieve greater sustainability within limited resources and to deliver more efficient public services to society.

API solutions facilitate governments' digital interactions with internal (G2G) and external (G2C and G2B, as well as the reverse: C2G and B2G) actors. APIs are the glue of functional digital ecosystems. The creation of an 'ecosystem' of providers and consumers fosters synergies and efficiency, and can also spawn the development of innovative service models, some of which may lead to revenue generation for the agencies concerned. Their ability to provide access to the heart of government in turn allows governments to realise their objectives of openness and of delivering efficient, secure, transparent and interoperable citizen-centric services. APIs are, therefore, a crucial technological component of empowering the evolution of public service delivery models, enabling agencies to accelerate their transformation from e-government to digital government.

API adoption carries budgetary, organisational costs and important challenges. Depending on the role that government takes when adopting APIs, these costs can greatly vary. From the results of our research the yearly budget used to maintain APIs is rather low. Nevertheless, coordinating the API adoption at the whole organisation level requires more resources, in particular at the setup phase. Moreover, the adoption of API implies challenges such as those required to overcome the organisational change management and cultural shift and lack of skills, to protect cyber-security vulnerabilities and to adhere to current regulations, such as GDPR. In particular, cyber-security is a crucial aspect to consider in the digitalization process. APIs are 'doors' to access digital infrastructures thus, the security and resilience of digital environments will also depend on the robustness of the API infrastructure of organisations.

Multiple API-related activities are occurring at the European Union institutions level, within Member States and at regional and city government levels. Some of these activities are driven by governance policies, and an interoperability policy, but more often are ad hoc approaches. Private industry examples, however, show that where APIs are introduced in an ad hoc manner, over time they increase complexity and do not generate the desired benefits. To avoid ad hoc solutions, duplications and delayed action, European programmes implementing these policies should adopt APIs in a coordinated way (e.g. by publishing common EU guidelines) as soon as possible. Best practices are emerging for the adoption of government APIs, and there are a number of similarities in how innovative governments at all levels are implementing APIs. Stakeholders engaged and surveyed throughout the study prioritised best practices as a key area of knowledge needed to enable action. If APIs are successfully implemented across the government in a coordinated and cohesive way, there is a greater likelihood of increasing efficiency, and generating external value including both improved social value and new economic development.

Policy context

The policy relevance of APIs is linked to (i) their capacity to provide flexible access to digital assets and (ii) their connective role among different actors and systems. Current regulations such as the *Open Data Directive* (European Union, 2019a) and the *Payment Services Directive (PSD2)* (European Union, 2015a) do, explicitly or implicitly, require and mention the use of API solutions to streamline, both technically and organisationally, the exchange of data and functionalities among disparate actors.

More recently, the relevance of APIs has acquired momentum due to digitalisation, in particular as follows.

APIs are a key enabler for the European digital strategy. The creation of resilient and competitive digital ecosystems, which are underpinned by APIs, is highlighted in several European digital strategy documents supporting the priority *A Europe Fit for the Digital Age*. For instance, under the *European strategy for data* (European Commission, 2020a) the European Commission will 'explore the need for legislative action on issues that affect relations between actors in the data-agile economy'. Moreover, the *European industrial strategy* (European Commission, 2020b) stresses the need for a 'partnership approach to the governance of industrial ecosystems' to cross-fertilise products and services among sectors. Also, the *SME Strategy for a sustainable and digital Europe* (European Commission, 2020c) mentions the need to 'Empowering SMEs to reap benefits of the digital transformation'. In addition, the small and medium-size enterprise *(SME) strategy for a sustainable and digital Europe* (European Commission, 2020c) mentions the follow as a priority: 'Empowering SMEs to reap benefits of the digital transformation'. As regards the European approach to artificial intelligence uptake, APIs will have a role in empowering businesses to start, to scale up, to innovate and to compete on fair terms.

APIs are an enabler of the data economy and therefore can also support the priority of having 'Europe as a leader in the data economy'. The Commissioner for the Internal Market, Thierry Breton, said:

> '*Our society is generating a huge wave of industrial and public data, which will transform the way we produce, consume and live. I want European businesses and our many SMEs to access this data and create value for Europeans – including by developing Artificial Intelligence applications. Europe has everything it takes to lead the "big data" race, and preserve its technological sovereignty, industrial leadership and economic competitiveness to the benefit of European consumers*' (Breton, 2020).

When successfully used, APIs have become fundamental components for the private sector in making powerful digital platforms and enhancing the sector's and third parties' digital ecosystems. Indeed, these systems can reuse APIs in ways that were not forecast and can, potentially, lead to digital innovations. Making APIs available to third parties is often advantageous for both API providers and consumers. Application developers can reuse existing and solid APIs, making the creation of their products more efficient. In turn, API providers gain complementary added value by, for example, increasing the access control to their digital assets (and related products). In the best-case scenario for the platform firm, and depending on the sector, the type of data and the business model, APIs can become the basis of a successful ecosystem, with exponentially growing revenues and low marginal costs. APIs can efficiently streamline access to public data and allow the creation of new services, delivery models and service delivery channels by the private sector for the benefit of citizens and the improvement of businesses, including new business models.

Key conclusions

The evidence collected from our research for this study recognises the high value of APIs in enabling governments to deliver on digital transformation goals, to capitalise on the investment made on government (open) data, to form digital ecosystems and to move towards more platform-based models in which value is co-created with a range of external and internal stakeholders.

Our main recommendation is that EU governments at different levels and the European institutions should take systematic and structured approaches to increase the use of APIs. APIs are essential for implementing the requirements of the *Open Data Directive* on high-value and dynamic datasets (European Union, 2019a). APIs are also crucial to guarantee that the data spaces identified by the Commission communication *A European Strategy for Data* (European Commission, 2020a) will not become 'siloed' environments.

APIs and proper API strategies have to be adopted to support the new Commission priorities and policies at the EU level. Governments should incorporate APIs into their digital strategies to support these policy goals. To do so, **we suggest considering the adoption of the API framework summarised in this document and fully described in our dedicated technical report** (Mark Boyd et al., 2020a). The framework provides a cohesive, coordinated approach to

APIs that overcomes the challenges of complexity that result from ad hoc implementations. Given that the maturity of digital government structures is uneven, the framework has been designed to be flexible enough to help governments identify the specific actions they need to focus on. These actions are structured into four areas: (i) aligning API adoption with policy goals, (ii) building platforms and ecosystems based on APIs, (iii) organising teams and developing an API culture and (iv) developing processes based on API best practices.

Future work

Future activities will meet the following objectives: engage public- and private-sector stakeholders (e.g. by creating specific working groups and mixed public/private workshops), focus on cybersecurity and privacy aspects, analyse API legal and organisational aspects, and provide a set of technical recommendations on API discoverability and access.

Concrete tools to let governments assess their degree of adoption of APIs will also be provided. A maturity toolkit could allow self-assessment and guide governments in implementing the proposed API framework (Mark Boyd et al., 2020a). Within the framework, a tool has been undertaken to help governments identify their progress towards implementing it fully. An early online version of the tool has also been created to help governments quickly score their maturity and to help them to identify and prioritise future actions (Mark Boyd et al., 2020b). Further testing and refinement will occur on the framework so that governments can take a more cohesive approach while still gaining value from their current API-related activities.

Efforts will also be dedicated to work within the European Commission to invest in creating and improving a common culture on APIs. Best-practice operational guidelines and standards should be followed or created to assist governments in the implementation of product management and life cycle approaches. This study found a range of best practices being implemented by governments and private industry. There is sufficient agreement on architectural styles, security minimum standards and API design for these factors to be collected into standards and shared across European governments. While there is almost uniform agreement among governments and private industry that a product management approach should be taken, there are fewer resources available to guide government stakeholders in implementing best practices and tools. Efforts to support in defining and identifying this new skill set area will be provided also to align with exiting initiatives, such as the Interoperability Academy (European Commission, 2019a) and the European Support Centre for Data Sharing (European Commission, 2020d).

Quick guide

This report is organised in eight sections. The introduction (Section 1) gives a basic definition of APIs and describes the study motivation and methodology. The following sections illustrate the 'who' (Section 2), 'what' (Section 3), 'why' (Section 4), 'how' (Section 5) and 'where' (Section 6) of government APIs. The report also presents a set of policy recommendation (Section 7) and the final section presents the main conclusions of the study (Section 8).

The report targets IT managers, decision-makers and policymakers. Policymakers and decision-makers will be most interested in understanding the relevance of the adoption of APIs in government (Section 2), in the API EU policy landscape (Section 3.1), in the value generated by APIs (Section 4), in the description of the proposed EU API framework (Section 5.1), in the domains and thematic areas to focus on (Section 6) and in the policy recommendations (Section 7).

The technical aspects (including a discussion on APIs in Section 1.1), the landscape of API cases, standards and best practices (Sections 3.2, 3.3, and 3.4) and the various ways to adopt API in governments (Section 5) will be of most relevance to IT professionals. For those readers interested in more API technical details, our APIs for digital government (APIs4DGov) report on web API standards and specifications provides more information (Santoro et al., 2019).

1 INTRODUCTION

SUMMARY

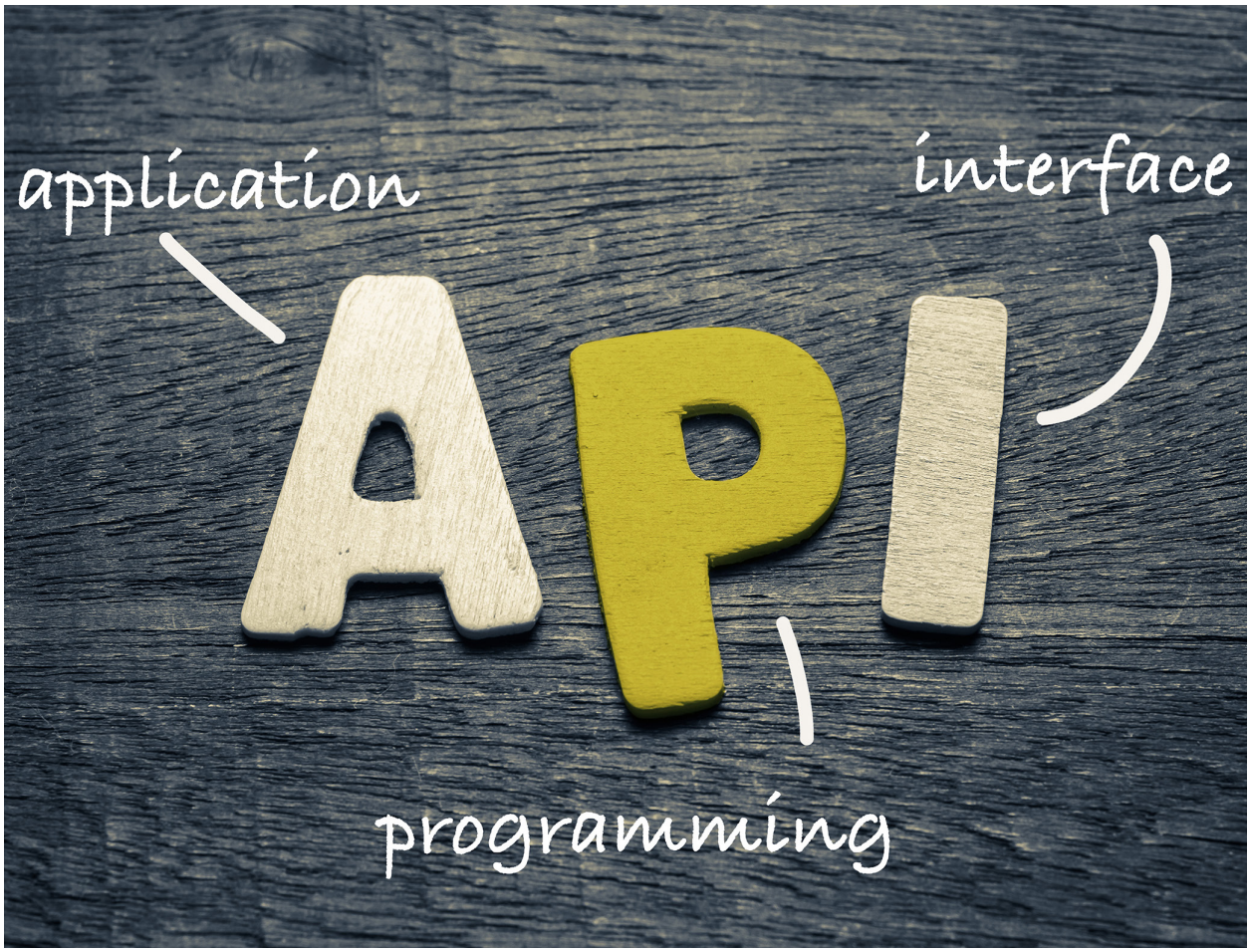
This report presents the results of the European Commission application programming interfaces (APIs) for digital government (APIs4DGov) study, which aimed to understand the role of APIs in the public sector and, specifically, the motivations for their use and the way governments should implement them. This first section defines APIs, illustrates the motivations behind the study and briefly explains the applied research methodology.

An API is a machine-to-machine interface, different from a machine-to-human interface, such as web applications. Instead, it works behind applications, in the sense that applications can use APIs to exchange information with other applications to share digital assets (i.e. data and services).

Technically, APIs constitute the interfaces of the various building blocks that application developers can assemble to create their products to reach specific goals. The notion of APIs is not new but, with web APIs acquiring more and more importance, they are now the main way used by organisations to exchange data and services among software applications.

APIs' main technical advantage is the possibility for a provider to publish machine interfaces to let applications access the API provider's digital assets. These interfaces can be exposed to regulate the access to information for different users and, depending on the sharing policies of the provider, they can be reused multiple times, both for the original purpose that the APIs were created or for different purposes. API users, in turn, can also 'mesh' multiple APIs to build new innovative applications.

APIs also create business opportunities, as they can be seen as other software products that, in the context of the API economy, have a value chain. This is how, for example, pioneering companies such as Amazon, Google, Facebook, Apple and Twitter have exposed amazing technological solutions to the public, transforming existing businesses and creating new industries.



1 INTRODUCTION

Application programming interfaces (APIs) are machine-to-machine digital interfaces that facilitate the exchange of data and services (functionalities). The purpose of this report is to support the European Commission institutions and initiatives, Member States and public institutions in their effort to adopt the use of APIs when pursuing the digital transformation of their government and public administration operations. Therefore, although it will sometimes be necessary to address the API topic by describing its technical details, this report is not intended to address mainly technologists or information technology (IT) practitioners in governments who directly create and use APIs. Instead, this study aims to serve parties interested in understanding the reasons for implementing an API adoption strategy and the many ways in which this adoption can be accomplished.

This document has been prepared as a final deliverable of the study *Application Programming Interfaces for Digital Government (APIs4DGov): The road to value-added open API-driven services*, performed by the Joint Research Centre (JRC), in collaboration with the Directorate-General for Communications Networks, Content and Technology (DG CNECT) of the European Commission. The 2-year study started at the beginning of 2018 and was conducted in the context of the European Commission's digital single market (DSM) strategy. The work aims to improve the understanding of the current use of APIs in digital government and their added value, as well as to assess the feasibility of establishing a European API framework for digital government. In short, it attempts to answer two questions.

1. Why should governments invest in the adoption of APIs?
2. How should they do it?

1.1 | Application programming interfaces: definition

Informally speaking, an API is, first of all, an interface, a concept that all of us are familiar with. A typical example of an interface is that between a plug and power socket for connecting electric equipment to the alternating current power supply in our buildings. A second example of an interface that is often used is the mobile phone interface that many of us use to interact with web applications. Like these, an API is also an interface but, instead of energy, it exchanges data and services and, instead of with a human, it exchanges this information between two computers. Thus, an API is a programming interface in the sense that it links computers via two types of software programs: an application running on a provider computer and one or more applications running on a client computer.

The notion of APIs is not new, as they are the interfaces of the various building blocks that application developers can assemble to create their products to reach specific goals. This notion probably first appeared in 1968 (Cotton and Greatorex, 1968). Since then, APIs have been used for many purposes so that, technically, they are 'the calls, subroutines, or software interrupts that comprise a documented interface so that an application program can use the services and functions of another application, operating system, network operating system, driver, or other lower-level software program' (Shnier, 1996). With the advent of the web, APIs acquired more and more importance and they now represent the main way that applications created by organisations exchange data and services. As we are particularly interested in these kinds of APIs, in the remainder of this document, unless otherwise specified, the term 'API' will be used to refer to web APIs.

One of the key uses of APIs is to transfer data between providers' and clients' applications. Figure 1 shows an example taken from the Danmarks Adressers Web API (DAWA) in which a client application requests a list of physical addresses from the DAWA repository and a provider application API returns them (Danish Agency for Data Supply and Efficiency, 2019).

If we look at the 'request' made by the client application, it contains two parts ([1]): the first is the API URL (the unique identifier on the web that indicates the API) and the second is formed of the API parameters (a set of 'filters' that let the user define which parts of the data are needed). Thus, in this example, the API offers the possibility of requesting the exact subset of values of a dataset needed by the client application. Compared with the traditional 'bulk download' of a dataset from a traditional data catalogue ([2]), this allows the client application to save transactional time and storage. This example also shows that APIs offer a stable and controlled layer to access the datasets. There is no need to download the entire dataset and to manage the alignment of the local data with the remote data. In this sense, APIs could represent a strategic

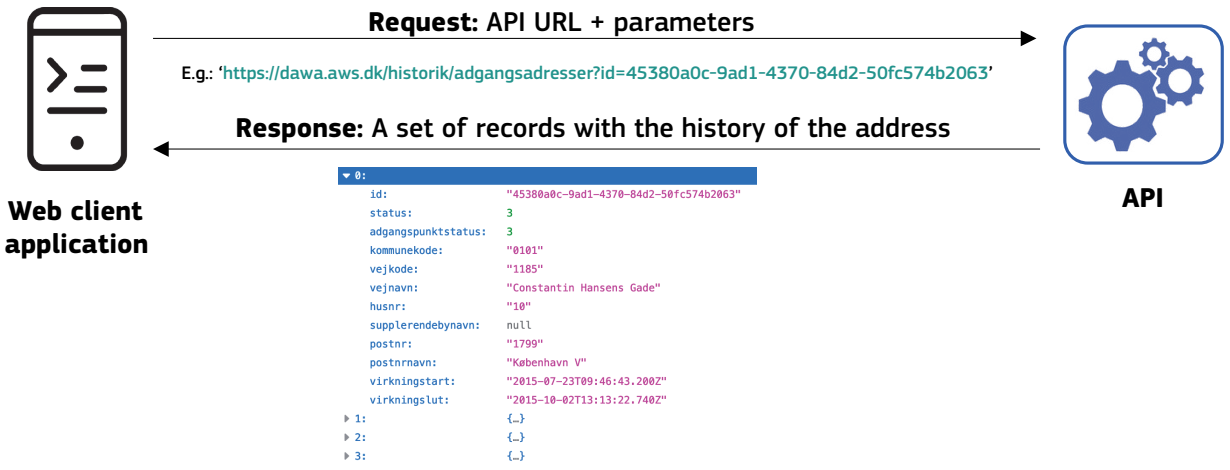


FIGURE 1: Example of a web API requesting data from DAWA.
Source: JRC, own elaboration.

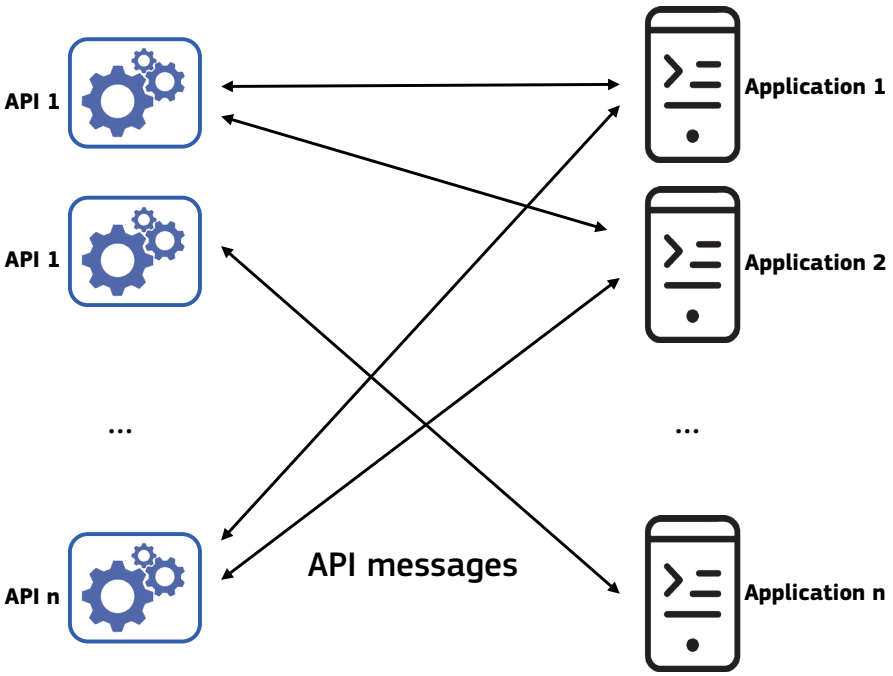


FIGURE 2: One or more APIs can be reused by one or many applications.
Source: JRC, own elaboration.

solution to exploit the investments made in the publication of government open data.

APIs can also be used to offer reusable services (functionalities). These functionalities can be very simple but also very complex, such as powerful artificial intelligence (AI) functionalities (ProgrammableWeb.com, 2019a) or mapping components (Google, 2020a).

Moreover, as shown in Figure 2, APIs can be reused many times by different user applications. Thus, they can either be used to build the final programs for which they were designed or be 'meshed' to build innovative products.

Technically, APIs can be designed and implemented in a number of different ways that depend on the use of available standards and specifications. Section 3.3 gives an overall summary of these solutions. Should the reader be interested in more detail, we suggest our report on web API standards and specifications (Santoro et al., 2019).

APIs are also (technical and service) contracts that, once in place, let developers rely on them and access their resources. To be reliable, the essential characteristics of APIs are their availability, documentation, consistency and versioning. Websites, besides the fact that they implement a machine-to-human interface instead of a machine-to-machine interface, are not contracts, as their final users can adapt to them even when they change their appearance and structure. Software applications are not as flexible (at least currently) as humans and need the definition of a contract to include interaction with each

> *"APIs are calls, subroutines, or software interrupts that comprise a documented interface so that an application program can use the services and functions of another application, operating system, network operating system, driver, or other lower-level software program"*

> *APIs are technical contracts that can be seen as software products that have a value chain*

other through APIs. This does not mean that an API cannot change. Instead, its implementation can change but its interface must remain stable (or at least must implement a versioning strategy) to let applications built on it while continuing functioning (Jacobson et al., 2011).

APIs can also be seen as software products that, in the context of the API economy, **have a value chain** (Gartner, 2016; Jacobson et al., 2011). APIs represent an indirect channel for data and service providers to reach the end users of web applications and act 'behind the scenes' (i.e. they are used by web applications to access the digital assets needed). Figure 3 represents actors, products and interrelationships of a basic API value chain. The model is 'basic' in the sense that it does not take into consideration other intermediaries in the system. These intermediaries can, for example, build platforms that aggregate and distribute data and APIs, such as the one presented in Figure 20.

The flow in Figure 3 includes the following roles and products.

— The flow starts with a **digital asset provider** that wants to allow others to use and share its products. Products are represented by digital assets, such as data (e.g. a satellite map, a registry of companies or statistical data), functionalities (e.g. weather forecasting or returning the geo-coding of an address) or other assets (e.g. streaming of internet of things (IoT) data or cybersecurity mechanisms). It is important to understand that these digital assets must have a 'value' (e.g. social or economic value) for the end users. If there is not this value the API will not be used.

— The **API provider** allows APIs to exchange digital assets in the best possible way to be used by the intended audience. The API provider can be the same as the digital asset provider, but this is not always the case. Private API providers can, for example, distribute government open data through APIs. API providers can also offer the possibility of discovering their APIs through API catalogues or portals.

— Once the API is created, a number of **API consumers** can make use of digital assets to create applications. Technically, application developers can develop applications that run on

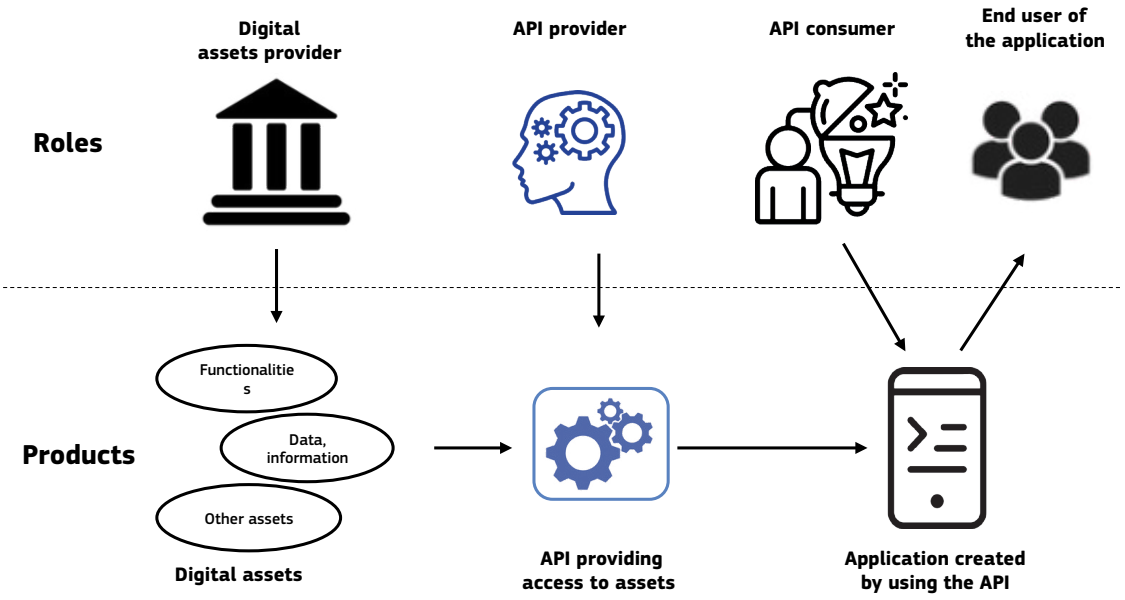


Figure 3: API value-chain.
Source: JRC, own elaboration.

a client machine (e.g. within a web browser on a mobile phone). API consumers can publish their application in private-sector marketplaces or in catalogues offering public-sector digital services.

— Finally, the application can be used by a number of **end users** to satisfy their needs (e.g. to book a medical visit, check the timetable of public offices, register their company in a public registry, check and find bicycle paths or find a children's playground in their city).

1.2 | The digital government context

Digital technologies are changing every dimension of our lives, including our interaction with public government authorities and services. The term 'digital transformation of the public sector' refers to the process of the conversion or substitution of analogue public administration operations to/with their digital counterparts. This transformation has an impact both within the organisational boundaries of public administration and on external actors of the private sector, civil society and the citizenry.

The Organisation for Economic Co-operation and Development (OECD) identifies the elements of digital transformation in governments. The OECD argues that digital transformation can improve service delivery and efficiency within the public sector and achieve wider economic growth and increased social equality. The OECD also highlights the benefits of increased transparency and improved citizen engagement through such an approach (OECD, 2014).

In addition, the OECD clarifies that it is not enough to simply introduce information and communications technology (ICT) solutions into public administrations. Instead, the potential integration of technology needs to be grounded in the wider context of the modernisation of the public sector. More specifically, the OECD suggests that increased social inclusion, transparency and accountability, alongside participatory democracy, collaboration and partnership, are key aspects in the progression towards digital government. Achieving digital government will, in some areas, require progression through a period of e-government, the middle stage in digital transformation. Under e-government, governments make greater use of digital technologies, particularly the internet, to achieve better government, focusing on delivering services tailored to individuals' needs, but also on providing a means to improve the public's contribution to policymaking. It is argued that, to reach digital transformation and a true digital government status, organisations will need to pass through an e-government stage involving the increased use of internet technologies for 'better government, focusing on delivering services tailored to individuals' needs in a user- or citizen-driven setting, while also achieving improved efficiency and productivity' (OECD, 2016).

In a recent study proposed within the European Location Interoperability Solutions for e-Government (ELISE) action, as part of the interoperability solutions for public administrations, businesses and citizens (ISA^2) programme, the authors define a digital transformation framework, with different levels of maturity of digital government for an organisation. The framework proposes and describes in detail the characteristics of five transformation stages: (i) e-government, in which the focus is on having services online for users' convenience and cost savings; (ii) open government, which often takes the form of public programmes intended to promote transparency, citizen engagement and the data economy (e-government and open government programmes often coexist, with different leadership and priorities); (iii) data-centric government, whereby the focus shifts from meeting citizens' or users' needs to proactively exploring new possibilities that are inherent in strategically collecting and leveraging data; (iv) fully transformed government, whereby the organisation, agency or department has fully committed to a data-centric approach to improving government and to innovation in government; and (v) smart government, whereby the process of data-centric digital innovation is embedded across the entire government and the innovation process is predictable and repeatable, even in the face of disruptions or sudden events that require rapid responses (Valayer and Williams, 2018).

The public sector in the European Union has advanced a lot in terms of e-government and digital transformation initiatives both in developing on an individual level and in integrating cross-sector and cross-border initiatives (European

Commission, 2019b). Specifically, in the last 10 years, the political instruments used to advance the modernisation of public administrations across the European Union have been the e-government action plans ([3]). These have supported coordination and collaboration between Member States and the Commission and led to joint actions on e-government. The most recent EU e-government action plan (2016–2020), in particular, has helped to put in place key objectives for the DSM and policy developments supporting open government and modernisation goals. The vision of this plan requires that 'by 2020, public administrations and public institutions in the European Union should be open, efficient and inclusive, providing borderless, personalised, user-friendly, end-to-end digital public services to all citizens and businesses in the EU. Innovative approaches are used to design and deliver better services in line with the needs and demands of citizens and businesses. Public administrations use the opportunities offered by the new digital environment to facilitate their interactions with stakeholders and with each other' (European Commission, 2016a).

To implement this vision, the 2016–2020 action plan had three main policy priorities, all of which would be supported by the adoption of APIs in the digital transformation of governments:

1. to modernise public administration with ICT, using key digital enablers;
2. to enable cross-border mobility with interoperable digital public services;
3. to facilitate digital interaction between administrations and citizens/businesses for high-quality public services.

Each of these priorities set out concrete actions to accelerate the implementation of existing legislation and the related uptake of online public services. In the next section, we focus on the link between these priorities and the adoption of APIs in governments (i.e. on the motivations and objectives behind this study).

1.3 | Motivation and objectives

This report explains how APIs support digital governments and help create new public services, new delivery models and new service delivery channels, aiming to better serve citizens and enable new business models to be developed. The research, analysis and results of this study aim to contribute to the following specific EU digital government policy documents and initiatives (see also Section 3.1):

- the Open Data Directive (European Union, 2019a), which specifically requires the mandatory use of APIs for 'high-value' and dynamic datasets as 'conditions for [their] reuse';
- the communication *A European Strategy for Data* (European Commission, 2020a), which reports on the future investment in 'the establishment of EU-wide common, interoperable data spaces';
- the communication *Towards a Common European Data Space* (European Commission, 2018a) which, in terms of business-to-business (B2B) data sharing, reports that 'there is strong support from stakeholders for non-regulatory measures, such as fostering the use of APIs for simpler and more automated access to and use of datasets';
- the EU e-government action plan 2016–2020 (European Commission, 2016b);
- the implementation of the European interoperability framework (EIF) (European Commission, 2017a);
- the implementation of the 'once-only' principle (OOP) (European Commission, 2017b);
- the 'building block' approach adopted in the Connecting Europe Facility (CEF) telecommunications programme (European Commission, 2020e).

This work complements the following studies that have been carried out in this area, analysing a great wealth of open government cases to better understand its enablers, drivers and barriers and the value of its services in e-government:

- the study on collaborative production in e-government (European Commission, 2014a);
- the report *Towards faster implementation and uptake of open government* (European Commission, 2016c).
- an analysis of the value of the new generation of e-government services (European Commission, 2016d).

This study aims to gain an understanding of the current use and socioeconomic impact of APIs in digital governments and to assess the feasibility of establishing a European API framework for digital government. In particular, the study focuses on the following topics.

- **Investigating the state of play of the use of digital government APIs.** This topic includes a review of the current landscape of digital government APIs in the public sector in Member States and outside the EU. The landscape includes an analysis of the opportunities enabled by digital government APIs for public administrations, individuals, business and society, and reports on current trends and horizons of APIs in the private and public sector in Member States and outside the EU. This investigation also identifies key enablers and drivers of, as well as barriers to, the provision and roll-out of government APIs and the assessment of potential risks and mitigation actions for the public sector and society.
- **Identifying the added value of digital government APIs.** This topic explores if and, if so, why APIs should be considered an option to support the digital transformation of the public sector. Potential socioeconomic impacts of the adoption of APIs by governments to support data-driven government services are of central importance to understanding the added value of APIs.
- **Defining a basic digital government API EU framework and the road ahead.** To understand how the public sector could capitalise on a digital government API ecosystem, the study aims to identify the ICT standards, and to provide a set of recommendations and guidelines for public administrations and a set of policy recommendations for digital government services and APIs. It also identifies a set of domains and thematic areas in which the opening of digital government services through APIs would be most beneficial.

This report presents the main results of the study and closes and complete the series of publications and outputs published within the study, listed in Annex 3.

1.4 | Structure of this report

This report is organised as follows: besides the introduction, the policy recommendations and the concluding sections, the other sections illustrate the 'who' (Section 2), 'what' (Section 3), 'why' (Section 4), 'how' (Section 5) and 'where' (Section 6) of government APIs.

In particular, this section gave a definition of APIs and illustrated the overall purpose of the study.

Section 2 demonstrates the relevance of APIs in digital government and related government roles.

Section 3 continues with a deep analysis of the API landscape in governments in different areas. First, it illustrates the European Commission initiatives that are most closely related to the API topic. It then gives a summary of the API cases published by governments and public institutions, with a specific focus on the cases selected and analysed for the study. Next, it summarises the main web API technical specifications and standards. Finally, it discusses the study literature review of the API best practices for governments.

Section 4 explains why governments should invest in APIs. It gives a qualitative analysis of the costs, benefits, opportunities and challenges distilled from our research. It also highlights aspects related to the API impact in society.

Section 5 focuses on how governments could adopt APIs. It first presents a robust proposal for a basic digital government API EU framework. The proposal was built on the study API landscape outcomes and was validated in a number of different ways (through focus groups in workshops, the advisory board of the study and a pilot project). Section 5 then illustrates how to select operational tools and measure the impact of the adoption of APIs. Next, it gives an overview of the legal aspects to be considered when adopting APIs in governments. Finally, it gives a list of key enablers, drivers, barriers and risks that we have identified in our research.

Section 6 identifies the main thematic areas, technologies and digital domain ecosystems that the governments of the European Union area should focus on when adopting APIs.

Section 7 summarises our policy recommendations.

Section 8 concludes the report and illustrates further steps.

The annexes contain a glossary that focuses on government APIs (Annex 1), a description of our research methodologies (Annex 2), a list of the study outputs (reports, datasets, workshops and tools; Annex 3) and a reference list of the main EU policy legal instruments related to the adoption of APIs in governments (Annex 4).

2

RELEVANCE OF APPLICATION PROGRAMMING INTERFACES IN DIGITAL GOVERNMENT

SUMMARY

A description of API strategies can assist governments in their digital transformation by steering the necessary organisational change management process. APIs can provide crucial information on the use of resources, actors and dynamics in digital interactions, as well as on processes' performance, and can ultimately support budget allocation decision-making. This information is key to designing the transformational roadmap and ultimately improving government efficiency by means of (i) increasing the innovative potential of public service provision and (ii) enhancing policymaking by facilitating access to virtually any relevant information required in all phases of the policy cycle (policy design, implementation and monitoring). This work has identified potential links between the adoption of APIs in governments and the achievement of these goals, in particular regarding efficiency, accountability, inclusion, security, fairness, sustainability, transparency and trustworthiness.

The foundation of digital ecosystems is built on the interconnection of APIs. Inherent features of APIs, such as reusability and modularity, potentially enhance the exploitation of digital assets by both internal and external players. Digital solutions can be composed of a highly flexible assemblage of APIs involving several actors. Owing to these enabling characteristics, the definition of API strategies is crucial for the development of a functioning digital ecosystem.

Organisations can publish APIs for internal and external purposes and can restrict their use to a selected number of users or release them with no constraints. Based on the constraints on APIs, users can be identified only within the agency that publishes the APIs or among multiple government agencies. APIs can also be shared among different organisations of both the public and the private sectors. Thus, beneficiaries of APIs published by a government agency can be identified within it or inside the same government. Beneficiaries can also include other governments, public service providers, the private sector, non-profit organisations and citizens.

Governments can play different API-related roles within digital ecosystems, namely as ecosystem active participants, ecosystem owners or ecosystem regulators. As ecosystem active participants, governmental entities can take roles such as digital asset curators, API providers, API consumers, digital service providers or API assemblers.

This report focuses in particular (but not only) on the role of governments as API providers, which can share their APIs with different target groups, both internal and external to the organisation.

2 RELEVANCE OF APPLICATION PROGRAMMING INTERFACES IN DIGITAL GOVERNMENT

This section describes the relevance of APIs in the context of digital government. It then further explores the topic from three different angles: (i) how government APIs can support government goals, (ii) what the role of APIs is in public service provision and (iii) which API-related roles a government can take, with a specific focus on the API provider role.

Advances in digital technologies have sparked a tidal wave of transformation, transforming society and rewiring the interactions between each of its components. Governments are no exception in this transformational wave. The digital transformation has altered the relationship between citizens and governments. For instance, it has altered citizens' expectations of government performance, government interactions with citizens and public service delivery. In this context, the digital government objective is twofold. On one side, governments need to transform into robust digital ecosystems that are flexible enough to adapt to advances in technology and that are able to rewire the interactions among societal actors. On the other side, governments need to oversee the behaviour of digital environments and ensure societal well-being and stability (e.g. counteract technology-driven monopolistic behaviour and control the abuse of power due to information asymmetries).

APIs play a fundamental role in this transformation from both the **technical** and the **governance** perspectives (Bonardi et al., 2016; Briscoe et al., 2011; Huhtamäki et al., 2017; Iyer and Subramaniam, 2015a; Jacobson et al., 2011). On the technical side, API solutions provide digital environments with a high degree of flexibility (innovative potential) and virtually unlimited access to digital assets

> *APIs play a fundamental role in digital transformation of governments both from the technical and the governance perspectives*

> *APIs are boundaries where the interactions among digital actors are defined: what digital assets are exposed, to whom, under which conditions*

(digital ecosystem enabler). On the governance side, API solutions allow digital environments to modulate digital interactions. In essence, **APIs are boundaries through which interactions among digital actors are defined**: what digital assets are exposed to whom and under which conditions (Ghazawneh and Henfridsson, 2013). All in all, APIs technically enable (i) the creation of digital environments and (ii) the control and monitoring of dynamics among their actors. In this sense, the definition of API strategies is crucial for the development of digital ecosystems (Briscoe and De Wilde, 2009).

The relevance of the creation of resilient and competitive digital ecosystems is highlighted in current European strategy documents. For instance, under the its data strategy, the European Commission will 'explore the need for legislative action on issues that affect relations between actors in the data-agile economy' (European Commission, 2020a). Another example is the industrial strategy (European Commission, 2020b), which stresses the need for a 'partnership approach to the governance of industrial ecosystems' to cross-fertilise products and services among sectors. In this sense, the connecting role of APIs makes them a key factor in understanding how digital environments work and evaluating interactions among their stakeholders. This information can support the assessment of the robustness, resiliency and competitiveness of digital environments. Therefore, the understanding of API dynamics can inform policymaking to steer digital environments (e.g. infrastructure needs, capacity building, market incentives, market regulations, API-related challenges and opportunities derived from the pervasive deployment of IoT and AI applications).

From an organisation's perspective, APIs are policy-relevant technical enablers of the digital transformation of government, and the definition of API strategies can assist governments in steering the necessary organisational change management process. APIs can provide crucial information on the use of resources, actors and dynamics of digital interactions, and processes' performance, and can ultimately support budget allocation decision-making. This information is key to designing the transformational roadmap and ultimately improving government efficiency by means of (i) increasing the innovative potential of public service provision and (ii) enhancing policymaking by facilitating access to virtually any relevant information required in all phases of the policy cycle (policy design, implementation and monitoring).

2.1 | Application programming interfaces' support to government goals

The European Union aims to create a fertile environment that allows for inclusive growth, sustainable development and well-being. In this context, governments' policies, administration and public services should be designed to be human-centred and efficient, robust, secure, fair, transparent and accountable. Following this rational, this work has identified potential links between the adoption of APIs in governments and the achievement of these goals, in particular in terms of the following factors.

— **Efficiency.** Inherent features of API solutions, such as reusability and modularity, endow organisations with internal efficiency gains. These gains stem from the flexibility that APIs provide to create easily scalable interorganisational digital solutions. Efficiency gains are attained through the reduction of costs (e.g. avoiding data infrastructure replication) and by increasing efficacy (e.g. reducing response times, improving digital assets' quality or the functional reduction of errors due to increased validation capabilities). Moreover, APIs can help streamline government processes via innovation. Digital solutions that integrate different APIs can assess the efficiency of processes modularly. This information is key to understanding flaws and opportunities for improvement. The modular nature of APIs eases the re-engineering of the process. Examples of these efficiency gains can be found in Section 4.1.2.

In a broader sense, the adoption of APIs can lead to improved efficiency of the organisation itself. APIs allow the monitoring of what assets are accessed and who is accessing them. This demand-side information is crucial for designing solutions that best match real needs. In the context of government, the analysis of such demand information can provide enhanced fiscal footprints in the budget and, ultimately, support budget allocation management in a period of fiscal consolidation (for instance, government authorities in the Netherlands provide government spending data through APIs). These data could be combined with the reported usage of associated digital assets (with a level of granularity up to API modules) to justify budgetary decisions (e.g. which specific data or functionalities are most relevant) and thus channel funds towards them.

— **Accountability.** API solutions provide access to specific digital assets by stipulating a technical contract that defines what access is granted, to whom and how. Digital services may be composed of the integration of disparate APIs, potentially owned by different departments or even institutions. Making the full-service chain modular may imply that the accountability of actions can be well defined and compartmentalised. Coordination efforts are needed to orchestrate the accountability chain appropriately (e.g. through service-level agreements (SLAs) or terms of reference).

— **Inclusion.** A loosely coupled API landscape provides high flexibility in designing digital public services. Typically, the costs of adding customisation features to digital services are contained. In this sense, theoretically, digital service provision could be adapted to the specific needs of all citizens (i.e. user-centric design), ensuring no one is left aside.

— **Security.** An API is an open door that, if not properly implemented, might increase the vulnerability of a digital system. The resilience of a system of interconnected APIs is key and therefore the security dimension of relevant digital assets should be scrutinised and guaranteed. This has both social (in terms of stability, with the worst case scenario being a government shutdown) and economic implications, such as a significant increase in costs.

— **Fairness.** A direct link between the use of APIs and the achievement of equity in the distribution of public resources is not obvious unless indirect effects of specific applications are considered. Equitable distribution to public resources requires the identification of the usage of resources by the disparate social groups. APIs may facilitate this on the condition of the existence of digital assets that allow the correlation of usage with classification by social groups.

— **Sustainability.** API deployments rely on ICT infrastructures that have energy consumption (Roberts, 2009). API design should assess ICT infrastructures' energy footprint. This practice would facilitate the evaluation of environmental, social and governance metrics to analyse ethical impact and sustainability practices of organisations. There are already initiatives investigating this area, for example the Sustainable Digital Challenge launched by APIdays global, which is intends to identify the key principles and best practices of sustainable design, architecture and code to develop more sustainable software (APIdays global, 2020).

— **Transparency.** An API is a technical interface that provides access to digital assets. Therefore, an API is the technical means to provide access to open data and public-sector information in a machine-readable fashion. In this sense, providing access to public-sector information through APIs could facilitate the automation of the monitoring of government processes and therefore could contribute to institutional transparency goals. As an example, the Open State Foundation (OSF) integrates data provided through APIs by government authorities within the Netherlands to create a real-time visualisation of governments' spending.

— **Trustworthiness.** Digital services operated through a chain of APIs leave a digital trace of their use. Technical means can be put in place to trace who did what and when. Digitalised processes follow the logic of software procedures and are performed equally in all cases. The combination of the detection of unexpected anomalies in processes' flows and tracing back these anomalies to potential offenders, facilitated through APIs, may improve the trustworthiness of service provision. In Slovakia, for example, taxes collected from home-based tourist accommodations can be reconciled with tax income thanks to APIs and can potentially identify under-reporting and allow more accurate tax collection (Sidor et al., 2019).

2.2 | Application programming interfaces in public service provision

Public service is the operational realm of government. Public services are meant to facilitate interactions between citizens and their government. In the context of digital government, public service provision is expected to happen through digital channels. Technically, digital service provision by government does not differ from that provided by the private sector. Nevertheless, the objectives of public and private service provision do differ. Public services are meant to support socioeconomic well-being and stability, while private services aim to generate profit. In a way, the objective of public service provision resembles the concept of 'customer satisfaction' in supply chains, except that the customer is society as a whole.

Following the supply chain analogy, a public digital service is defined as the digital product resulting from the assemblage of different digital assets (data or functionality) provided by different intermediaries (internal or external to the organisation) so that the consumers (the citizenry) can satisfy their own needs regarding their interaction with the government (see Figure 4). In this context, **APIs are instrumental to the connective nature of public digital service provision**. In particular, APIs facilitate the connection between intermediaries (e.g. API and application developers) and also modulate the interactions between them (i.e. who can access what and under which conditions).

Also similar to supply chains, public digital service provision creates value by adding intermediaries, as intermediaries' assets can help to better address citizens' needs. From an organisational perspective, the more API-related intermediaries there are, the more flexibility there is to cross-fertilise and improve digital services. However, this also implies great coordination efforts among all actors involved. Along this line, Figure 4 illustrates the four actors embodied in digital service provision from an API perspective, namely, institutional bodies, digital service providers, intermediaries and the citizenry. The following paragraphs will describe each actor, explore their objectives and challenges, and provide an example.

An **institutional body** is any government entity (national, local or regional) in charge of organisational decision-making about public service provision. This actor should look for opportunities that maximise socioeconomic gains, ensure robustness of the digital system and improve its innovative potential, all within the public budget constraint. Table 1 lists potential policy options that institutions might consider for streamlining the adoption of digital solutions facilitated through APIs. An example of an institutional body is the regional administration of Regione Lombardia (Italy). Within this study, we have analysed the API

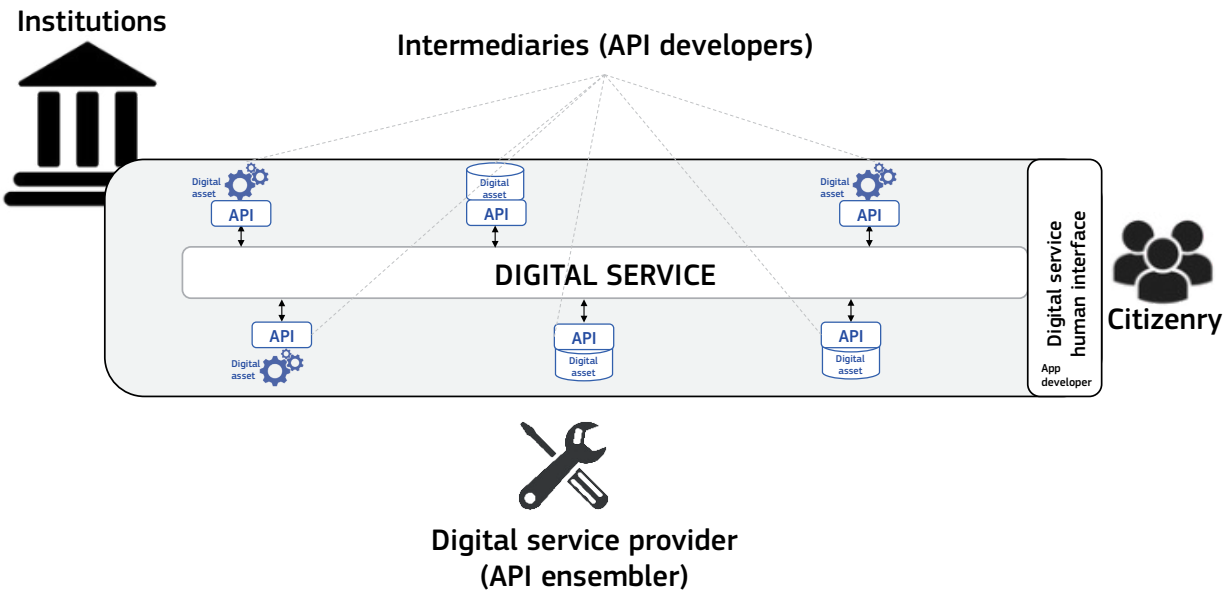


FIGURE 4: Actors of digital service provision.
Source: JRC, own elaboration.

Area	Policy options
Legal	— Legal acts — Amendments to current regulations
Financial	— Budgetary lines for service provision through APIs — API procurement workflows (externalisation) — Funding mechanisms (e.g. co-financing)
Organisational	— Setup of new agencies or governance bodies — Setup of new profiles in existing bodies — Setup of interagency committees
Technical	— Training programmes to upgrade skills of civil servants — Infrastructure requirements — Assessment frameworks — Guidelines and recommendations

TABLE 1: API-related policy options.
Source: JRC, own elaboration.

ecosystem of this institution and also collaborated with its representatives to implement a pilot project on the validation of the API framework illustrated in Section 5. Regione Lombardia coordinates 16 directorates that are in charge of implementing different policies (e.g. agriculture, employment, environment, mobility and transport, and tourism). At the time of writing, Regione Lombardia sets out, through regional legislation (Regione Lombardia, 2012) the obligation to adhere to the API-enabled digital ecosystem for data exchange. It has created a governance body 'E015' to orchestrate and foster the dynamics of the ecosystem and its participants (Regione Lombardia, 2020a).

A **digital service provider** is any government entity in charge of the design, implementation and operations of a digital service. This actor will pursue the optimisation of the efficiency of the processes of service provision. To realise this, the entity has to manage a number

> *"APIs are instrumental in public digital service provision for its connective nature"*

of organisational, financial and technical aspects. An example of a digital service provider is the environmental directorate of Regione Lombardia (see Figure 5), which is in charge of the air quality monitoring service. This public service entails the integration of data coming from both internal and external sources (e.g. air quality monitoring sensors, vehicle characteristics, industry emissions, traffic and meteorological data). The availability of APIs eases the exchange of these data. An example of a digital service built on those APIs is 'Move-in' (Regione Lombardia, 2020b). This digital service supports the implementation of the environmental policy on emissions by private vehicles. Move-in is concretely implemented as an application that allows the users of pollutant vehicles to drive a number of kilometres a year in restricted areas. The calculations are based on the type and environmental efficiency of the vehicle. Move-in is an adaptive solution that provides citizens with some flexibility to adapt to current environmental requirements without drastically disrupting their household income (e.g. by purchasing a new vehicle).

Intermediaries of the digital service chain can include API providers and application developers. These players might benefit from the reduction of costs (e.g. unneeded duplication of resources), from the improvement of the quality of their digital assets (based on usage insights and feedback loops), from becoming empowered and resourced

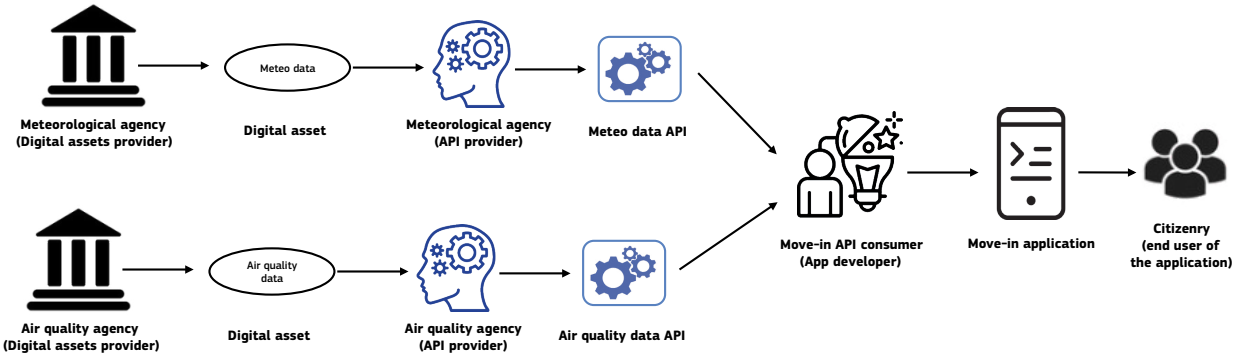


FIGURE 5: Move-in API system.
Source: JRC, own elaboration.

owing to the scalability demand and from increasing profits in the case of the private sector (G2B intermediary). However, these opportunities may bring risks, such as the exposure of internal inefficiencies, competition with other entities or increased costs to ensure security. Examples of APIs provided by intermediaries in the Move-in system are those that provide data from the meteorological stations (Regione Lombardia, 2020c) and those that provide data about the quality of the air (Regione Lombardia, 2020d). The app developer then developed the Move-in mobile application, which provides citizens with a user-friendly interface where they can find out the number of kilometres that are still available.

In turn, **citizens** are the end users that consume digital services. The citizenry could benefit from the overall increase in efficiency and from improved transparency and trustworthiness in the processes while facing potential exclusion owing to the digital divide or pressure through imperative demand of skill adaptation.

Understanding the objectives of all actors is key for modulating the interactions between them. In this sense, the adoption of APIs in the digital transformation of public services poses new organisation opportunities for the modular composition of APIs. There are multiple combinations of participants involved in the design of digital service chains. In this sense, digital service provision can be (i) **direct**, when entirely managed by and composed of government actors with no mediation of external participants (private or third sector), (ii) **indirect**, when managed by external participants, governed by public institutions and composed of a combination of internal and external participants, and (iii) **mixed**, when the management and composition of the digital provision is a combination of internal and external participants.

2.3 | Government roles in application programming interface-enabled digital ecosystems

The foundation of digital ecosystems is the interconnections between APIs. The inherent features of APIs, such as their reusability and modularity, increase the reach of digital assets both within and outside organisations (Iyer and Subramaniam, 2015b). Digital solutions are often composed of a highly flexible setup of APIs (Kane et al., 2015) involving several actors. Owing to this connectivity, the definition of API strategies is crucial for the development of a functioning digital ecosystem (Briscoe et al., 2011).

Governments can play different API-related roles within digital ecosystems, namely as ecosystem owners, ecosystem regulators or ecosystem active participants.

- As ecosystem owners, governments can technically and organisationally control the dynamics of their digital realms through the monitoring of their APIs.
- As ecosystem regulators, governments can use APIs to technically define (i) the terms under which digital interactions can happen in regulated environments and (ii) the metrics that the actors involved should report to allow for the control and monitoring of regulatory actions. Each of these actions has different financial, legal and organisational implications.
- As ecosystem active participants, government entities can play two of the roles identified in Figure 3 (i.e. API provider and API consumer, including application developer, digital service provider or API assembler, as illustrated in Section 2.2).

> *Governments can play different API-related roles within digital ecosystems: ecosystem owner and ecosystem regulator and ecosystem active participant (providers and consumers)*

In this section, we will describe in detail all of these roles and provide examples of their implementation, illustrating, in particular, the role that is the focus of this report, that is, governments acting as API providers.

2.3.1 Governments as ecosystem owners/controllers

Benefits of the setup of digital ecosystems have been documented. Specifically, benefits can be gained through direct internal efficiency gains (e.g. a reduction in error rates or in digital services' implementation time and costs) and through fostering organisations' innovation by exposing digital assets and profiting from internal and external complementarities (Bonardi et al., 2016). However, to realise these outcomes, the definition of flexible digital interactions is key to streamlining efficiency gains while guaranteeing the robustness and sustainability of the digital ecosystem. Steering the potential of API-enabled digital ecosystems requires strong strategic organisational coordination (Kane et al., 2015). A government can play the role of the owner of the digital ecosystem and thus modulate the digital interactions through the ruling of API dynamics.

As an example, the ICT department of Regione Lombardia (Italy) has adopted an organisational approach to the ruling of API-enabled digital ecosystems. Figure 6 illustrates the role of APIs within this approach (Regione Lombardia, 2020a). Specifically, Regione Lombardia has conceptualised the following aspects: (i) the legal context, namely regulatory incentive systems; (ii) organisational arrangements, namely actors, dynamics and responsibilities; (iii) financial aspects; and (iv) technical pillars, namely conceptual subenvironments, vertical (domain-specific) and horizontal digital blocks, and the marketplace for APIs. Disparate digital services are designed within the ecosystem in different policy-relevant domains: mobility, air quality monitoring, health, emergency responses and tourism promotion. Regione Lombardia stresses the unexpected innovative power that cross-fertilisation brings for both public service provision and public administration processes (Panebianco, 2019). Regione Lombardia describes its digital ecosystem as a living organism that evolves and learns from its own experiences.

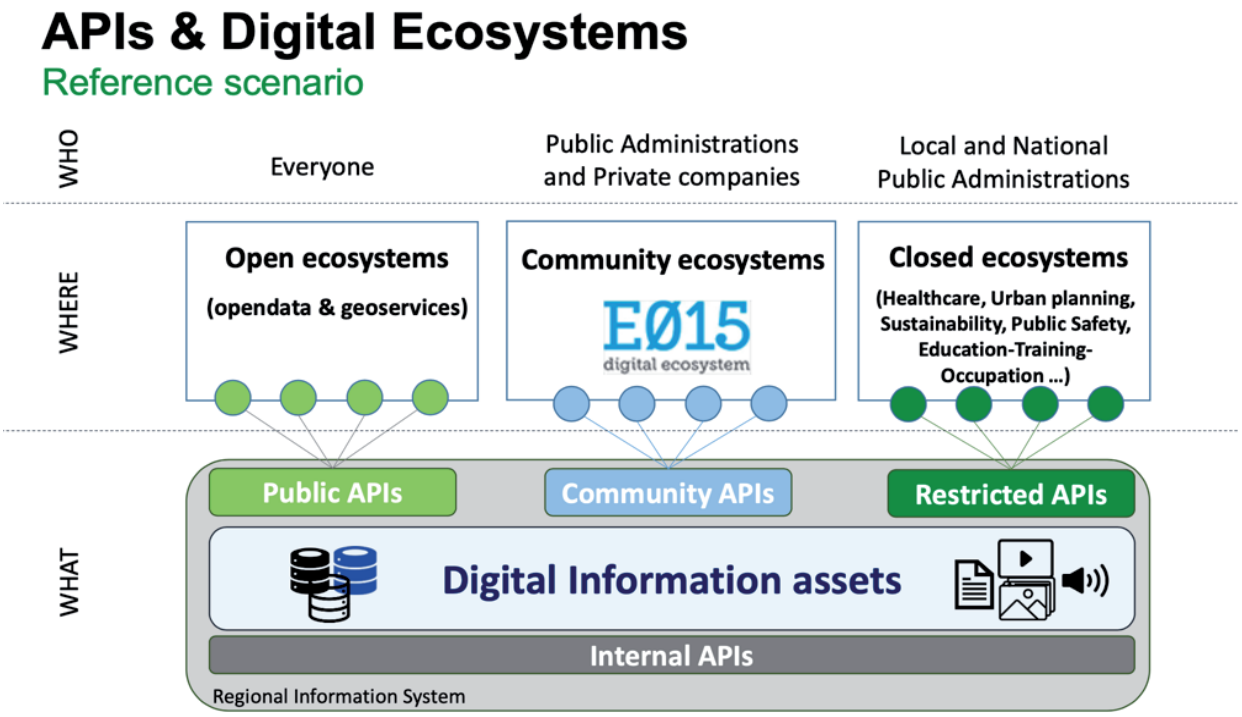


FIGURE 6: The E015 initiative.
Source: (Panebianco, 2019).

2.3.2 Governments as ecosystem regulators

The digital transformation of society entails the deployment of robust and resilient digital ecosystems. The governance of digital ecosystems is key to strike the balance between competition and collaboration among players within digital chains while ensuring system stability and societal gains. Governments are expected to monitor these environments and ensure that they contribute to the well-being and stability of the whole society they represent. An example of this role is the case of regulation of the banking sector, specifically under the second Payment Services Directive (PSD2) (European Union, 2018a). In this case, APIs have been largely adopted to implement PSD2 technically due to their flexibility and modularity. Another example is the Open Data Directive, for which the use of APIs has been suggested for all the datasets and stated as mandatory for 'high-value' and dynamic datasets (European Union, 2019a).

2.3.3 Governments as application programming interface consumers

APIs offer the possibility of accessing digital assets, such as data or functionality, in an efficient and effective way. The availability of a multitude of APIs endows organisations with high flexibility to utilise both internal and external digital assets. By acting as API consumers, government entities may incorporate external digital assets (G2G, B2G or C2G) into their process flows. In this sense, governments are more flexible to adapt to digital transformation by means of cross-fertilisation and the fostering of innovation in government process flows. The reuse of external digital assets could bring complementarity benefits such as a reduction in costs (see also Section 4.1).

For example, in the case of DAWA, one of our case studies (Williams, 2018), governments consume APIs from government sources (G2G). DAWA exposes data and functionality regarding Denmark's addresses, access addresses, road names and postcodes and is used to establish address functionality in IT systems. The target audience for DAWA APIs is developers who want to integrate address functionality into their applications/IT systems. At the time of our analysis, there were approximately 5 000 IT systems that collected data regarding Danish addresses using DAWA, many of which were other government entities that integrate DAWA digital assets into their processes.

Another example of governments consuming APIs, this time from external actors (B2G), is the consumption of Airbnb data by the Danish tax authority. Airbnb signed a collaboration agreement with the Danish tax authority to ensure that hosts on Airbnb can share their homes responsibly and enjoy new benefits: hosts can enjoy tax-free earnings up to DKK 28 000 for primary homes and up to DKK 40 000 for summer houses (compared with DKK 11 000 on non-data-sharing platforms. In return, Airbnb plans to start sharing earnings data on hosts who have a listing in Denmark with the Danish tax authorities for all bookings made as of 1 July 2019. The information shared will be subject to strict European and national privacy rules (Airbnb, 2019).

2.3.4 Governments as application programming interface providers

In this section, we analyse in detail the role of governments as API providers. We will define the different kinds of APIs that a government can publish, list the different types of consumers of these API providers and, finally, present the beneficiaries of these APIs.

API solutions can expose government digital assets and facilitate digital interactions with both internal (e.g. G2G intra-agency interactions) and external players (G2G interagency interactions and G2B and B2G extra-government interactions). In this sense, API solutions enable the creation of public-sector digital ecosystems. Depending on the different types of stakeholders involved, the ecosystem can develop internally or externally to the government agency that provides the API. In the former case, the ecosystem is built within a government entity (e.g. agency or department) or between different government entities. In the latter case, it may be wider reaching, for example between a government and another government or between a government, third-party provider or private company and a large number of developers. In any case, the APIs will define the interaction among the participants both technically and organisationally.

APIs can be classified by the type of access provided to different stakeholders. Different authors (Jacobson et al., 2011; Lacheca, 2016; Mehdi et al., 2018; Webster, 2018) agree on the categories, but not on how to name them. In particular, there is currently no agreement on the precise meaning and disambiguation of the terms 'private', 'public' and 'open'. A 'private' API can refer, for example, to an API provided by the private sector or to APIs used privately within an agency. A 'public' API can refer both to APIs provided by the public sector and to APIs that are publicly available on the web. An 'open' API can also refer to APIs publicly available on the internet or to published APIs that can be used without restrictions, as is the case for 'open data' (OpenKnowledge foundation, 2020).

For this reason, we adopt the classification of Williams (2018), but use the following terms to disambiguate the semantics of the different types of APIs for government and any other kind of organisation APIs:

FIGURE 7: APIs stakeholders and API types.
Source: JRC, own elaboration, based on Lacheca (2016).

— ***Internal APIs*** generally used to facilitate the sharing of data and services *between* systems within an agency, avoiding the need for complex point to point integration. They are not visible to any system outside of the agency that created the API and are generally in the domain of its IT department.

— ***External APIs*** designed to be accessible outside the agency boundaries, ranging from interagency interactions to the wider population of web and mobile developers. This means they may be used by developers both inside and outside agency.

Additionally, the access to organisation APIs can be *restricted* and *unrestricted* to the API consumers:

— **Restricted APIs** limit the access to the digital assets they provide to a number of authorized stakeholders.

— **Unrestricted APIs** do not limit the access to the digital assets they provide. Optionally, registration or the citation of the attribution of the APIs could be requested.

Depending on the stakeholders identified in Figure 7, APIs can be further classified into different categories.

— **Intra-agency system APIs** are used to facilitate the sharing of data between systems within an agency, avoiding the need for complex point-to-point integration. They are not visible to any person or body outside the agency and are generally in the domain of the IT department. An example is a link between an internal human resources system and a payroll solution.

— **Interagency system APIs** are available to other government agencies and allow them to share data only once they have been authenticated. This supports many of the core tenets of digital government, allowing agencies to collect data on a citizen only once, and then share it securely. An example may involve the sharing of citizen data between, say, the agency responsible for income and taxation and those providing benefits so that eligibility can be confirmed. Although not specifically mentioned in Figure 7, the ability to use APIs is not constrained by sector or geographical boundaries. These APIs could include, for example, an application-to-application link between governments of different Member States.

— **Partner service provider APIs** are open to partnerships perhaps in the private sector, which may include healthcare providers, for example, who in some countries are interested in sharing healthcare records or confirming eligibility for free or subsidised treatment based on data held by a government agency.

— **Commercial developer APIs** integrate data from several sources with commercial purposes. They create

business opportunities by 'mashing' the data (e.g. combining data on public transportation networks with location data available on an individual's smartphone to help the citizen make travel choices in real time). APIs make third-party integration of software and data easier and less problematic than not using them. Developers have access to the API at all times, so they can ensure that the two-way communication between assorted pieces of software is correct, rather than having to guess at the appropriate methods to use. It is also worth noting the economic stimulation that this can bring. For example, Transport for London's policy (ProgrammableWeb.com, 2019b) of working with major IT players (Google, Apple, Waze, etc.) but allowing their data to be available via the Open Government Licence has led to the creation of additional economic activity of the order of GBP 100 million of direct value and has enabled the creation of some 1 000 jobs (European Commission, 2017c).

— **At-large developer network APIs** do not require permission to access them. These APIs are the access point for developers to access large public data sources such as census information or other similar statistical data, including live sensor data from which to create citizen-facing applications.

Beneficiaries of government application programming interfaces

There are many beneficiaries of the government delivery of its digital assets with APIs. All sectors of society can benefit from more efficient government operations, reduced duplication and greater departmental collaboration (European Commission, 2020a). In this context, we have identified a number of target groups that can consume government APIs.

— **The internal agency/department that created the API.** Based on the implementation of the software three-tier/*n*-tier architecture best practice, known also as 'dogfooding', the main users of an API should be the creators. APIs should be used first by the internal government agency that created them. Thus, they are regularly monitored and understood from a user perspective. In addition, they will be aligned with need, to primarily create value for the internal agency. For example, a frequently updated dataset that is maintained by a government agency could be accessed via an API so that internal agency users share a single source of truth that can be trusted to always be the most current version of the database, rather than uploading and checking the version control of multiple copies of a dataset accessed by various staff members (Varteva, 2016).

— **Other government agencies/departments.** A second key user group generating high value from a government API would be other government agencies. Ideally, datasets and other assets should be shared across government (API-first model) rather than each agency creating its own dataset for the same domain. For example, many agencies across a government may need to liaise with schools and educational institutions. Typically, each agency creates and maintains its own schools' database and updates it as needed. In an API-first model, the education agency may create and maintain a standard database of all school and education contacts and other agencies would access this via an API in their systems (Thomson, 2015).

— **Other governments (tiers).** Within one nation, multiple tiers of governments need to use APIs from other government tiers. For example, national governments may have census data, demographic data and population projection data available via an API. City governments may need to use these data for their planning services and city plans.

— **Other governments (cross-border).** One of the key goals of European Union policy is to enable better sharing of data across borders (European Commission, 2017a). This is required in domains including tax, migration, tourism, trade, logistics, education, business registrations and personal healthcare records. Providing data on the movement of goods, people and money can best be managed using APIs to ensure that a single source of truth is maintained, that data can be updated in real time, that duplication in data entry (and therefore the potential for errors) is reduced, that exchanges can occur more efficiently and that mechanisms to protect the privacy and security of data are efficaciously adopted.

— **Industry.** Industry sectors can make use of government APIs. For example, weather data are

useful to many stakeholders in the agricultural industry. Also, ports' logistics data are useful to stakeholders in manufacturing, retail, transport and healthcare. Industry can also make use of key shared services available via APIs. For example, in Singapore, banks predominantly use the government's national identity verification APIs, which has sped up citizens' ability to open bank accounts and that of banks to approve loans to validated customers (Lee, 2019).

— **Business.** At the individual business level, the use of government APIs can help companies and small and medium-sized enterprises (SMEs) to speed up their processes, access relevant market information, communicate more effectively with government and generate more revenue. For example, businesses can consume government tax APIs directly in their book-keeping software so that their accounts are always in line with tax regulations, reducing paperwork and providing more certainty with regard to tax requirements. In turn, governments can reduce auditing costs and more effectively communicate tax regulations and rates (OECD, 2019a). For example, as detailed in Section 4.1.5, API-AGRO is an online data exchange platform based on APIs, namely a two-sided market that brings together data suppliers and data users. The API-AGRO platform gathers various data assets drawn from multiple data sources and for multiple purposes. At the same time, the platform gathers open data from administrative files concerning farmers and integrates open data APIs from the French ministry of agriculture and food published in the French national API portal (Government of France (DINSIC/DINUM), 2020a).

— **Non-profit organisations.** Non-profit organisations can use government APIs to better inform their constituencies, demonstrate demand, verify users and enhance their product features. For example, the Barcelona-based open-source technology provider Decidim uses a city plan API and government national identity verification APIs to create feedback and consultation platforms that can verify that individual users are citizens of the local government (Aragón et al., 2017).

— **Providers of services of public interest.** Such service providers (e.g. utility companies such as electricity and water supply) can use government APIs to identify service users, define service catchment areas, confirm eligibility and work with governments on providing holistic care. In New York City, service providers have requested access to the city's services catalogue via an API so that they can integrate service directories and eligibility criteria directly into their intake process. This reduces the likelihood of clients being asked the same questions and helps ensure that clients are provided with information for all of the services they are eligible to receive within a single process (Quaintance, 2019).

— **Researchers.** Academic institutions can access data and services directly from governments via APIs to enhance their models and research programmes. As governments increase investment in digital assets useful for AI and machine learning algorithms, and increase their use of IoT sensors for air quality management and for geospatial intelligence, researchers will need real-time access to data to partner with governments on evaluations, impact assessments, the uptake of technology and support policy (Glickenhouse et al., 2016).

— **Citizens.** Citizens will benefit from the use of apps and services that consume government APIs. Weather apps could make use of weather data provided by government APIs. Transport route planners and ticketing apps could consume government transport data APIs. An event-based life approach to provide government services will automate and proactively engage citizens at key life event stages (e.g. birth, educational attainment, marriage, business creation and retirement) and utilise APIs to trigger and automate communications on service access and citizen requirements (Smart Nation Singapore, 2020).

3

APPLICATION PROGRAMMING INTERFACE LANDSCAPE FOR GOVERNMENTS

SUMMARY

The European Commission has, in many ways and for a considerable time period, encouraged the adoption of digital technologies across the EU. This has included providing guidance and suggesting voluntary measures to foster the development of digital government and the adoption of APIs, in addition to adopted legislation in specific domains, such as the Open Data Directive, which makes the adoption of APIs mandatory for high-value and dynamic datasets, the Single Digital Gateway (SDG) Regulation and the INSPIRE Directive. The European Commission also reinforces the concept of data sharing via APIs through other policy documents, such as the communications *Towards a Common European Data Space* and *A European Strategy for Data*, and initiatives such as the EIF, the ISA[2] programme, the EU e-government action plan 2016–2020 and the building blocks of the CEF.

The adoption of APIs by governments in the European Union is still in its initial stages. We have currently identified, collected from heterogeneous sources and classified 219 government APIs available on the internet. The main finding of the preliminary analysis of a selected set of cases studied is that web **APIs strongly support the digital transformation of government** and that when API strategies and solutions are implemented (at least in certain cases and domains), their uptake is **rapid** and **extensive**.

A specific and comprehensive survey on API strategies, implementation projects and vision in European Union governments reveals that API strategies in Europe are rather new – the oldest having been implemented only in 2014 – and several are planned to be deployed within 2020. A workshop on the same topics has uncovered further elements related to API adoption in government. In particular, it seems that the current efforts are focused on making individual organisation's resources available, but little thought is being given to the more strategic elements related to the creation of an ecosystem of APIs.

This study has collected a total of 78 documents on web API standards and technical specifications that can be used for different purposes: to represent a digital asset and transmit it, document it, make it secure, evaluate its performances and share it with the right terms of use. This study also looked at emerging government best practices and guidelines from around the globe, with a specific focus on activities undertaken in the European Union. Over 3 900 links were found, scanned and analysed for their relevance to APIs. Of this combined pool of documents, 968 were reviewed and 343 were chosen as relevant for government API best practices. An analysis of the common approaches, a strengths, weaknesses, opportunities and threats (SWOT) analysis and a gap analysis of the documents have been used to build the basic EU API framework presented in this report.

3 APPLICATION PROGRAMMING INTERFACE LANDSCAPE FOR GOVERNMENTS

This section presents the current landscape of API adoption in governments as distilled from our research. In particular, we will tackle four perspectives, one political and three technical. In the first part of the section, we list European Commission initiatives, both legal and operative, that either support or regulate API initiatives in the European Union. In the second part of the section, we present the landscape analysis of API cases and strategies produced by the European Union public institutions. The list of API cases has been gathered from a series of resources, including API catalogues and directories, previous studies and internal activities within the study (workshops, surveys and case studies). The workshops and the survey on API strategies in the EU highlighted the essential elements we needed to identify government API enablers, drivers, barriers and risks. Next, we explore if Member States and leading-sector countries outside the EU are currently producing guidelines for digital government APIs. We also summarise the characteristics of the main standards, technical specifications and methodologies useful to design APIs at the technical level. In the final part of the section, we give an overview of the available literature on best practices for the adoption of APIs in government.

3.1 | Application programming interfaces in the European policy context

For a long time, the European Commission has been working on a series of initiatives and activities that deal with the digital transformation of governments and the adoption of APIs in governments. The aim of this section is therefore to provide some insight into these current regulations and initiatives; information has been gathered both from the available policy documents and literature and from a number of meetings, workshops and interviews with specific related working teams of the European Commission.

3.1.1. European Union legal instruments

Within the context of the digital transformation of governments, the importance of the use of APIs is highlighted in relevant European Union legal policy documents. In this section, we group these documents into those regarding the provision of data assets, those related to the provision of public services and those regarding the provision of digital assets in the geospatial and banking sectors.

Provision of data assets

The **European Commission Open Data Directive** (European Union, 2019a) provides a common legal framework for the European market for government-held data (public-sector information). This directive entered into force on 16 July 2019 and replaced the Public Sector Information Directive (Directive 2003/98/EC), dated 2003, which was subsequently amended by Directive 2013/37/EU. The new directive is built around two key pillars of the internal market, namely transparency and fair competition, and introduces substantive changes to the past legal text, especially linked to the use of APIs. In fact, even though the directive does not specify any particular API standard or technical specification, it mandates public organisations to make use of APIs to make their 'high-value' and dynamic datasets accessible. In particular, Article 5 ('Available formats') states the following.

— **The high-value datasets, as listed in accordance with Article 14(1) shall be made available for re-use in machine-readable format, via suitable APIs and, where relevant, as a bulk download.**

It also states the following.

— **Public sector bodies shall make dynamic data available for re-use immediately after collection, via suitable APIs and, where relevant, as a bulk download.**

> *"The provision of 'high-value' and dynamic datasets through APIs is mandatory to facilitate data reuse"*

The European Commission communication *Data, information and knowledge management at the European Commission* (European Commission, 2016e) recognises the need to act in the field of data management and data sharing. To facilitate the implementation of the communication, the European Commission has developed an internal digital strategy (European Commission, 2018b) with a supporting internal data strategy that aims to transform the European Commission into a fully data-driven administration. The aim is to develop an ecosystem consisting of a set of interconnected and interacting elements, and one of the basic building blocks is the use of APIs.

Regarding specifically the **data economy domain**, business-to-business (B2B) data sharing is reported by the European Commission communication *Towards A Common European Data Space* (European Commission, 2018a), which states that 'there is strong support from stakeholders for non-regulatory measures [regarding B2B data sharing], such as … fostering the use of APIs for simpler and more automated access to and use of datasets' and that the 'Support Centre for data sharing under the Connecting Europe Facility programme will put in place a set of measures to make it easier to share private sector data in addition to public sector data. It will offer know-how and assistance on data sharing by providing best-practice examples and information on APIs, existing model contracts and other legal and technical aspects'.

Moreover, the new communication *A European Strategy for Data* (European Commission, 2020a) reports on the **future investment in 'the establishment of EU-wide common, interoperable data spaces'** and states that

> *'the Commission will work on making more high-quality public sector data available for re-use, in particular in view of its potential for SMEs. In order to open up key public sector reference data sets*

for innovation, it shall start the procedure for the adoption of an Implementing act on high-value data sets (Q1 2021) under the Open Data Directive, ***making these data sets available across the EU for free, in machine-readable format and through standardised Application Programming Interfaces (APIs)****'.*

In particular, the communication requires both the public and the private sectors to join the efforts, and also explores the need for a 'data act' legislative initiative in setting up true European data spaces. This will allow the EU to create a single market for data and to unlock unused data, allowing them to flow freely within the European Union and across sectors for the benefit of businesses, researchers and public administrations. These data should be available to all, whether public or private, start-up or giant companies. Data spaces will require 'mechanisms for ensuring interoperability' and this will require the use of APIs. Indeed, APIs are an enabling technology that can allow this flow of data, ensure governance and access security considerations are embedded in that flow, and allow those data to be used in a variety of systems.

To protect the processing of personal data and on the free movement of such data, the European Union established the **General Data Protection Regulation (GDPR)** (European Union, 2016). The regulation is an essential step in strengthening individuals' fundamental rights in the digital age and facilitating business by clarifying rules for companies and public bodies in the DSM. As a novelty, the GDPR introduces the right to the portability of personal data, which will allow a customer to share the personal data that he/she has provided to a company with other companies with which he/she engages. The three key elements of the regulation are as follows.

1. **Consent.** For processing specific types of data, companies will be required to request specific, informed, unequivocal and, in some cases, explicit consent from its customers/users.

> *"The European Data Strategy envisages investment in the setup of common, interoperable data spaces. APIs will be technical enablers of these environments"*

2. **Data portability and the right to be forgotten.** A consumer can request that a company provide all the personal data that it has on him/her. These data should be transmitted in a structured, commonly used and machine-readable format directly to the other companies (at the request of the consumer) when technically feasible. The right to be forgotten entitles the data subject to have the data controller erase or block his/her personal data.

3. **Security and traceability.** For certain data processes, companies will be required to create certification mechanisms defined by law, aimed at reducing the legal risk and building up customer trust.

One aspect of the GDPR is that, if you have shared personal information with other parties, then you need to be able to provide a list of whom you have shared it with and ensure these other parties remove these data from their systems if requested to do so by the natural person to whom the data refer. In a digital ecosystem scenario, multiple stakeholders may also share personal information with third parties via APIs. Therefore, specific measures need to be implemented to log which parties have obtained the personal information. In addition, notification APIs might be supplied to the parties if the information needs to be corrected or removed.

Provision of public services

Government commitments to the **Tallinn Declaration** (Estonian Presidency of the Council of the EU, 2017) can be supported by the adoption of APIs in public service provision. This can enable governments to deliver high-quality, efficient, secure and user-centric digital public services for citizens, as well as seamless cross-border public services for businesses. Key areas to consider are the 'digital-by-default' and 'inclusiveness and accessibility' principles, supporting transformative actions such as user centricity, in general, and the consistent quality of digital public services and their users' experience, as well as working to increase the readiness of both businesses and

citizens to interact digitally with public administrations. The latter action may not only imply the use of APIs to support interaction but also the readiness of non-governmental actors to make use of those digital resources, including continued investment in digital skills for all involved and accessible digital services. Similarly, the Tallinn Declaration highlights the principles of 'trustworthiness' and 'security'. Here, public service design needs to consider security and privacy needs involving modern solutions.

As a response to the call made by heads of state during the Digital Summit in Tallinn, Member States committed to accelerating the OOP for key public services. The OOP means that citizens and businesses should supply information only once to a public administration in the EU, regardless of what Member State they are in. This is also part of the proposal for the SDG. The **SDG Regulation** (European Union, 2018b) is a regulation that aims to eventually allow citizens and businesses to benefit from fully electronic public services in a cross-border manner by the end of 2023 for 21 procedures. This will require some fundamental changes to how information about public services is exchanged and made available publicly. The European coordinator of the SDG has to collect the descriptions of public services from European public administrations in one unique portal; the collection would be automated to prevent problems caused by human error and to eliminate the need for manual updates. Member States and the Commission should aim to provide links to a single source of the information required for the gateway to avoid confusion among users as a result of different or fully or partly duplicative sources of the same information. To minimise human intervention in the updating of the links to be used by the common user interface, a direct connection between the relevant technical systems of the Member States and the repository of links should, where technically possible, be established. 'The information included in the repository of links should be made publicly available in open, commonly used and machine-readable format, for example by APIs, to enable its reuse' ([4]). The common ICT support tools could use the Core Public Services Vocabulary, which publishes its APIs to facilitate interoperability with national service catalogues and semantics (European Commission, 2019c).

Application programming interface regulation in specific domains

For the geospatial domain, the European Commission aims to create, with the **INSPIRE Directive** (European Union, 2007a), a European spatial data infrastructure for the purposes of EU environmental policies and policies or activities that may have an impact on the environment. To ensure that the spatial data infrastructures of the Member States were compatible and usable in a community and transboundary context, the INSPIRE Directive required that common implementing rules be adopted in a number of specific areas, including for specific web services. Recently, some proposals have been published to adopt APIs and map them with existing INSPIRE web services to exchange geographical feature datasets (Lutz et al., 2019) and geolocated sensors (Kotsev et al., 2018).

In the case of the banking sector, the European Union introduced in 2007 the **first Payment Services Directive (PSD)** (European Union, 2007b), which regulated the information requirements, the rights and the obligations of payment service users and the requirements of payment service providers for entering the market. In 2015, a revised version of the **PSD (PSD2)** (European Union, 2015a) introduced several changes, of which the most relevant, for the scope of this report, was the introduction of third-party actors in the payment service market. It establishes that 'account servicing payment service providers such as banks, shall allow third parties to obtain real-time data relating to customers' accounts as well as provide access to such accounts by executing payment orders initiated through digital interfaces, on condition that customers give their explicit consent and that the account is available online'. Fintech companies are largely adopting API solutions in the implementation of PSD2 solutions and there are a lot of standardisation efforts ongoing in this domain, which is pivotal for the implementation of the directive. As well as public-sector organisations being customers or even potentially third-party providers, it is possible that some technical advances in this sector could lead to solutions for reuse in the public sector (Astore, 2018). At the technical level, PSD2 is supported by regulatory technical standards that include an API definition to help enable interoperability among banks and third parties (EBA, 2017).

3.1.2. European Union policy provisions

One of the actions of the e-government action plan 2016–2020 requires the European Commission to 'Present a revised version of the European Interoperability Framework (EIF) and support its take-up by national administrations'. The **EIF** (European Commission, 2017a) supports increased ICT-based cooperation between Member State organisations. In particular, focus area 4 ('Develop, maintain and promote key interoperability enablers') of the interoperability action plan highlights the need to define components for enabling the exchange of content between public administrations, businesses and citizens through a common approach for better (end-to-end) quality public services. Indeed, implicitly, APIs play a fundamental role in enabling the exchange of this content.

The implementation of the EIF is mainly supported by the **ISA** programmes (European Commission, 2017d). The last ISA^2 programme entered into force on 1 January 2016 with the aim of supporting long-standing efforts to create a European Union free from electronic barriers at national borders (European Union, 2015b). ISA^2 facilitates cross-border and cross-sector interaction between European public administrations, businesses and citizens, enabling the delivery of electronic public services and ensuring the availability of common solutions, enabling them to benefit from interoperable cross-border and cross-sector public services. The ISA^2 programme has launched many actions that are relevant to the adoption of APIs in governments. The team responsible for the ISA^2 'catalogue of public services' action (European Commission, 2018c), for example, has recently conducted a study on APIs (European Commission, 2019d) that encourages public administrations to define the data models supporting the public service implementation by following the Core Public Service Vocabulary Application Profile data models. These data models should be used to design the APIs that share these data and are used to access the EU *Catalogue of Services* (European Commission, 2018c).

Another relevant ISA^2 initiative addresses the Innovative Public Services project (European Commission, 2018d). This action aims to provide support for identifying the innovation potential and conditions of emerging disruptive technologies such as blockchain and distributed ledgers, AI- and IoT-related infrastructures, or technological solutions and platforms already mature in the private sector such as APIs, to better assess their impact, namely if they lead to more efficient and improved public services, as well as improved interactions between governments, citizens and business.

A further action of the e-government action plan 2016–2020 requires the Commission to be 'using the common building blocks such as CEF DSIs [digital service infrastructures] and follow the EIF'. The **CEF** funds a set of generic and reusable digital service infrastructures (DSIs), also known as 'building blocks' (European Commission, 2020e). The CEF building blocks offer basic capabilities that can be reused in any European or national project to facilitate the delivery of digital public services across borders and sectors. Digital building blocks have been created to help teams deliver digital public services faster, comply with regulation and make the DSM a reality. They include basic capabilities ([5]) that can be reused in any project to facilitate the delivery of digital public services across borders and sectors. Some of the building blocks use APIs and expose them to let third parties participate in the digital ecosystem enhanced by the building block (see also Section 3.1.2). These building blocks include the big data test infrastructure, a context broker, e-delivery and e-translation.

Recently, a set of pilot studies were developed to explore how CEF building blocks can support the **OOP** (European Commission, 2017b), which is also a core principle of the e-government action plan 2016–2020. According to this principle, citizens and businesses should be able to provide information once and have those data shared and reused with other public administrations. Communication with the government is, in many cases, compulsory for both natural and legal persons (e.g. declaring taxes, requiring a permit to operate in a specific field or applying for a social benefit). When the specific data are not in possession of a given authority, the public authority has two options: either request the information required from the person themselves or enable the application of the OOP. Efficient data sharing within the public sector would cut costs for citizens and public administrations (European Commission, 2017e), and APIs can greatly facilitate both OOP data sharing and the creation of interoperable digital services.

The EU-wide application of the OOP is also one of the pillars of the strategy for the DSM and one of the basic principles of the EU e-government action plan 2016–2020 (European Commission, 2016b). **The OOP Project** (TOOP) aims to explore and demonstrate the OOP across

borders while focusing on data from businesses. TOOP led to the creation of a solution architecture that connects 40 information systems using CEF building blocks, including e-delivery, e-signature and e-identification. To highlight this, TOOP's service design requirements are based, where possible, on the reuse of building blocks that have proven effective in cross-border interoperability environments. To implement TOOP architecture, both the data provider and the data consumer must use the **TOOP connector**, a software component that implements the full process of the message exchange in TOOP. Message exchange with the TOOP connector has to be performed via representational state transfer (REST) APIs (TOOP, 2018).

Under the CEF programme, the European Commission has also established a **European Support Centre for Data Sharing** to help organisations share and access data including through APIs. The scope includes both public and private organisations and focuses on two main activities. The first is a 'data-sharing practice observatory for collecting existing experience in data-sharing and developing original research on legal and technical aspects of data sharing'. The second is a 'helpdesk and feedback service … supporting practitioners while capturing the richness of their experience in the field, and offering it back to the community'. The activity also aims to develop public awareness and promote tools and services for generating economic and societal benefits. Moreover, the centre is active in organising specific API training modules (Support Centre for Data Sharing, 2020).

A quite recent activity supported by the European Commission and the Committee of the Regions, and promoted by many stakeholders and network of cities, is the '**join, boost and sustain**' declaration. The main purpose of the declaration is to scale the development of urban platforms and digital solutions in a coordinated way to maintain European cities' and communities' technological sovereignty. Within the initiative, the *Consolidated report of technical specifications to scale Living-in.EU*, referenced in the declaration, indicates in its high-level architecture framework model that APIs can enable both southbound and northbound interoperability (European Commission, 2019e).

Indeed, APIs are one of these key interoperability enablers, as they provide tools for faster and more efficient processing of data within public administrations; efficient public services can result in significant cost savings or the development of new kinds of services at the same cost.

3.1.3. Main conclusions from the analysis of the policy context

In the previous sections, after an introduction of the overall digital government context, we have listed the main policy initiatives in the European Union that enforce, support, enable and implement the digital transformation of governments and the sustainable and strong digital economy in Europe. Where needed, we have identified where these documents are associated with the adoption of APIs in governments and how this adoption could support reaching the goals proposed in the documents.

From the analysis of these documents, we observe that APIs are explicitly mentioned by the most recent policy legal instruments (European Union, 2019a; European Commission, 2020a). In many cases, these documents require the mandatory use of APIs to implement their specific goals. However, the implementation instruments, such as programmes and activities, identified in Section 3.1.2 still rarely explicitly mention the adoption of APIs in governments. This might mainly depend on the recent formulation of the policy and legal instruments and the necessary time to reach the implementation phase of these policies.

Following the trends illustrated in the next sections, API adoption in governments will possibly explicitly be sustained by the next policy provisions, under the next **digital Europe programme** (European Commission, 2018e) ([6]). As we also propose in Section 5 and recommend in Section 7, this could be the best time to adopt APIs across the whole European Union in a uniform, consistent and coherent way.

3.2 | Government application programming interface adoption

In the previous section, we have reported about the policy setting of the API adoption in European Union. The goal of this section is to go more in depth and check where and how APIs have been concretely implemented in the public sector. In the first part of this section we present our results about found government API cases, focussing in particular on the European Union statistics. Then, we present our analysis of the API strategies we have gathered with different research methodologies and activities: A multiple-case study on seven specific government API cases, a workshop and a survey on government API strategies in the European Union. Finally, we summarize our main conclusions.

3.2.1. Government application programming interface cases

Government API cases are exposed by governments in different ways, formats and standards. For this reason, it is currently difficult to find automatically government API cases published on the web. Indeed, since the beginning of the study, we have been investigating the best methodology to collect them in an automatic and systematic way. Unfortunately, we soon discovered that, to date, this is not so easy. In fact there are not well-identified API catalogues where such cases can be found and filtered. In addition, as APIs are not websites, there is not a dedicated web search engine for them. Research has been conducted by IBM in a project called 'API harmony' (Wittern et al., 2016) but the project was recently discontinued. There are also some individual API experts (Lane, 2019) and companies' initiatives that have investigated building API search engines, but they rely on their own API collected databases (APIs.io, 2020; ProgrammableWeb.com, 2020a) and/or are run on specific types of APIs (APIs.guru, 2020).

To gather and analyse the API government cases that could support our research, we identified and used a specific number of sources, including API registries and past API initiatives. We also organised a workshop and launched a survey on government API strategies, from which we collected the cases of the participants and contributors. This list of sources includes:

— the ProgrammableWeb API directory (ProgrammableWeb.com, 2020a);

— a list of API endpoints collected within a survey performed within the e-government action plan steering board members (European Commission, 2016f);

— the database of 395 cases taken from the study *Towards faster implementation and uptake of open government* (SMART 2015/0041) (European Commission, 2016g);

— the news web page provided as part of the DSM initiative entitled 'Open eGovernment practices in all EU Member States make public services more collaborative, efficient and inclusive a useful list of relevant endpoints' (European Commission, 2016h);

— the European Union open data portal (European Commission, 2020f);

— the European Data Portal (EDP) (European Commission, 2019f);

— the INSPIRE data catalogue (European Commission, 2020g);

— the research activities of the study listed in Annex 2.

Starting from the cases gathered from these sources (approximately more than 1 000 cases), we have verified and selected only those cases related to government APIs, and perform a landscape analysis.

From our early analysis of the ProgrammableWeb directory, the API adoption in governments has grown steadily since 2012. However, the observed adoption of APIs in government in the European Union is still scarce and uneven. Figure 8 shows the number of web API records that have been registered since 2005 until the first quarter of 2019 in ProgrammableWeb.com, a primary community resource for amateurs and professionals in the API industry. This resource maintains a directory of information about publicly accessible API endpoints that developers themselves self-declare and enrich. In August 2019, this directory listed 21 202 records, of which only 417 (~2%) had been categorised as 'government' (primary keyword).

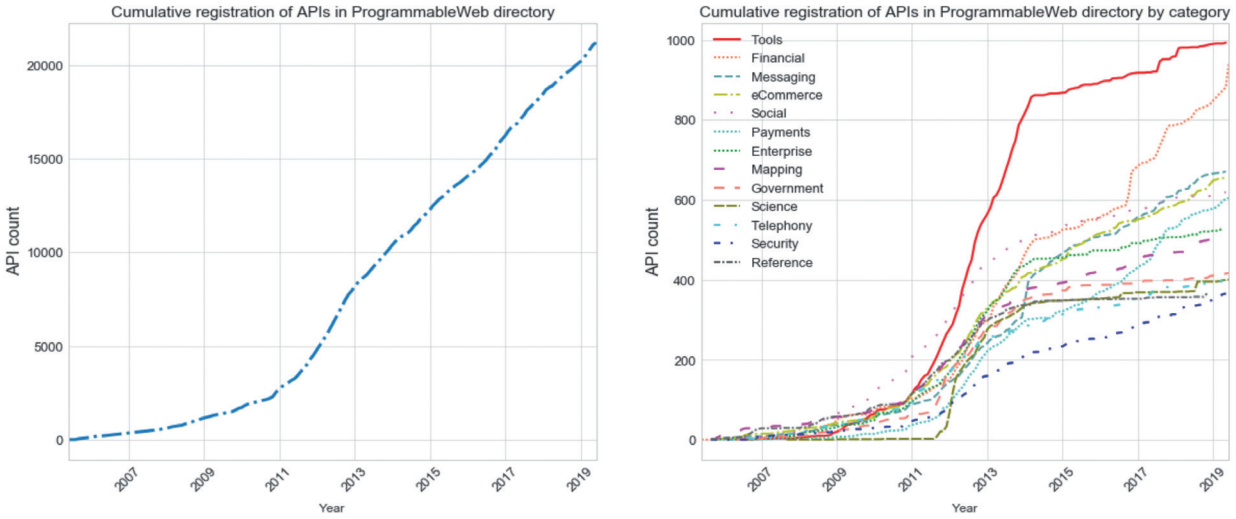


FIGURE 8: Adoption of web APIs.
Left panel: cumulative count of the number of web APIs reported. Right panel: cumulative count of the numbers of the most common APIs by category.
Source: JRC, own elaboration, based on ProgrammableWeb.com (accessed in June 2019).

An indication of the purpose of the API is found in the information about its category, as listed in the directory. Table 2 lists the most frequent categories ([7]) among the API records registered. Among the top categories are the financial and e-commerce categories, as well as the payments and enterprise categories. The right panel of Figure 8 also shows that the trends in the number of records of APIs registered in the payments and financial categories increased after the publication of PSD2 (European Union, 2015a), which might have influenced the development of this trend. Finally, we highlight that the government category ranks among the most frequent categories of records.

From the analysis of the ProgrammableWeb cases and of the other sources, we have identified 219 cases collected from the European Union Member States, the United Kingdom and the European Free Trade Association (EFTA) countries (Vaccari, 2020). The API cases belong to different categories of APIs, each of them giving access to a different type of API digital asset.

— **Specific API.** This is a unique API built for a specific purpose that gives direct access to data or functionalities. It can have many endpoints or methods (see an example in Box 1).

— **API registry.** This is a list of APIs grouped in a catalogue, registry or directory.

— **Data catalogue API.** This is an API published to access the metadata of datasets (i.e. giving 'indirect' access to datasets), normally exposed by a government (open) data catalogue.

— **API platform.** This is a platform that supports the use of APIs.

Rank	First category	Number	Rank	First category	Number
1	Tools	993	11	Telephony	398
2	Financial	944	12	Security	366
3	Messaging	671	13	Reference	366
4	E-commerce	657	14	Search	346
5	Social	619	15	Email	346
6	Payments	605	16	Video	340
7	Enterprise	528	17	Travel	321
8	Mapping	510	18	Education	311
9	Government	417	19	Sports	303
10	Science	401	20	Transportation	292

TABLE 2: Most common categories of registered web APIs.
Source: JRC, own elaboration, based on ProgrammableWeb.com (accessed in June 2019).

— **API tool.** This is a tool used to manage APIs.

— **API standard.** This is a set of standards related to government APIs normally published by a public-sector institution ([8]).

Table 3 shows the distribution of the API cases by country and by administrative level (city, international, national and regional levels) and the total number of cases for each country.

We have also identified a number of APIs that are not specifically linked to any country, but have been published by the European Union (42 cases) or by international communities active within the European Union or EFTA countries' boundaries (15 cases). Box 1 illustrates the example of Europeana, an initiative of the European Union that gives access to thousands to European archives, libraries and museums to share cultural heritage for enjoyment, education and research (European Union, 2020a).

Country	City	Internat.	National	Regional	Total
Austria			2		2
Belgium	2		4	5	11
Bulgaria			2		2
Croatia			1		1
Cyprus			1		1
Czechia			7		7
Denmark	1		9		10
Estonia		1	4		5
Finland	6		4		10
France	3		6		9
Germany	5		4		9
Greece			5		5
Hungary			1		1
Iceland			1		1
Ireland	1		4		5
Italy	2		5	4	11
Latvia			2		2
Liechenstein			1		1
Lithuania			1		1
Luxembourg		1	2		3
Malta			1		1
Netherlands	4	1	8		13
Norway			2		2
Poland			4		4
Portugal			2		2
Romania			1		1
Slovakia			2		2
Slovenia			1		1
Spain	5		2	5	12
Sweden	1		3		4
Switzerland			1		1
United Kingdom	4	1	20		25

TABLE 3: API cases by country.
Source: JRC, own elaboration based on Vaccari (2020).

Box 1.
A specific API example: European Union cultural heritage – Europeana APIs

Europeana collections are an initiative of the European Union, financed by the European Union's CEF and the European Union Member States. The Europeana collections contain over 50 million cultural heritage items, from books and paintings to 3D objects and audiovisual material, that celebrate over 3 500 cultural institutions across Europe. Europeana offers sophisticated search and filter tools to help the user find what he/she is looking for.

Europeana also offers APIs. The Europeana REST API allows a developer to build applications that use the wealth of Europeana's collections drawn from the major museums and galleries of Europe.

Over the past couple of years, the Europeana REST API has grown beyond its initial scope, as set out in September 2011, into a wide range of specialised APIs. At the moment, Europeana offers several APIs that can be used to not only get the most out of Europeana but also to contribute back to the initiative.

It is possible to use the Europeana APIs in a simple way (e.g. to request all results for the word 'cat') via the 'Search API' function. However, it is also possible to delve into the structured metadata of Europeana (e.g. to ask for all the French 18th-century painters with at least five artworks available through Europeana) via a sophisticated SPARQL Protocol and Resource Description Framework (RDF) Query Language (SPARQL) service (W3C, 2013).

To obtain all of the information (metadata) associated with a single item, the 'Record API' function can be used. It also possible to obtain a larger amount of metadata and to ultimately harvest the complete Europeana repository by using the Open Archives Initiative Protocol for Metadata Harvesting (OAI-PMH) service. Regarding contextual information that is associated with items, Europeana also offers an 'Entity API' function that gives access to information such as topics, persons and places. Finally, it is also possible to contribute information about the items that are available on Europeana via the 'Annotations API' function.

Figure 9 shows the number of APIs classified for each type of API. The majority of them are 'specific' APIs (i.e. those that have been created for a specific purpose in government). In this group, we included APIs as they are intended in the 'traditional' way (i.e. an endpoint or a group of endpoints that let developers find a web URL that they can use to build their applications). Figure 1 shows an example of specific APIs of DAWA (Denmark).

APIs for 'data catalogues' represent a consistent and important way to access information ('metadata') that describes digital assets (normally open data) published by governments. A high number of APIs have been published to access datasets published in government data catalogues, which provides final users with an opportunity to search for, find and access these digital assets ([9]). Some of these catalogues, such as the European Union Open Data Portal (see Box 2) and the INSPIRE catalogue, let a developer search among thousands of datasets via APIs.

API 'registries' include various ways to publish a grouped set of APIs (e.g. by institution, theme or standard). API registries can be published as a simple list of endpoints or as an API catalogue (i.e. in a more structured and documented way). An example at the national level is the French API catalogue (see Box 3), whereas an example at the regional level is the E015 website of Regione Lombardia (Italy) (Regione Lombardia, 2020a), which also provides a set of guidelines for the publication of APIs for all the public institutions at the regional level (Regione Lombardia, 2020e).

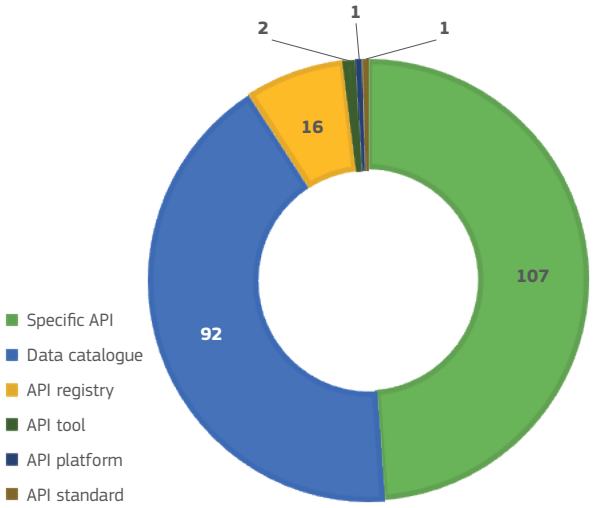


FIGURE 9: Types of APIs in analysed API cases (N=219).
Source: JRC, own elaboration, based on Vaccari (2020).

Figure 10 shows our classification by theme. API registries and APIs that grant access to data catalogues have been classified as 'various', as they give access to a number of heterogeneous APIs related to many domains. Geospatial APIs are normally made available by the geospatial catalogues (mainly retrieved from the INSPIRE geocatalogue), while government APIs are normally APIs that have been published by governments to give access to a service such as budgeting or administrative registries. A number of APIs have been published for companies' registries under the theme 'business' and on the transparency of government politics (e.g. on the activities by politicians) under the theme 'politics'.

Box 2.
APIs for the European Union Open Data Portal

The European Union Open Data Portal (EU ODP) aims to encourage the use of EU datasets for building third-party applications. To help achieve this, two APIs are proposed to be used by developers to search for datasets: a REST API and a SPARQL endpoint.

All the portal core functionalities (e.g. the dataset search functionality) are available through the REST API, which encompasses most of what a human user can do with the web interface. The information retrieved can then be used by an external code to transform, update or reference and provide new input for further calls to the API. Specifications of the new API are published in OpenAPI Specification (OAS) format and the description file, in OAS format, is also available for download in YAML Ain't Markup Language (YAML) format.

The SPARQL endpoint allows queries on the RDF descriptions of datasets. A graphical user interface is provided to enter your SPARQL queries. The models used to describe datasets catalogued on the EU ODP are described on the 'Linked data' page under 'Metadata vocabulary'.

Box 3.
The French national API registry

France scores among the top three countries in the European Union in terms of overall open data maturity and is one of the three trend setters in Europe (European Commission, 2019g). At the national level, France offers an API register that essentially gathers all of the APIs of the administration into a single portal with similar documentation. The API listing – administered by the Direction interministérielle du numérique et du système d'information et de communication de l'État (DINSIC) – contains information on technical and functional descriptions of each API, its access conditions and particularly the documentation of the interface of the API (Government of France (DINSIC/DINUM), 2020a). The API registry is part of the French national API strategy, which also includes the FranceConnect platform, which provides users with a trusted identity based on one of their existing accounts at the national level. In brief, the French API strategy includes the following elements (European Commission, 2018f):

— the development of APIs in each French administration and the gathering of every API description in the national catalogue;
— the development in each French administration of the use of existing APIs by facilitating onboarding of new service providers to consume existing APIs;
— the development of the FranceConnect platform, which provides a secure way to exchange information between FranceConnect service and data providers.

The API registry is not the same as the open data portal (DINSIC, 2020), which lets users access its datasets and services. The portal aggregates open data from all of the central administration entities, operating as a platform matching users and data providers. Each entry in this directory is accompanied by complementary assets such as documentation and often a showcase of potential reuse from third parties.

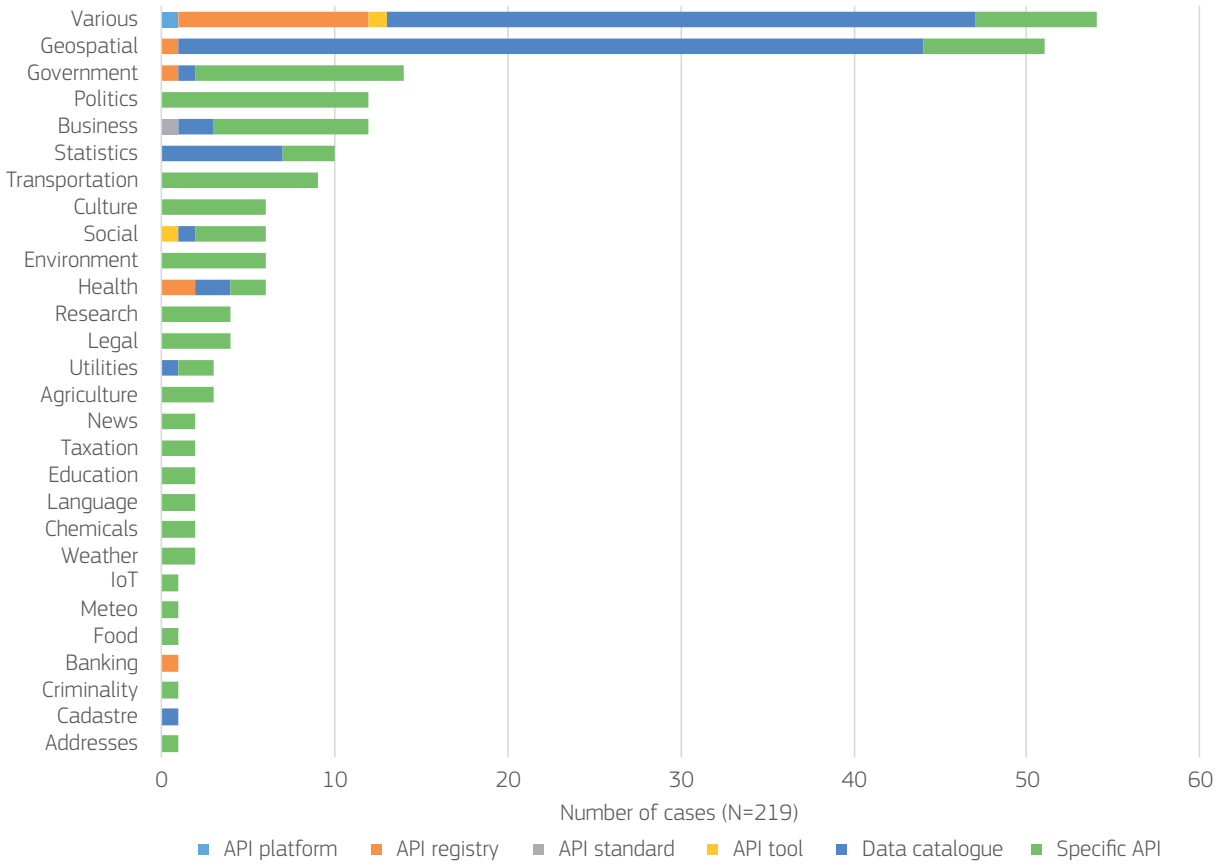


FIGURE 10: APIs classified by theme.
Source: JRC, own elaboration, based on Vaccari (2020).

The analysis of the cases concludes that, at least for the APIs publicly available on the web, government APIs in the European Union are still in an initial stage (i.e. the number of cases is relatively low). However, if we look at the cases of specific API initiatives, and exclude the horizontal domains (e.g. geospatial, government, business and statistics), the sectors that have developed more APIs include transportation, culture, environment, health, agriculture, utilities, taxation, education, chemicals and weather.

3.2.2. Key enablers, drivers, barriers and risks

This section presents our findings on the drivers and enablers of, and barriers to, the provision and roll-out of API strategies in governments. We also assess potential risks and mitigation actions for the public sector, society (e.g. not protecting individual rights) and business (e.g. monopolistic practices). These findings are the result of our analysis based on the case studies (Williams, 2018), the survey and the workshop activities, which are briefly presented in Annex 2. All of the sources provided rich information for the evaluation of the government API scene in Europe. We used these elements to provide an initial set of documents for the analysis of API best practices and to perform our analysis of why and how governments should adopt APIs (see Sections 4 and 5).

Key enablers

The survey explored the main enablers for API systems' adoption in government. Figure 11 depicts both the enablers identified in already functioning API strategies and those predicted as part of API strategies under design. The enablers evaluated fall into three groups, namely organisational, budgetary and technical.

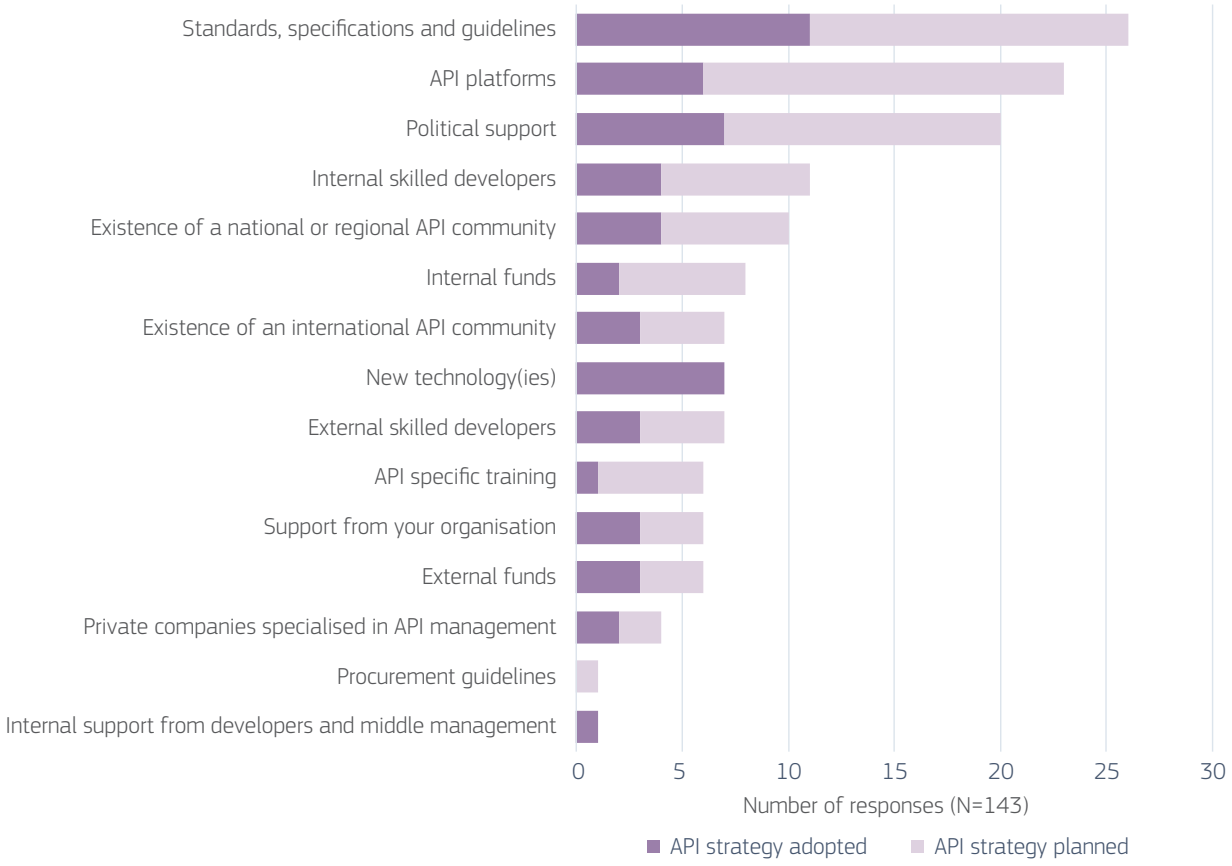


FIGURE 11: Key enablers for API strategies.
Source: JRC, own elaboration, based on the study survey results.

> *Multi-stakeholder and multi-level cooperation, political support and the existence of API development communities emerged as organisational API enablers*

— Regarding the organisational perspective, both in the survey and in the presentations and discussions during the workshop, **the multistakeholder and multilevel cooperation requirements for successful API solutions emerged as a key enabler**. Along this line, several governance initiatives were introduced, such as (i) dedicated governmental entities to coordinate and orchestrate digital strategy issues at the national level (e.g. the Government Digital Service in the United Kingdom, DINSIC in France, the Malta Information Technology Agency in Malta and the Digital Transformation Team in Italy), (ii) a multiagency cooperation board to steer governance and coordination of e-government services (e.g. the governance and coordination of e-government services (SKATE) in Norway) and (iii) stakeholder networks sharing the same kind of challenges, such as smart city network initiatives (Interreg North Sea region, 2019; OASC, 2019; 6Aika, 2019; Synchronicity, 2019; European Commission, 2018f).

  Enablers for API adoption, at a high level, included **political support and potentially legislation** (although these were not necessarily API specific). In more operational terms, capacity building was again highlighted, as were suggestions that organisations should define a business case for their APIs and that success stories from opening up data should be shared. Another enabler identified was the **existence of API development communities as a living ecosystem around the APIs**. In addition, political and organisational support was considered rather relevant as an enabler in actual API systems. The **availability of appropriate qualification profiles, both within and outside organisations, was recognised, and the lack of them was seen as a threat**. During our workshops, participants requested specific actions to (i) update education curricula to include development skills to fulfil upcoming demand in general and (ii) evaluate the internal needs and definition of roles in public administrations.

— From the budgetary perspective, **the availability of funds (both internal and external) was acknowledged as an enabler, although surprisingly not as one of the most relevant**. **EU initiatives and funding were also identified to help in API systems**, especially in terms of supporting experience sharing among stakeholders. In addition, one respondent suggested the availability of procurement guidelines as a means to streamline the adoption of API solutions.

— From the technical perspective, the most acknowledged enabler was the **availability of standards, specifications and guidelines**. Standards were also discussed during breakout sessions of the workshop. Some participants requested API common building blocks, specifically with specifications and sample software implementations. Some argued that standards and regulations were slow processes that impeded governments in keeping pace with technological advances and, therefore, with social expectations. **There was consensus that the identification of patterns of when to apply different standards for what purposes was an enabler.** In particular, examples and API generators (e.g. OpenAPI specifications (OAS) or RESTful API Modeling Language (RAML)) were highlighted as useful, as were testbeds, demonstrators and good documentation, which can make it possible for developers, in particular, to try out APIs, alongside tools and open-source code that could help create an ecosystem of APIs. Participants focused on how organisational contexts within standards and guidelines were important for their use. They also noted that many standards and tools are in place to offer 'something' as a service on the web (e.g. REST, JavaScript object notation (JSON), Security Assertion Markup Language (SAML), CEF e-Delivery, Future Internet Ware (FIWARE) and OAuth). Lower levels of ICT maturity in the Member States can often lead to adoption of a lower level entry architecture, which may have an impact on innovation (e.g. for APIs in the context of the OOP). In addition, it was suggested that solution reuse is less attractive for managers' careers, than building large-scale solutions, for which praise can be earned.

Other technical aspects such as the **availability of API platforms and connection with new technologies** (AI and the IoT) were considered in the survey and presented and discussed during the workshops. Finally, the **availability of new technologies** was seen as a key enabler.

> *"The availability of standards, specifications and guidelines are API implementation enablers"*

Drivers

Our survey explored the main drivers for API systems' adoption in government. The participants were requested to select, among a number of drivers, those most important for them, namely those that influenced their strategy, objectives or requirements. Figure 12 depicts both the drivers identified in already functioning API systems and those predicted as part of API strategies under design.

From the results of the survey, **the main drivers appear to be related to organisations' policies and external stakeholder demand**, including the demand both for specific APIs and for specific applications achieved by using APIs.

Legal drivers (EU/national and local) were not declared on already operational API systems in the survey. However, in the discussion of the workshop, it was recognised that **new legislation has encouraged the adoption of APIs, with motivations being to make data more universally available**. Legal drivers were also predicted as drivers in the API strategies under design. Moreover, **as suggestions, respondents indicated an interest in regulatory actions for APIs**. Specifically, there were requests for (i) an update to the Public Sector Information Directive (European Union, 2013) ([10]), (ii) enforcing a legal act to make the OOP mandatory as a means to mitigate the perceived GDPR legal barrier and (iii) enforcing the Services Directive (2006/123/EC) (European Union, 2006). In addition, the GDPR (European Union, 2016) was indicated as a possible enabler of API adoption, as it requires data minimisation ([11]) and APIs can provide filtered access to the data.

> *API drivers include organisation's policies, external stakeholder demand and new legislation*

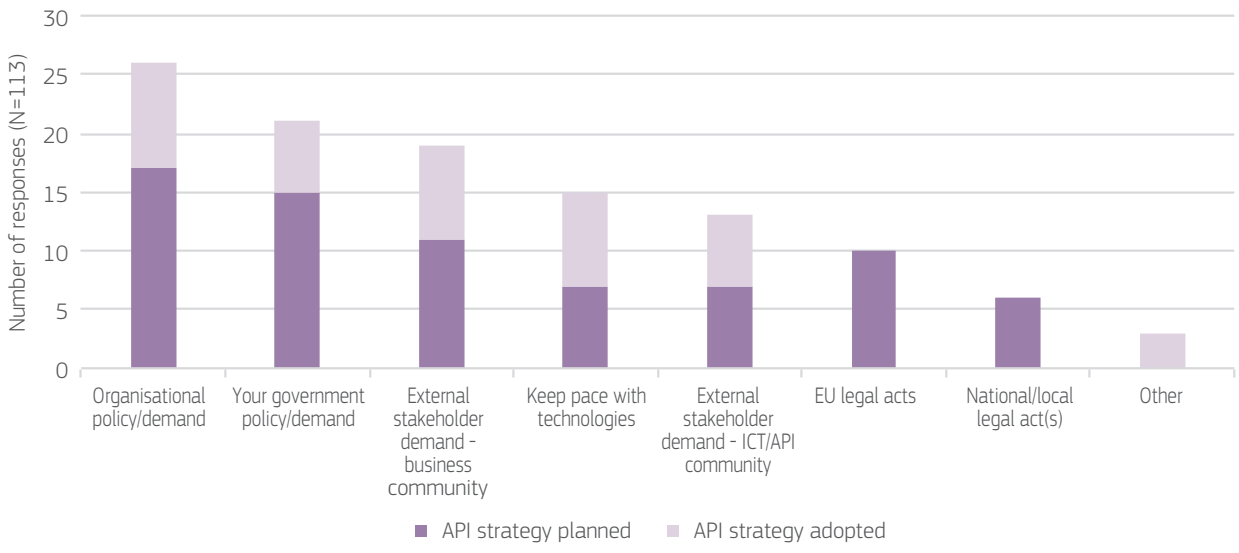


FIGURE 12: Drivers for API strategies.
Source: JRC, own elaboration, based on the study survey results.

Barriers

The survey explored the main barriers to API systems' adoption in government. Figure 13 depicts both the barriers identified in already functioning API systems and those predicted as part of API strategies currently under design. The main barriers declared were classified as social, political, legal, economic, organisational/cultural or technical/operational.

— The results of the survey pointed to **organisational/cultural barriers as the most relevant barriers impeding API adoption**. In particular, respondents mentioned barriers such as the fact that **APIs are often perceived as primarily beneficial for external parties**. A **change in the political context, strategies and goals** can also affect API investments in the medium and long term. A resistance to change should also not be overlooked, especially when APIs are presented as alternatives to the long-invested legacy systems that some organisations have in place and understand well.

Legacy systems tend to be monolithic and it can be difficult to re-engineer them to API solutions; in addition, current software as a service (SaaS) may not fit the present API implementation requirements. This also applies to outsourcing/procurement models. Along these lines, both survey respondents and workshop participants requested efforts to (i) facilitate the necessary shift towards an SLA-driven mindset (multisector/domain with strong cross-coordination), (ii) build in-house technical capabilities in public administration (knowledge, processes and roles) and (iii) explore novel public–private partnership models.

> *"APIs are often perceived as primarily beneficial for external parties"*

— The operational/technical barriers identified were mostly related to the **time and costs associated with re-engineering existing systems to APIs** and to the lack of harmonisation of agile solutions, even within organisations. It should be noted that, in the survey, only one case identified technical or operational issues as actual barriers, suggesting that API standards are both available and used. However, they are envisaged as a potential barrier, so it is **likely that improved systems will be needed to better inform, educate and report to the API government stakeholders on the availability and use of web API standards**. This was confirmed by the results of the working groups of our workshop that focused on how organisational contexts within standards and guidelines can be important for their use. Specifically, the proposals included interests in guidelines, common building blocks (e.g. for access and identity management infrastructure), sample software/reference implementations (especially for testing local-level developments) and the patterns identified for the application of standards in different situations/conditions. Other support could take the form of case studies and (incentivised) good practice examples, especially when organisations can join a community and build APIs around a standard.

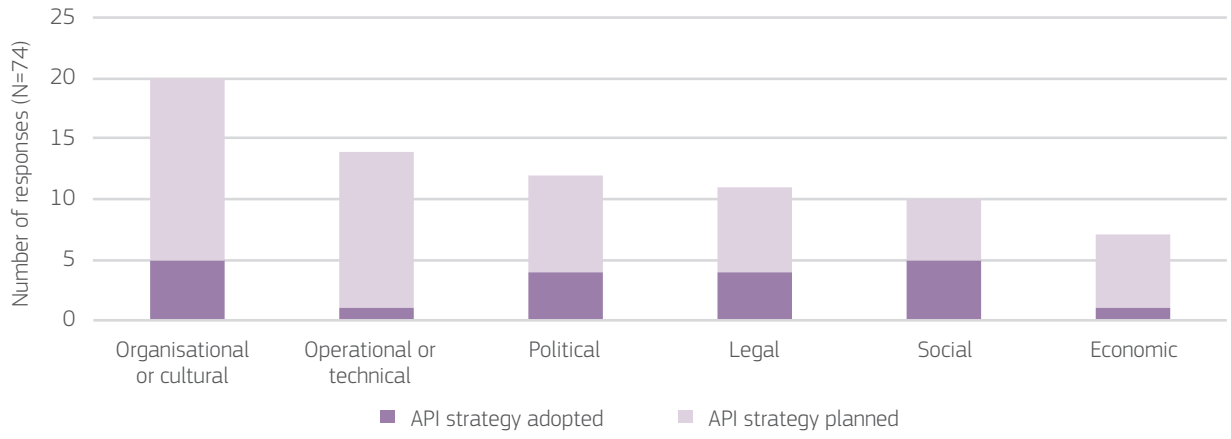


FIGURE 13: API barriers to API strategies.
Source: JRC, own elaboration, based on the study survey results.

— Two political barriers were mentioned by respondents, specifically **decision-makers' lack of understanding of APIs' potential and the lack of direct visible benefits for senior managers**. Participants explicitly mentioned as a political barrier in public organisations the competitive (allocation of budget resources), as opposed to collaborative, environment. To tackle this, there could be a **need to break the IT siloes that reflect the administrations' organisations**. From a broader perspective, it could be considered that the benefits of APIs would stand out more, from which we could deduce where the promotion of APIs should be located and measured organisationally (e.g. cross-departmental, cross-agency or cross-project).

— Regarding legal barriers, when implementing APIs, some specific regulations must be taken into consideration. The **GDPR in particular was acknowledged as a barrier that could slow down the API adoption on the basis of its implications on any project involved in sharing data**. In particular, the difficulty in assessing the necessary efforts needed to ensure secure ways of protecting data privacy appropriately was indicated. Respondents and participants at the workshop requested actions to define proper data ownership flows and the definition of patterns addressing particular use cases (e.g. consulted work, city contractors and third-party data).

— **Social barriers are not normally anticipated for the adoption of API solutions under design, although two of the API systems that were already operational and involved in the survey reported social barriers to the major adoption of APIs from a public-sector data provider and, within this context, to cooperation among the stakeholders**. From the API provider perspective, government agencies that manage data and public administrations (with a vision) are key figures. They normally include the presence of a senior leader/champion to help promote the adoption of APIs in their organisation and, potentially, communicate with counterparts in other organisations. From the API consumer perspective, the immediate users of APIs are intermediate actors that build applications on the top of APIs, while citizens were clearly identified as consumers of end-user applications based on government APIs. Therefore, communities of users/developers are key to ensuring the uptake of APIs. Other intermediaries, acting between providers and consumers, may offer solutions for both API sharing and consumption (e.g. providing API digital platforms and marketplaces). Private-sector partners may have a role to play as supporting organisations, and may help to create economic benefits from the opportunities offered by government APIs.

> *"There is a need to better inform, educate and report the government stakeholders on API culture"*

— Economic barriers to API adoption in government environments were also identified. Specifically mentioned were the fact that **APIs are more expensive than plain/bulk data exchange, along with the long-term commitments that API systems require**. The **difficulty in providing a good-quality governmental API ecosystem** was also described as a barrier in economic terms. Specifically, respondents indicated that (i) government APIs may not create real markets for companies and (ii) implementing charging mechanisms may incur major costs in terms of infrastructure for the institution.

In our working group discussions, the participants expressed concerns about the fact that other, more fashionable, technologies (e.g. blockchain) are **competing for resources with the adoption of API solutions** and therefore the size (in the sense of the availability of resources) of government organisations may affect their readiness to innovate through API adoption.

Risks and mitigation measures

Our survey explored risks for API systems' adoption in governments and related mitigation measures. Figure 14 depicts both the risks identified in already functioning API systems and those predicted as part of API strategies under design.

A number of risks were identified, which can be grouped into technical, organisational, legal and economic risks.

— Within the technical (and social) risks, **cybersecurity** is considered as the major threat in both actual and potential API strategies. Like any other additional channel to the 'outside' world of the web, APIs inherently increase the permeability of an organisation's network, which can expose new vulnerabilities for exploitation. Therefore, APIs must be appropriately secure in terms of protection against cyberattacks. A number of organisational solutions exist, such as the adoption of API gateways to reduce the number of web endpoints (and so the number of possible channels exposed to cyberattacks) of an organisation. Solid security solutions exist such as OAuth and certificate-based authentication, which are used in conjunction with a wider cybersecurity strategy and cryptography (see also Santoro et al. (2019) for more information about security standards).
Technical sustainability is also a concern for API adoption, including the risk of **producing APIs that either will not scale or prove to be unstable in the future, because of technical changes/updates**. In fact, even if standards for APIs are available in small pockets, such as the Open Geospatial Consortium (OGC) standards (OGC, 2019a) and the developing International Organization for Standardization (ISO) standard in financial services (ISO, 2018), many organisations are developing APIs based on an agreed internal specification or style guide to promote consistency, rather than what might normally be recognised as a de facto 'standard'. Each API comes with detailed documentation for consumers, which provides clarity on the type of API (RESTful, Extensible Markup Language (XML), GraphQL, gRPC (a remote procedure call (RPC) framework, etc.). There appears to be limited appetite for further standard development in the aftermath of open government models, which was different from the impact that open banking had in the EU, which precipitated the agreement of an API standard in the United Kingdom initially at least (European

> *"Cyber-security is considered as the major threat in API strategies"*

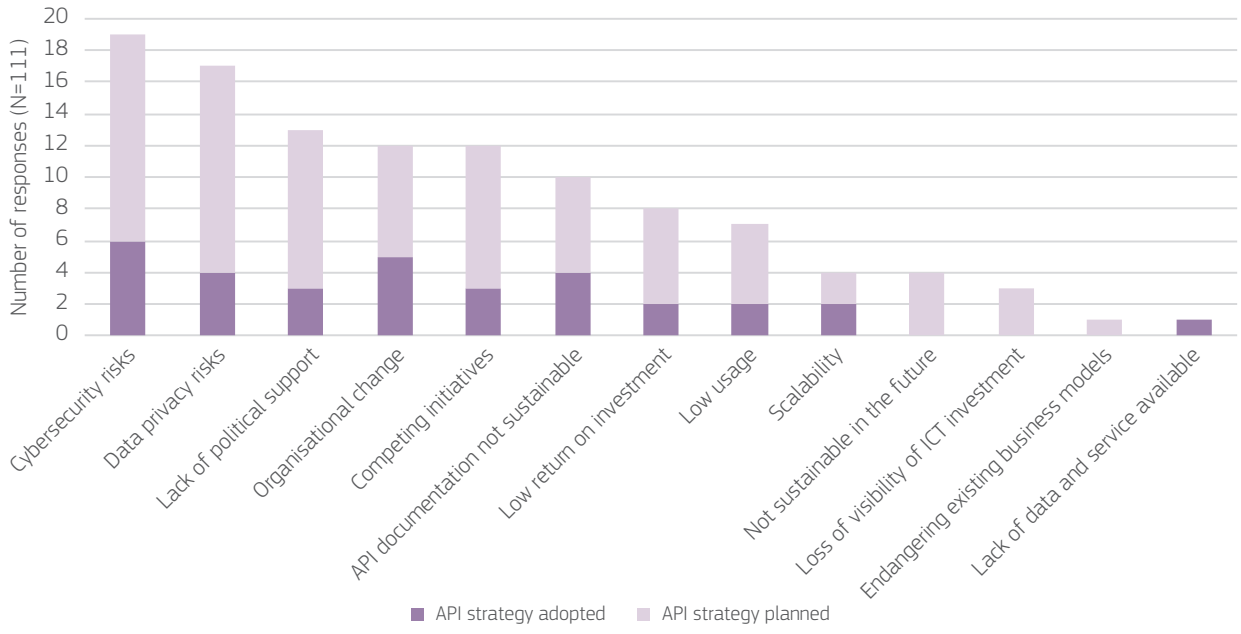


FIGURE 14: Risks for API strategies.
Source: JRC, own elaboration, based on the study survey results.

Payments Council, 2017). A possible mitigation measure is to identify, analyse and propose a set of existing standards that can be used to implement government APIs. To concretely implement this measure, we have recently published a JRC technical report on web API standards (Santoro et al., 2019).

A possible risk was indicated in the difficulty in **maintaining API specifications aligned with current version of APIs**. To mitigate this risk and facilitate the alignment between the documentation and the publication of APIs, many tools that help in semi-automatic documentation generation and alignment exist on the market (AlternativeTo.net, 2019).

Regarding mitigation measures, both respondents of the survey and workshop participants presented measures in place under their API initiatives. These measures included periodic security audits, the introduction of agile work processes for ICT and the allocation of resources for updating and maintaining API specification documentation, plus, of course, the use of widespread standards to guarantee the sustainability and the scalability of their API implementations.

— Related to organisational risks, **organisational change and a lack of political support** seemed to be particularly relevant. In addition, API adoption is likely to bring about organisational/business change and so a communication strategy would be needed. Such change may also be linked to, for example, a procurement strategy to help promote APIs. For instance, externalisation efforts should be rationalised and therefore more agile procurement systems should be put in place. Moreover, implementation decisions are being made by developers, but not necessarily involving inputs from enterprise architects. On the other side, developers have a strong end-user focus, but need to be informed of policy issues that have an impact on their work (e.g. the GDPR (European Union, 2016), which has a relevant impact on API adoption (Rizk, 2018)) while chief information officers need to pay attention to the possible impacts of developers' desire to 'experiment' in this context. As a mitigation measure, the creation of a central 'innovation agency' that can inform IT departments was seen as being beneficial, particularly in terms of communication and coordination.

Competing initiatives (i.e. the adoption of APIs without common guidelines and governance) have also been identified as both actual and potential risks. To mitigate these risks, development approaches should be considered that are iterative and continuous, and should potentially also be considered for the strategy itself.

— Legal risks include a **breach of the data privacy of people and organisations**. In our survey data, privacy is seen as the most relevant risk, together with cybersecurity aspects, for those API solutions still under design. Protection from possible access and misuse of these data must be considered as a primary goal for an organisation adopting APIs.

Moreover, in our discussion groups at our workshops, it was observed that, in relation to standards, **when they may have widespread support, legal requirements may limit the adoption of standards** by organisations needing to follow legal/sectoral requirements. Indeed, the formal change process can be costly and can take time.

— Economic risks include many aspects, such as the **risk of low usage of APIs**, the **loss of visibility of government activities on the web** (i.e. when APIs are invoked by third parties' applications and so the government' applications are substituted and become obsolete) and **business models becoming endangered by specific agencies or sectors of a public administration delivering their data via traditional channels**. Some mitigation measures have been introduced and, as observed in our research, regarding business models in the public sector, generating income from the provision of data that are publicly owned and are being used for the public good has not led to the charging of users who wish to consume or query this type of data. Examples of charging mechanisms being in place are limited, one being the United Kingdom's Ordnance Survey maps (Ordnance Survey, 2019) and another being the

> *"The risk of producing not scalable or flexible APIs could be mitigated by exploring and proposing a set of suitable standards"*

Cable and Pipe Information Portal (KLIP (Belgium) – one of the explored case studies), which charges map requestors to have a digital map of utility services generated for a specific location.

3.2.3. Conclusions on application programming interface adoption in governments

Besides the investigation into enablers, drivers, challenges and risks of the previous section, from our analysis we have found that the adoption of APIs in government is in quite an early stage, with the oldest API strategy having been implemented only in 2014, and several are planned to be deployed within 2018 (i.e. at the time the survey was proposed and the case studies were analysed). API strategies' stakeholder involvement and stakeholder dynamics vary greatly depending of the nature of the organisations (e.g. the sector, if it is a smart city and the difference between national and international bodies). Often, current API strategies are embedded within or linked to other ICT initiatives.

In addition, looking at the cases studied, **web APIs strongly support the digital transformation of government**. Table 4 summarises our results from the multiple-case study, that is, **when API strategies and solutions are implemented, their uptake is rapid and extensive**. This demonstrates, at least in the cases that we have analysed and that had a well-defined goal, that, when implemented, APIs are used by a huge number of applications (see, for example, the number of applications developed from the Madrid Mobility Labs). In addition, in the cases analysed, APIs enable a digital connection with a high number of third-party organisations, such as in the case of the X-Road national platform (e-Estonia, 2019).

> *APIs underpin the digital transformation of government: when API strategies and solutions are adopted, their uptake is rapid and massive*

Case study	API usage
DAWA	— 1.5 billion requests in 2017 and approximately 350 000 unique users per week — The number of API requests is limited to 100 requests per second — There is approximately 5 000 IT systems that request data regarding Danish addresses using DAWA — A unique point of access for addresses for everybody
Madrid Mobility Labs	— 480 million requests per year — More than 1 500 developers registered in the system — Around 50 apps developed (80 % of users)
X-Road	— 500 million requests per year — Over 1 billion transactions — 925 institutions and enterprises connected, including 706 public-sector institutions — 99 % of government services covered — Around 52 000 organisations are indirect users of X-Road services
Amsterdam city data	— 350 million requests per year — 8 000 visitors per month and an average of 20 minutes spent using the data interface
KLIP	— 120 million requests per year — 10 713 registered map requester initiators, including of 1 502 companies and 1 258 citizens — 200 000 map requests per year; for each request, six or seven utility companies are involved

TABLE 4: API usage in case studies.
Source: JRC, own elaboration, based on Williams (2018).

Our workshops have uncovered many elements related to API adoption in governments, with different levels of governments possibly behaving differently. National-level actors are perhaps more focused on providing access to data, whereas local organisations have more of a service-delivery focus. In addition, many of the examples being shared point to operational/implementation activities related to APIs. This is beneficial in helping the study to explore real examples, but there may currently be a limited view of the strategic elements that would place APIs in digital government thinking. In particular, it seems that the current efforts are focused on making individual organisation's resources available, but little thought is being given to the more strategic elements related to the creation of an ecosystem of APIs, whereby certain processes or applications rely on the reuse of APIs in multistakeholder contexts. To understand if this conclusion is biased by the fact that technology-managerial roles were very well represented in the workshops (with decision-makers less represented), we have further investigated these aspects in Section 3.4, which is dedicated to the analysis of the literature review of API best practices, recommendations and guidelines, and in the gap analysis that we used to develop the API framework proposed in this report (see annex 2 of Boyd et al. (2020a)).

Survey respondents also provided relevant links to their strategy documentation and technical guidance. All of the documents have been considered in our literature review about government best practices and have also been added to the complete list of API best practices, guidelines and recommendations published in the JRC data catalogue (European Commission, 2020h).

3.3 | Application programming interface technical design and standards

For governments to be able to adopt APIs, they have to become acquainted with the many factors (some of which are specific to APIs or e-government and others are specific to a domain (a sector or industry)) involved in adopting standards and technical specifications: legal and policy initiatives, the design and architectural styles used to build APIs, organisational and technological solutions, and the recommendations, guidelines and best practices from private actors or communities. All these resources make a vast, heterogeneous and sometimes contradictory field of study that is not easy to embrace. However, in spite of the difficult task ahead, tackling these issues with the adoption of standards is necessary to produce sustainable (stable and widely adoptable) API strategies. There are several advantages to encouraging the use of standards, including the following.

— **Standards increase the ease of use of APIs.** As an example, to enable third-party providers to create applications that could integrate multiple city data without needing to code integrations for each individual European city, Finland's 6Aika and CitySDK projects encouraged the use of common standards for city government APIs (6Aika, 2017a).

— **Standards can support communities of users.** For example, FIWARE's next-generation service interface (NGSI) standard makes it possible for a network of IoT developers and government partners to communicate around common building blocks (FIWARE Foundation, 2019).

— **Standards make it easier to create open-source tooling**, which can be shared among the sector to speed up API life cycle development practices. For instance, the OAS has led to the development of new tools such as automatic documentation and interactive sandbox generators, as well as new testing tools (OAI, 2019).

— **Standards remove the burden of upfront decision-making** by allowing government teams to default to industry best practices.

However, standards can also hamper government API adoption, and their drawbacks also need to be acknowledged and considered in any decision-making. Drawbacks include the following.

— Given the innovation that occurs with government APIs and the uniqueness of government API needs and approaches, **there are not always available, or known, standards to draw on**. The immaturity of some parts of the API tooling sector also means that the

discovery of emerging standards is difficult and may result in governments building new approaches because they are unaware a standard is being created. For example, the emerging Open511 standard, predominantly used in Canada but recently achieving version 1.0 status, is intended for transport data, but was rarely mentioned in government documents (OpenNorth, 2020).

— **Governments have often invested significant work in data models and approaches internally and may be resistant to moving to an industry standard.** Governments' existing work that is well accepted may not yet have achieved the planned return on investment, making it difficult to justify moving to a new standard. For example, many governments have created Simple Object Access Protocol (SOAP)-based APIs that meet functional requirements and so they cannot justify a move to REST-based APIs for all use cases.

— **Specifications and standards are continually evolving**, so adopting a standard will require a product-management approach in which keeping up to date with the changes of the standard becomes a new resource requirement.

— **A standard may be primarily funded or supported by a single organisation**, which may mean that the development of that standard might be steered by that entity's interests rather than the interests of the community at large.

In this study, we have collected, analysed and classified the most relevant documents for supporting governments in their technological API journey, also considering the abovementioned advantages and drawbacks. In this section, we give a summary of our analysis, the complete results of which have been previously published (Santoro et al., 2019). The first part of this section aims to support governments in choosing the correct architectural style. The second part illustrates the use of standards provided by standardisation bodies or, at least, technical specifications written by well-recognised consortia, vendors or users.

3.3.1. Application programming interface design and architectural styles

As mentioned in Section 1, it is important, when dealing with API technological aspects, to clarify the differences between APIs and web services. While the former have already been defined, various definitions exist of the latter. These definitions extend that given by the World Wide Web Consortium (W3C, 2004) by defining a web service as a service that is offered over the web, irrespective of the usage of specific protocols and message formats. While the generic definitions reported above generalise the restrictive and technology-driven definition of the W3C, they do not clarify the difference between a **service interface** and a **programming interface**: the former is provided by a web service, while the latter is a distinct characteristic of an API. In this report, we consider this difference relevant, as it affects the design of APIs, their implementation and their potential use. Web service interfaces, in fact, are designed to offer self-contained functionalities; they are a 'black box to their consumers and have a well-defined interaction contract' (Claus-Torp Jensen, 2014), which makes it difficult, for example, to use them in a flexible and agile way to build mobile applications. On the other hand, even if, technically, APIs are also web services, they are designed to be more flexible, ad hoc and easy-to-use and to be used at a micro level, and can be more easily combined to develop applications such as those for mobile devices (Claus-Torp Jensen, 2014). Thus, web services and APIs differ at the design level but not at the technological level.

Regarding the **architectural styles**, APIs can be broadly categorised into the following main types: (i) **RPC APIs** and (ii) APIs that adhere to the REST architectural style, or **RESTful APIs** (Santoro et al., 2019).

The first category is characterised by a set of procedures or methods that the client application can invoke and that are executed by the server to fulfil a task, for example a data exchange or a data validation service call. **RPC APIs** essentially operate by replacing in-memory object messaging with cross-network object messaging (RPCs) in object-oriented applications (Feng et al., 2009).

RESTful APIs are based on the REST architectural style introduced by Fielding (2000). The REST architectural style, more oriented to resource management and representation, is a hybrid style derived from several of the network-based architectural styles and combined with additional constraints that define a uniform connector interface. In essence, here

the term 'constraints' refers to the set of characteristics that defines the REST architectural style (client–server, stateless interaction, uniform interface, resource identification, self-descriptive messages, manipulation of resources through representations and hypermedia as the engine of application state (HATEOAS)). In addition to resource representations, server responses also provide the operations that can be performed on such resources, e.g. data, as well as the endpoints that provide them.

Both RPC and REST require the same understanding of the data model, format and encoding of messages that are exchanged between the client and the server. In other words, when a message is exchanged, both the client and the server must be able to read it (data format and encoding) and 'understand' its content (data model ([12])). However, the two architectural styles differ in several aspects, such as scalability and performance. From an interoperability point of view, the main difference between RPC and REST lies in the degree of client–server coupling, with coupling being tighter for RPC, and the REST architectural style allowing looser client–server integration. The degree of coupling has implications on how much a client and a server can evolve independently over long periods but remain interoperable.

Generally, whether REST or RPC is adopted depends on a specific predicted use case. Usually, REST better fits use cases in which the provider aims to share the resources with client applications, allowing them to navigate and modify such resources, or when the service may benefit from the distributed nature of Hypertext Transfer Protocol (HTTP) features (e.g. caching, as explained in Fielding (2000)). On the other hand, RPC is used to share functionalities with client applications that invoke such functionalities to fulfil some task (Maleshkova et al., 2010).

RPC and REST both adhere to the general request–response paradigm, but in recent years, **event-driven architectures** popularity has started to drastically increase as many organisations are realising they must react in real-time to their users, decouple their systems and transform into event-driven organizations. Event-driven architectures are software architecture paradigms promoting the production, detection and consumption of, and reaction to, events (Michelson, 2011). This architectural pattern supports loose coupling among software components and services. The advantage is that an event emitter does not need to know the state of the consumer, who the consumer is or how the event will be processed (if at all). It is a mechanism, for example, of pushing data through a persistent stream.

3.3.2. Web application programming interface standards and technical specifications

For the digital sector, especially in relation to the web, the existence of proper standards and specifications guarantees interoperability among countless digital assets, as defined by a number of standardisation bodies and communities. Standard APIs support reusability and are an enabler of interoperability. Reusability in any form improves quality because it extends operational use, as well as saving money and time. This makes the standardisation of APIs a major contributor to the development of a DSM in the EU. Some EU standards and specifications also exist in the domain-specific interoperability frameworks and should be applied more widely. For example, the INSPIRE Directive sets out interoperability standards for network services and for many thematic areas such as addresses, cadastres and roads of relevance to many public administrations (European Union, 2007a). These existing standards and specifications can and should be used more widely, namely beyond the domain for which they were originally developed.

A total of 78 documents were collected within the study, of which 15 are related to RPC and 21 to the REST architectural style. The rest of the documents can be considered 'general purpose' or neutral with respect to the design style. This distribution of technical specifications and standards reflects the fact that both RPC and REST are widely adopted and that the choice of which type to use is likely to be based on the specific use case to be implemented.

Figure 15 depicts the number and the type of technical specifications and standards for each category that we have used to classify the collection of documents. The largest number of technical specifications or standards have been classified as resource representation ([13]) and (communication) protocol ([14]) categories, reflecting the high level of available proposals. The licence category has the smallest number of technical specifications and standards; at the moment, in fact, API-specific licensing is relatively rarely used even if, of course, general work licences, such as the Creative Commons licences, can be used.

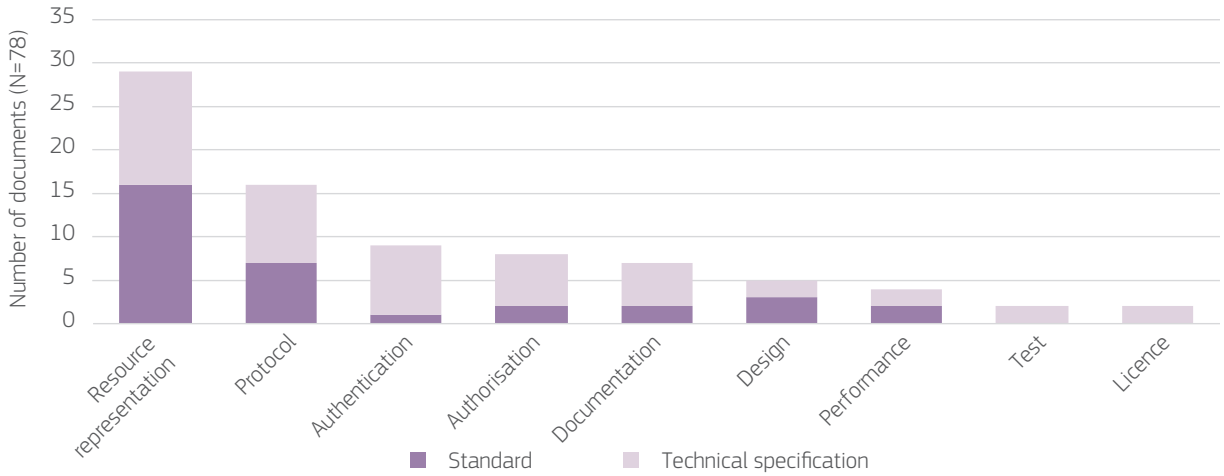


FIGURE 15: Number of technical specifications and standards per category.
Source: JRC, own elaboration based on Vaccari and Santoro (2019).

Category	Subcategory	Name
Functional specification	Resource representation	Hypermedia specification: — Hypertext Markup Language (HTML) (W3C, 2019; WhatWG, 2019) — Hypertext Application Language (HAL) (Kelly, 2011) — JSON for linked data (W3C, 2020) — JSON:API (Katz et al., 2015) — Structured Interface for Representing Entities (SIREN) (Swiber, 2012) Media and link types: — Internet Assigned Numbers Authority (IANA) link relation types (IANA, 2020a) — IANA media types (IANA, 2020b) Vocabularies: — Hydra core vocabulary (Lanthaler, 2020) — ISA core vocabularies (European Commission, 2020i) — Schema.org (Schema.org community, 2020)
	Communication protocols	— GraphQL (Facebook, 2020) — gRPC (Google, 2020b) — SPARQL (W3C, 2013) — WebSocket (Google and Isode Ltd., 2011)
Security	Authentication	— API key (Wikipedia, 2020a) — OpenID Connect (OpenID Foundation, 2020) — SAML (OASIS, 2019)
	Authorisation	— Extensible Access Control Markup Language (XACML) (OASIS, 2017) — OAuth 2.0 (IETF, 2020)
Usability	Documentation	— AsyncAPI (AsyncAPI initiative, 2020) — OpenAPI specification (OAI, 2020)
	Design	— EIF (European Commission, 2017a) — FIWARE (FIWARE Foundation, 2019) — OData (OData, 2019)
Test		— Postman collections (Postman, 2020) — Swagger (Swagger.io, 2019a)
Performance		— Cloud computing (ISO and IEC, 2014a; ISO and IEC, 2014b) — IT, loud computing and SLA framework (ISO and IEC, 2016a)
Licensing		— Choose a licence (Creative Commons, 2019a) — How to choose a licence for your own work (Free Software Foundation, 2018) — JoinUp Licensing Assistant (JLA) (European Commission, 2019h) — Open-source licence tool from GitHub (GitHub, 2019a) — Swedish API licence (Swedish Governmental Agency for Innovation Systems, 2020)

TABLE 5: Shortlist of API standards.
Source: JRC, own elaboration.

With the aim to support API stakeholders in the identification and selection of such web API standards and solutions, Table 5 focuses on the web API standards landscape and is directed mainly at professional practitioners, providers, consumers and technical users working within the API digital universe ([15]). The documents have been classified in different categories, each of them indicating their use with respect to API adoption. For each category, we give a shortlist of documents based on their utilisation, maintenance and stability. The shortlist will give the reader basic information about a selected number of technical specifications and standards that support the study and/or that are of particular (real or potential) importance for administrations engaging in the use of APIs.

The shortlist, based on the work of Santoro et al. (2019), of the concepts and standards presented is the result of the gathering and analysis of a more extensive list of documents that is considered an integral part of the report and can be retrieved from the JRC data catalogue (Vaccari and Santoro, 2019).

3.4 | Application programming interface best-practice documents

This section gives an overview of the best practices, guidelines and recommendations we have gathered from the analysis of the currently available literature on API adoption by governments. A detailed description of our research, analysis and results in relation to these documents is available in Boyd et al., (2020a). In this section, we first clarify the terms used and our methodology. We then provide some statistics on the geographical distribution and on the type of documents. Next, we give some literature review highlights. Finally, we present a shortlist of the documents that could be used as current reference literature by governments.

3.4.1. Definitions and methodology

The challenge for governments in implementing APIs is that, when introduced in an ad hoc manner, they can create additional complexity. Private industry has shown that, to be used effectively, APIs must align with broad business goals, use common rules and standards, and avoid simply reflecting organisational structures and instead stick to the needs of the end users. In this way, APIs can be used consistently as a common technology across business operations (Vaughan and Boyd, 2018).

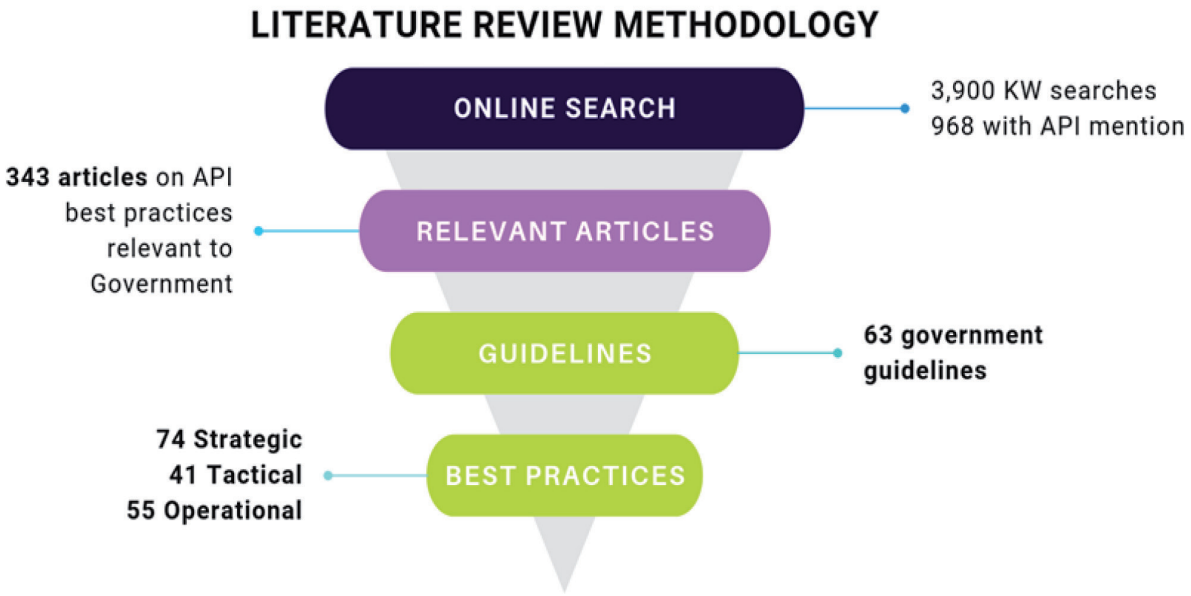


FIGURE 16: Literature review methodology document selection funnel.
Source: JRC, own elaboration based on (Mark Boyd and Vaccari, 2020).

Governments are now facing a similar learning curve to that experienced in the private sector in the past. The public sector will need to understand what the best available solutions and best practices are for driving the adoption of APIs in a sustainable, fast, efficient and effective way. In our literature review, the documentation is ranked by its robustness of evidence into best practices, guidelines and recommendations, which, respectively, align with the terms 'must', 'should' and 'may' (IETF, 1997).

We have based our collection of literature on a solid methodology and distilled publications from more than 300 online documents, the analysis of a number of case studies, and the workshops and survey organised within the study. We have also engaged many stakeholders both from the private sector (i.e. through our participation at and co-organisation of three APIdays conferences in 2019) and the public sector, to transfer their knowledge to our research. Moreover, we have used this extensive and systematic best-practice literature review, using both government and private-sector sources, to build a proper evidence-based digital government API EU framework (see Section 5.1). Over 3 900 links were found and scanned for their relevance to APIs by using a keyword (KW) search, in addition to these documents. Of this combined pool of documents, 968 documents were reviewed and 343 were considered relevant for government API best practices. This included 63 specific government API guidelines and best-practice documents ([16]). Figure 16 gives an overall summary of this process.

3.4.2. Literature review statistics

Figure 17 illustrates the geographical distribution of the literature we found. Of the documents selected, 67 covered the European Union area and 91 were classified as 'international', coming from either private industry or international organisations such as the OECD or the UN. The remainder were from European Member States and other countries. The full table, with a breakdown by country, can be found in the JRC data catalogue (European Commission, 2020h).

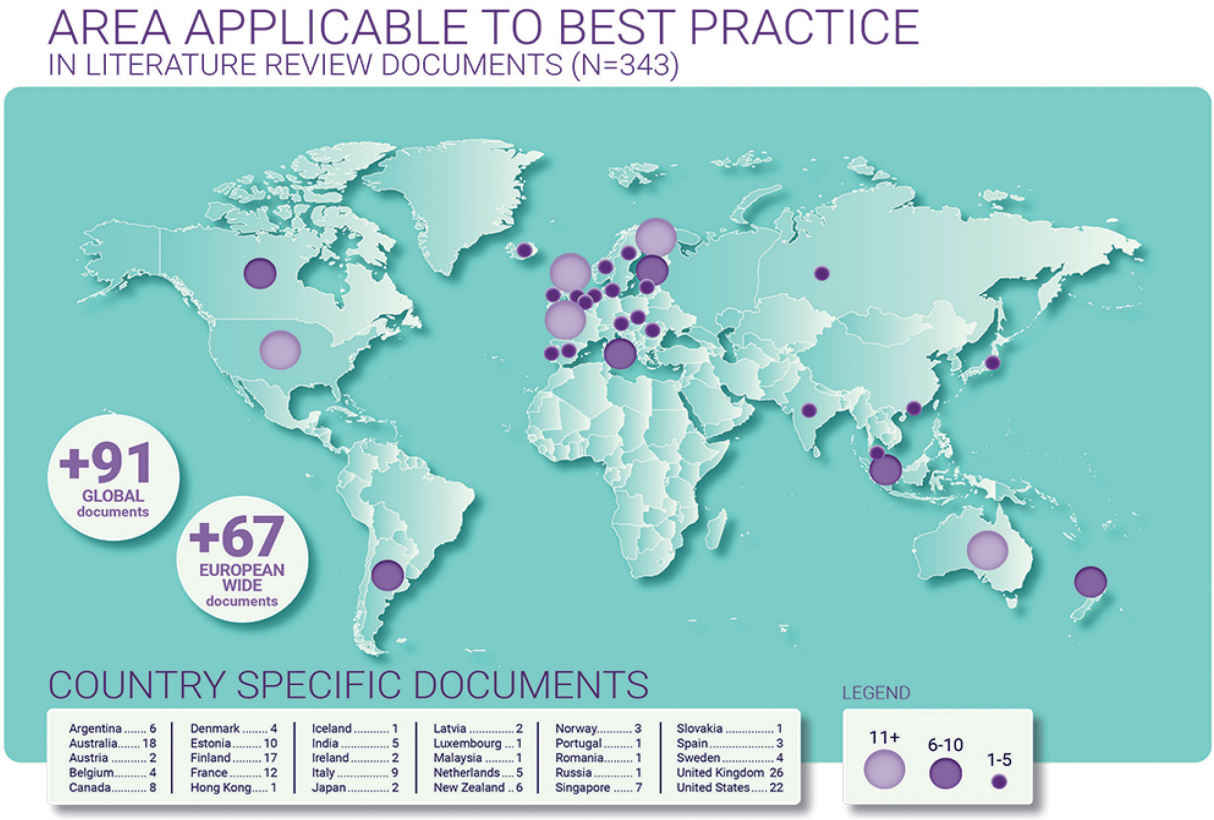


FIGURE 17: Literature review by density of country as document source.
Source: JRC, Brendan McGrath of Grathx elaboration based on (Mark Boyd and Vaccari, 2020).

As shown in Figure 18, the majority of literature reviewed (57.7 %) was drawn from public-sector sources, 11.7 % of the sources came from experts and 11.4 % came from private or not-for-profit companies. A relevant proportion of the documents was also authored by experts, consortia and communities, international organisations, academics, journalists and the non-profit sector.

In Figure 19, the main topic covered by each document is categorised, with these then grouped into API strategy (violet), API tactical (light violet) and API operational (grey). In the literature, the strongest consistency and evidence-based agreement was on operational aspects of API implementation, especially operational issues that were technical in nature, such as in designing APIs.

Following the completion of the analysis of all 343 documents, we selected and created a shortlist of documents that could be used by governments as reference literature. The list includes the following documents:

— international and strategic-oriented documents:

- the UN Environment Programme (UNEP) science business policy forum discussion paper: *The case for a digital ecosystem for the environment* (David Jensen and Campbell, 2018);
- the new EIF (European Commission, 2017a);
- the European Commission's European Union Location Framework (EULF) blueprint (European Commission, 2019i);

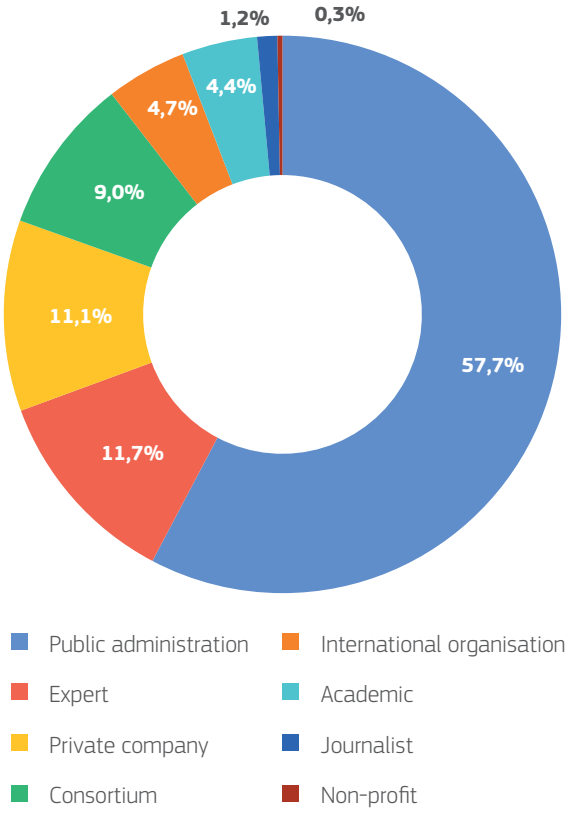


FIGURE 18: Literature review by type of author (N=343).
Source: JRC, own elaboration based on (Mark Boyd and Vaccari, 2020).

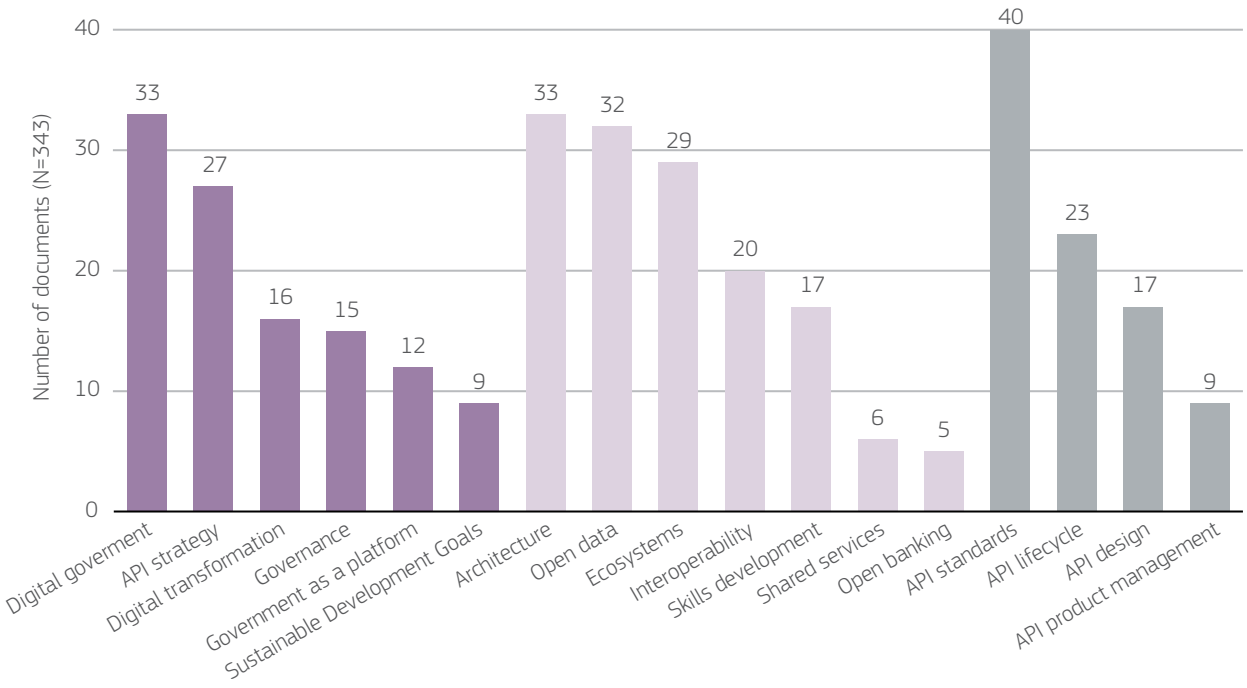


FIGURE 19: Main topics covered in literature review. Grouped by API strategy (violet), API tactical (light violet) and API operational (grey) documents.
Source: JRC, own elaboration based on (Mark Boyd and Vaccari, 2020).

- McKinsey and Company documents on its works with a wide range of large enterprises on reorienting their operations towards an API-first approach (McKinsey, 2019; Iyengar et al., 2018);

— guidelines at the national level (in alphabetical order):
- Canada: API guidelines (Government of Canada, 2019a);
- France: the FranceConnect system (presentation) (European Commission, 2018f);
- Italy: the Italian 2019–2021 3-year plan for IT in the public administration (Italian digital agency (AGID), 2018);
- New Zealand: API guidelines (Government of New Zealand, 2016);
- Singapore: Finance-as-a-Service: API playbook (ABS-MAS, 2016);
- the Netherlands: API strategy for the Netherlands government (Geonovum, 2019);
- the United Kingdom: helping government use APIs better (European Commission, 2018f) and Making Government as a Platform Real (Loosemore, 2018);
- Victoria: API guidelines and related information management framework (Victorian Government, 2019a; Victorian Government, 2019b).

3.4.3. Analysis of the literature

Our analysis of the documents identified and gathered in this study includes a summary of the common approaches identified from multiple governments and from private industry that have been designed and deployed for adopting government APIs.

During the literature review analysis, best practices, guidelines and recommendations were collated as 'snippets' from documents and grouped into the three levels of government application (strategy, tactical and operational). These snippets were tagged with relevant topic headings such as 'governance', 'metrics', 'security', 'API design' and 'documentation'. Topic headings were later grouped into thematic areas. These thematic areas included 'governance', 'policy alignment', 'technical implementation' and 'team composition'. They helped identify common areas of work that would need to be undertaken in a cohesive framework approach and they gave rise to the four pillars of the API framework illustrated in Section 5.1.

During this distillation and categorisation process, common government-specific practices became apparent. These common approaches demonstrated best practices and emerging standard approaches to creating, hosting, publishing and managing government APIs.

The following list shows the most common approaches to government APIs observed in the literature. The common approaches were then grouped according to the thematic areas and included in the framework proposals. An indication of how these common approaches align with the specific proposals of Section 5.1 is given. These have been organised into strategic, tactical and operational levels.

— **Strategic**.
- The implications of providing an API on whole-of-government operations need to be considered (proposal 1).
- When delivering digital platforms, platform owners need to measure platforms on both their ability to spur the desired activity and their likelihood of creating arbitrary advantage for a few users (proposal 1).
- Governance structures that are cross-departmental need to be established (proposal 3).
- Government departments should articulate the core principles that apply to the creation and delivery of APIs and digital services in general (proposal 4).

— **Tactical**.
- Governments should define and support domain ecosystems to help understand use cases and ensure that consistent standards and data models are available for each ecosystem (proposal 6).
- API design should be 'harmonised' within government and across government tiers so that reuse is promoted. This will also help third-party providers to consume an API in a way that then allows them to scale their products and services to multiple jurisdictions (proposal 6).
- API team structures need to be established that include an API team leader (product manager), an architect, an evangelist and developers (proposal 7).
- APIs need to be viewed as products (proposal 8).

— **Operational**.
  - Modern web methodologies need to be used in designing and implementing APIs, such as REST (proposal 10).
  - APIs should provide appropriate documentation and ensure a high developer experience (proposal 11).
  - Before an API goes live (i.e. before it is released for use), provisions should be in place to support the internal development and testing of APIs, handle release management, support the onboarding of application developers, define the service-level objectives and indicators that API consumers can expect from the API, support the usage of the API, encompass API life cycle/change management, cater for incidents/events, and manage security and privacy (proposals 11 and 12).

After this analysis of the literature, we performed a SWOT analysis, which was conducted to review gaps and challenges in the available literature. A gap analysis to identify missing guidance in the current approaches and specifically to identify the differences between private- and public-sector practices was also performed. This is important because, in some cases, governments can learn from private industry adoption, but governments have a different mandate, different roles and different goals from the for-profit private industry. Therefore, best practices from private industry must be considered within this broader context. These three analyses have been used to build the API framework described in Section 5.1.

4

WHY GOVERNMENT SHOULD ADOPT APPLICATION PROGRAMMING INTERFACES

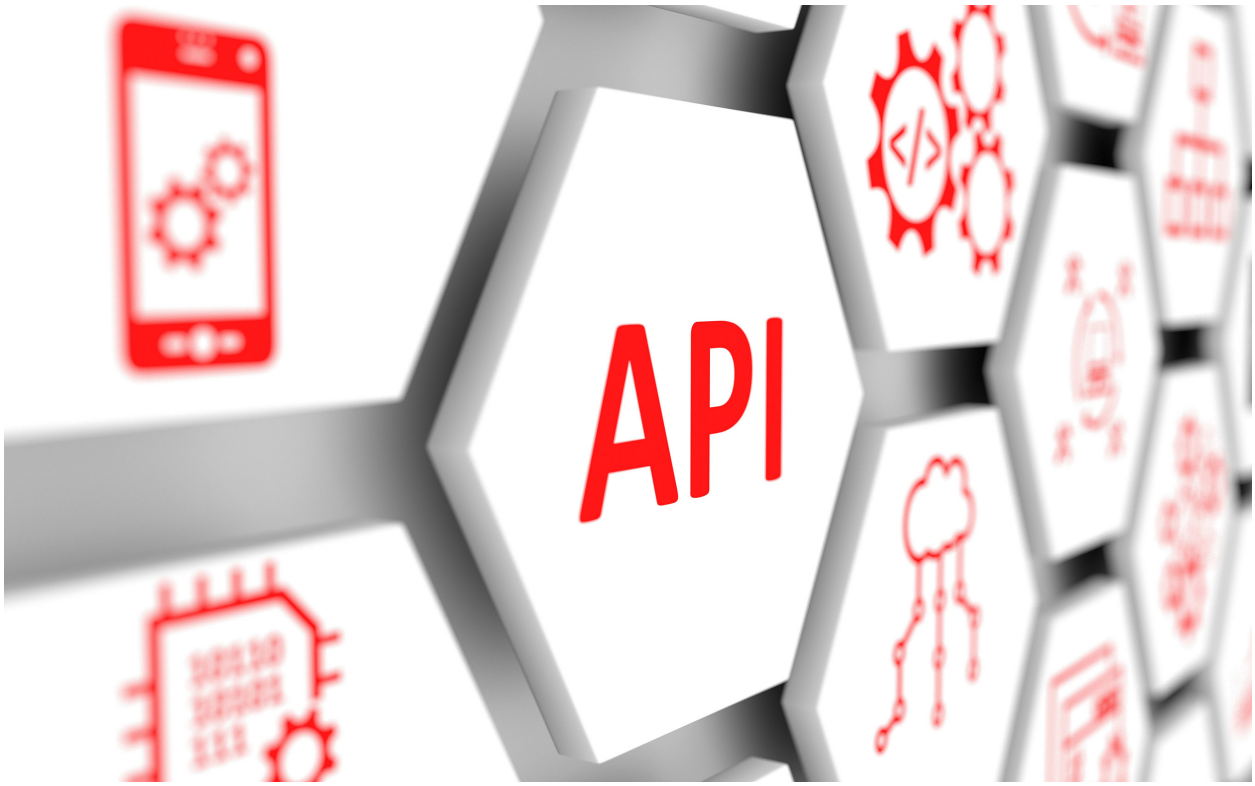
SUMMARY

This section presents the study's findings about the motivations and challenges behind the adoption of APIs in the public sector. There is evidence that the deployment of functional API systems has positive effects on performance in private organisations. However, how does the above reasoning hold in government environments? Governments' objectives fall beyond organisational profit. However, governments' performance and innovation can benefit from the potential that APIs bring to organisations.

Internal and external benefits have been identified for governments when they share their digital assets. Internal benefits include innovation triggering, efficiency gains and improving access to and the use of government (open) data digital assets. External benefits include the enablement of digital ecosystems, the rewiring of interactions with society actors, new economic opportunities and the possibility to orchestrate digital ecosystems. In addition, we have also observed economic benefits when government assumes a regulatory role in APIs.

API adoption also carries both **technical and organisational costs**. Moreover, the adoption of APIs implies **challenges** such as those involved in overcoming the organisational mindset shift required and the potential lack of skills, addressing cybersecurity vulnerabilities and adhering to current regulations on privacy aspects (e.g. as required by the GDPR).

By facilitating access to digital assets such as open data, APIs have an impact on government openness and transparency. In addition, governments can generate trust with citizens via additional mobile or desktop applications built on APIs to create virtuous feedback loops when citizens engage with government.



4 WHY GOVERNMENT SHOULD ADOPT APPLICATION PROGRAMMING INTERFACES

APIs are an essential component of the digital transformation of organisations. In this context, APIs are a technological enabler for improving government operations and processes, and for streamlining data flows to inform policymaking. However, capturing the contribution of APIs in this government transformation is a challenging exercise and it is even more challenging to quantitatively assess the impacts of API adoption. The low number of API strategies adopted by governments, the variability in technical complexity of API-enabled solutions and the breadth of application domains makes it currently unachievable to reach generalised conclusions. Moreover, both relevant academic literature and data for quantitative analysis are scarce and scattered. Nevertheless, this section presents a qualitative analysis of evidence of motivations and disincentives for the adoption of APIs in the public sector collected from case studies, surveys, expert interviews and desktop research. Specifically, we found qualitative evidence regarding **benefits and opportunities**, **costs and challenges** and **social implications**.

4.1 | Benefits and opportunities

There is evidence that the deployment of functional API systems has positive effects on performance in private organisations (Benzell et al., 2017). APIs provide organisations with high digital flexibility owing to their capability for reuse and their modularity. In this sense, the design of digital solutions can benefit from the inclusion of external digital assets. Potential benefits result from eliminating the maintenance cost of external digital assets or from fostering innovation with a relatively low investment. In addition, APIs can provide valuable insights into the usage and usability of digital assets. Organisations can use this information to value their assets and to facilitate priority setting for their digital infrastructures. All in all, APIs can be used to streamline the innovation of digital solutions and ultimately boost profit. Moreover, the scaling of API solutions entails marginal costs close to zero. This implies that the reach potential of digital assets through APIs is virtually unlimited. All these characteristics

have intrinsic economic implications, such as the potential achievement of economies of scale and economies of scope, and ultimately the fostering of sectoral innovation.

However, how does the above reasoning hold in government environments? Governments' objectives fall beyond organisational profit. However, governments' performance can benefit from the innovative potential that APIs bring to organisations. The ultimate goals of government fall outside the organisation: optimising societal well-being and ensuring stability. To realise these goals, governments utilise means from their legislative and executive branches, in particular **policy design** and the **execution of public administration and public service provision**.

This section analyses the benefits of sharing government digital assets through APIs. Internal benefits include innovation triggering, efficiency gains and improving access to and the use of government (open) data digital assets. External benefits include the enablement of digital ecosystems, the rewiring of interactions with society actors, economic opportunities and the possibility to orchestrate digital ecosystems.

4.1.1. Fostering innovation in the public sector

Evidence of the innovative potential of APIs includes their power as **change inducers**. For instance, the OSF integrates API open data from each government authority within the Netherlands – made available by the

Box 4.
EU example: Estonia's X-Road platform

'X-Road is the backbone of e-Estonia. Invisible yet crucial, it allows the nation's various public and private sector e-Service databases to link up and function in harmony' (e-Estonia Briefing Centre, 2019).

X-Road is a government API framework developed by the Estonian government and licensed under the Massachusetts Institute of Technology (MIT) licence. It is also used as a backbone of the Finnish national data exchange layer. Originally built for SOAP/XML web services, it now extends to REST APIs. Rather than requiring governments to develop API management directly, X-Road provides an API management layer, including an API gateway, which is open sourced and available to governments worldwide (Finnerty, 2018).

The X-Road solution includes a security server to provide identity and access management for government API access. It also provides central monitoring of API traffic. In addition to the management of APIs, it also provides an aggregation layer in front of multiple databases. This facilitates the creation and delivery of data-access APIs.

As each government service/agency has its own database, they all use X-Road to securely communicate and share 'private and sensitive' data to protect the OOP of sharing data with government. The service also incorporates many other sectors, with over 900 organisations and enterprises including those in the banking, health and utility sectors. While they may use the platform to perform functions such as identity verification, powerful use cases such as automated extraction of funds from bank accounts for those failing to keep up to date with taxes are possible. All that being said, X-Road itself is a 'very low level engineered application' (Williams, 2018).

Following certification, an organisation deploys an X-Road gateway so that it can hold secure private communications via APIs with other certified organisations that are legally able to share data with it. As a collective toolset, the e-Estonia services provide the Government of Estonia and its partners, including Finland, with a platform on which to innovate and use digital transformation to deliver new services across the globe.

It should be noted that, currently, Estonia is also working on a next-generation government platform technical architecture that considers 'proactive services', intelligent virtual assistant, microservices, event-driven messaging environments and 'chaos engineering' to build messages 'rooms' called 'X-Rooms' (Vaher, 2020).

> *APIs induce change in organisations*

Dutch Centraal Bureau voor de Statistiek (CBS). The OSF application offers a real-time visualisation of governments' spending. When the OSF started, there were limited data available via APIs. The OSF advocated the use of APIs for publishing these data. Once a sufficient number of individual cities made their data available to the OSF, it became the norm to publish these data via APIs.

APIs also **facilitate the adaptive evolution of legacy systems** towards digital government. For instance, the API infrastructure in Estonia (i.e. Estonia's X-Road platform (Nordic Institute for Interoperability Solutions, 2019)) is used to overcome the restrictions of traditional integration solutions. Currently, Estonian citizens provide 'private and sensitive' data to administrations only once (e.g. marital status). These data are stored and maintained in legacy systems. An API layer was built on top to allow the exchange of information, complying with privacy and security requirement constraints (see also Box 4).

Similarly, the Italian Digital Transformation Team helps many Italian public-sector organisations to produce their own API solutions, supporting digital transformation programmes, where APIs are seen as enablers towards greater adoption of digital government services. The work relates to a legal base in 2017, a national 3-year plan for digital transformation (Williams, 2018). The plan identifies APIs as the key technology to deliver on the government's vision of a whole-of-government shared platform that

> *APIs facilitate the adaptive evolution of legacy systems towards digital government*

evolves the previous legacy platform. The new platform provides an ecosystem model with private industry actors, non-profits, research institutions and citizens leveraging APIs to create new values.

Moreover, we found cases on which operational API systems are also used to **design, test and try new public services**. For example, the art and technology (eTOPIA) project in Zaragoza (Spain), which combines a physical space in the city (MillaDigital) with the innovative power of an SME incubator, feeds from data provided by the government through APIs. The ambition is to support the design of novel public service solutions, to facilitate decision-making processes (e.g. urban planning regeneration), to test smart city solutions in controlled environments (e.g. mobility as a service) and to investigate new models of 'public spaces' facilitated by digital transformation.

> *APIfication can improve internal government processes and public services*

4.1.2. Efficiency gains

From the cases we have analysed, there is evidence of efficiency gains related to the **reduction of costs** through API adoption in government. For example, the interviewee of the case of X-Road (Estonia) estimated that if 8 % of the requests are submitted by human users, and assuming that every request saves 15 minutes, the total time saving corresponds to 800 working years every week. In the case of KLIP (Belgium), the API-based solution cost reduction was estimated to be 80 % when becoming fully digital. The Brønnøysund Register Centre, the Norwegian government agency responsible for the management of numerous public registers (e.g. marriages, companies, political parties, etc.), declared a reduction of costs related to the adoption of APIs of EUR 1.7 million per year.

In addition, APIs set incentives to **improve the quality of** and **reveal deficiencies in digital assets**. The quality of information has many dimensions, including intrinsic characteristics of quality such as completeness, being free of error and consistent representation, but also some additional requirements such as accessibility, an appropriate amount of information and timeliness (Kahn

> *Making open data more accessible has an impact on the transparency, accountability and trust of governments*

et al., 2002). An example is the case of API-AGRO and the Ministry of Agriculture in France illustrated in section 4.1.5. In this case, all stakeholders participated in the design of the service delivery of agriculture data owned by the government. Specifically, APIs were used to define the interactions among partners to streamline the provision of agriculture data (digital asset); as a result, the quality of the data asset was improved to better fit the needs of the whole digital chain. Regarding the latter aspect, 'user-centricity' plays an important role as 'government agencies that succeed all place the user at the centre and design services around their needs' (Siné et al., 2015). A recent analysis of the Lisbon Council recognises that 'co-creation techniques are being applied across a wide variety of areas' including 'developing new services' (Arundel et al., 2020).

APIs also **improve the performance of both internal government processes and public services.** 'APIfication' decouples digital processes into modules. These modules can easily be recombined. Changes in one module should not affect other modules. Together, all of these factors streamline the re-engineering cycles of government processes and services. For instance, Amsterdam city data (the Netherlands) calculated a 1- to 2-hour per day saving for each civil servant using the API-enabled application designed to use and search city-managed data. This information system connects more than 50 departments, and around 2 000 civil servants use the final application that relies on internal APIs. It was calculated that the use of APIs saves 1–2 hours per day for each user that needs and searches for data. In addition, we can gain an indication of the improvement of government public services through API by cross-fertilising with external digital resources. For instance, the emergency response of Regione Lombardia has benefited from APIs of other regional departments offering relevant information for their service, such as hospital bed numbers and traffic events. As a result, the region declared a significant reduction in the service's response times.

APIs are also one of the ways in which an EU data provider can improve its control over access to its data. APIs let data providers have more control over the amount of shared data (with respect, for example, to bulk downloads, often used in data catalogues). Besides this, APIs could also be relevant from a policy point of view, as the use of APIs authorises sharing the right data and services with final users, also improving, in some cases, the privacy and security of the original data.

Another opportunity identified was the **enhanced reporting flows in government processes**: in Slovakia, for example, taxes collected from home-based tourist accommodations can be reconciled with tax income thanks to APIs and can potentially identify potential under-reporting and allow more accurate tax collection (Sidor et al., 2019).

4.1.3. Improving access to (open) data

When datasets are openly available, APIs improve the accessibility and usability of these data. Usually, a government agency publishes an API for its dataset to open up new and innovative ways of accessing the data. A developer might create a mobile or web app to display the data intuitively, allow simple queries or automatically generate charts. In the EU, the most relevant example of exposing government datasets is the EDP (European Commission, 2019j). The portal also offers the possibility of accessing its metadata via APIs (both REST and SPARQL). These APIs give access to the documentation (metadata) of the published datasets and so, in an indirect way, give to access datasets through APIs (see also Box 5).

APIs help to streamline internal processes by easing data exchange among internal and external actors. Our case studies revealed the relatively contained costs and low development efforts involved in making data assets available through APIs (see Table 6).

APIs also increase internal and external data-sharing processes: internal APIs are used to better organise the interface between internal and external data-sharing

Box 5.
The EDP

The EDP provides access to 79 different catalogues, most with tens of thousands of open datasets provided by Member State governments. The same site also provides access to over 300 use cases (services or applications) that have been developed using the open datasets available. Some of these applications have been created using APIs to query the EDP.

Access to the portal is provided by a machine-readable API that enables its users to search, create, modify and delete metadata on the portal (European Commission, 2016i). APIs of the portal APIs are available via both the Comprehensive Knowledge Archive Network and SPARQL endpoints (European Commission, 2019k).

The EDP also uses APIs to automatically gather and update its information from the data catalogues from a number of public-sector organisations of each European Union Member State.

processes and internal and external actors. APIs are helping to streamline internal processes, a key aspect of digital government, and to increase the efficiency of digital service delivery to external actors. In some of our case studies, APIs are used to enable the information held in one system or department to be readily and securely available to another without significant and expensive development effort.

Making open data more accessible also has an impact on the transparency, accountability and **trust of governments**. For example, in the case of transparency, a keystone and driver of e-government, APIs could be seen to offer a clearer view on data and how it can be accessed. If details about such an API were to be made publicly available, this would offer a greater degree of transparency about the information an organisation holds and how it is allowing others to interact with it, such as in the case of the OSF in the Netherlands (see also Box 6). If the API were to be further documented in terms of the government processes it is used in, then this would offer even more transparency in terms of the **decision-making** in government. To achieve such aims, there is more needed than simply implementing the API; decisions in other contexts are needed to make the API function in a way that would achieve the transparency objective.

The transparency benefits of open data are clear; however, it is difficult to find quantitative evidence of these benefits in socioeconomic terms. While open data are acknowledged as an essential component in open government model, the provision of open data through APIs should be justified in terms of data-asset value. The value of the dataset can be defined in such terms as usability (demand) or

Box 6.
The OSF, the Netherlands

The Dutch CBS produces government society-oriented statistics. The CBS API enables statistical visualisation through an online application, as well as exploration and product development of datasets via an API. The API provides access to more than 4 500 datasets in 2020 and keeps growing. The OSF is a Dutch non-governmental organisation based in Amsterdam with the goal to promote governments' digital transparency. To do this, the OSF integrates APIs from each government authority within the Netherlands, made available by the CBS, to create a real-time visualisation of governments' spending. This is updated regularly, with the goal to provide as short a time lag as possible on government spending transparency. When the OSF started, there were limited data available via API, despite there being a standardised dataset that could be used to create an API. Once a sufficient number of individual cities began making their data available to the OSF, it became the norm to publish open data via APIs. Moreover, APIs were also used as common practice to reduce the need to establish specific agreements to share government data.

transparency relevance. In this sense, if the value of the data asset is not enough, the cost and risks derived from the development, operations and maintenance of the API should not be assumed.

To date, open data APIs have been more easily proven to generate value in key sectors. Static datasets such as museum, venue cultural asset and tourism data (such as on local landmarks), as well as demographic and geospatial data, have been able to generate new value through the creation of new data and services. Real-time data in transport and weather also have proven economic value, which is discussed in greater detail below. There are some current efforts, such as the French government's Emploi Store model, which seeks to open employment, labour force and skills data as APIs, in order to spur new economic value. A barrier identified is the lack of frameworks, which would have ensured consistency across datasets (format, data model, consistency, availability, accessibility, etc.). Therefore, the actual accessibility and usability of datasets is often low. Efforts from harmonisation initiatives such as Open and Agile Smart Cities (OASC), Synchronicity and 6Aika are currently focused on creating API standards and data models, so that businesses building digital solutions for cities can scale their products to a larger market base.

4.1.4. Enablement of digital ecosystem

There is plenty of **evidence of APIs' digital ecosystem-enabling power**. For instance, at the city level, Zaragoza's digital ecosystem stems from an open data initiative channelled through APIs. Both external and internal stakeholders plug into this API system using government digital assets for designing, testing and socially experimenting with the impacts of innovative public service provision. Specifically, this API-enabled ecosystem engages actors such as civil servants, academia, industry and Zaragoza's government. Another example is Transport for London (TfL), which provides figures of its technical ecosystem: 200 data elements engage some 12 000 developers that produce around 600 applications that are ultimately used by the 40 % of Londoners. Regione Lombardia with its E015 portal is also an example of the organisational approach in the use of APIs to enable digital ecosystem (Regione Lombardia, 2020a).

> *APIs contribute to the rewiring of interactions among society actors*

We have also found evidence of how **APIs contribute to the rewiring of interactions among society actors**. For instance, an example of a government–citizens–government (G2C2G) interaction, the Norwegian Brønnøysund Register Centre, was developed as a result of demand from the private sector to digitally interact with the government's registry services. The Port Authority of Rotterdam sought to modernise and digitise port operations through the use of APIs to improve container management, optimise logistics and minimise environmental impacts (Port of Rotterdam, 2020). However, when commencing the modernisation, there was significant confusion among private company stakeholders, which were reluctant to share shipping data such as container contents, as they wanted to preserve their commercial competitive interests. By facilitating a network in which industry stakeholders could work together, the port authority was able to identify specific data fields that could be opened up from private company data to help in the development of new collaborative business models such as sharing logistics and managing import and export through sharing container services (thereby also reducing environmental burdens of shipping half-empty containers). In this example, a government's port authority did not directly create APIs to stimulate added value to economic activity, but instead assumed a networking facilitator role to drive new economic opportunity.

4.1.5. Economic opportunities

We have found evidence of economic opportunities generated by government API provision. For instance, we observed **entrepreneurship stimulation** (e.g. TfL declared the creation of 600 applications by SMEs (see Box 7) and Empresa Madrileña de Transporte (EMT) reported the more that 50 registered applications had been developed by SMEs (see Figure 21)).

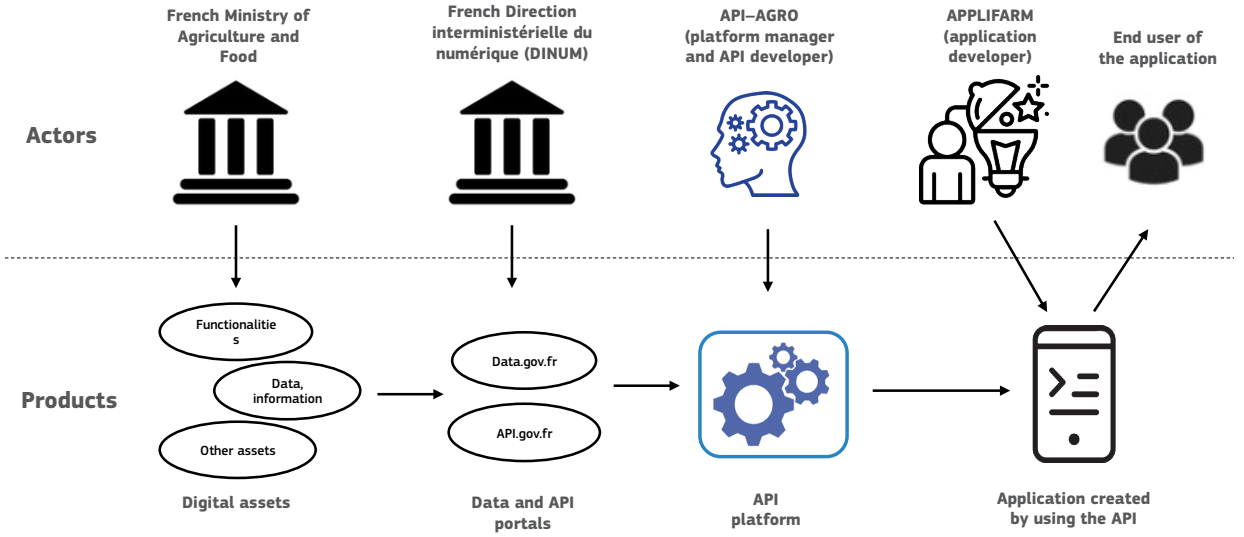


Figure 20: API-enabled data ecosystem in agriculture: a French case at the national level.
Source: JRC, own elaboration.

APIs make **profit generation possible by external partner stakeholders** (e.g. in the case of DAWA (Denmark), the economic benefit of ensuring correct address data through APIs for business, citizens and government itself was estimated to be EUR 33.5 million per year). In addition, the Brønnøysund Register is thought to create major rationalisation benefits for Norwegian consumers, public agencies and the financial industry. It is estimated that the application will bring a financial gain of EUR 1.3 billion over a 10-year period (The Brønnøysund Register Centre, 2020). In relation to this, **the availability of open data and shared services via APIs stimulates new economic development in digital ecosystems**. Third parties may build on government APIs to create new products. These new products generate revenue in their own right but, more importantly, they generate further economic opportunities for other participants in the digital ecosystem. We have selected and analysed some examples in specific domains in detail.

— **Agriculture: specific domain platforms, built by third parties that exchange government data via APIs, have started growing on the web.** This is the case, for example, for API-AGRO, a two-sided online marketplace that brings together data suppliers and data users, in the agricultural domain, via APIs (Siné et al., 2015). API-AGRO provides APIs that can be used by a number of end users to develop applications for final users, such as in the case of APPLIFARM (API-AGRO, 2019). The goal of this application, which displays API-AGRO datasets, is to increase the data exchanges made available to all stakeholders in the farm industries in a secure manner. The roles of actors in this case are illustrated in Figure 20.

The case study builds on the presentations of and interactions between those invited to the event, namely experts from public-sector agencies that provide data assets and actors outside the public sector that take the data assets and provide APIs via a specific online platform. The invitees delivered presentations during a workshop activity co-organised at an industry event, namely the September 2019 Barcelona APIdays conference. The experts were an enterprise architect from the French Interministerial Directorate for Digitisation (Direction interministérielle du numérique – DINUM), a representative of the French Ministry of Agriculture and Food and a product manager from the API-AGRO data marketplace platform. The roles of these institutions are outlined below, highlighting their interactions.

At the national level, DINUM provides data through its open data portal (data.gouv.fr) and through APIs via the api.gouv.fr portal. Together, these two projects are the main channels of dissemination of public-sector data assets in the French public sector. The open data portal aggregates open data from all of the central administration entities, operating as a platform that matches users with data providers. Each entry in this directory is accompanied by complementary assets such as documentation and a showcase of potential reuse by third parties. The number of visits to this portal has grown exponentially in recent years.

In the data.gouv.fr portal, the Ministry of Agriculture and Food and its agencies contribute and maintain around 400 open datasets. The ministry holds significant data assets, which are derived from the administrative footprint of farm and related businesses that are active in the primary sector in the country. Various policy actions – such as the administration of the Common Agricultural Policy, relief actions to farmers in the case of extreme weather events and regulatory oversight of food safety inspections and agricultural produce – are gathering large data assets at the level of the ministry and its agencies. Indeed, the ministry has more data on individual farmers and farm businesses than can be made public under current legal constraints.

API-AGRO is an online data exchange platform, namely a two-sided market that brings together data suppliers and data users. In terms of the economics of platforms, it is both a transaction and an innovation platform, enabling data exchange in a digital marketplace. The origins of API-AGRO can be traced to a 2-year project partly financed by the Ministry of Agriculture and Food in 2014 with the participation of many diverse actors. The participants in the early project saw a business opportunity, namely to build a platform for data exchange among different stakeholders, namely an ecosystem of actors with different roles and therefore with different data generation processes and different data use requirements. In 2019, the platform had become a consortium of private and public organisations, including the Technical Institute for Applied Research and the Chambers of Agriculture, which are development companies acting in the rural areas, as well as other private companies and individual developers.

The API-AGRO platform publishes various data assets drawn from multiple data sources and for multiple purposes. It attracts data providers who collect primary data originating from farm businesses, agricultural plantations and plot parcels undertaken by IoT and related sensors, as well as from software solutions under an individual agreement of reuse including, most importantly, those relating to informed consent clauses under the GDPR. At the same time, the platform gathers open data from administrative files concerning farmers and integrates in its platform open data from the ministry's APIs posted in the api.gouv.fr portal. Users of these data are accredited participants of the marketplace under individual contracts, which enable the platform to essentially customise its revenue model according to traffic volume, in addition to ensuring trust among platform participants.

The data exchange platform offers customised contracts that include terms relating to the volume and the flow of data offered, which is measured in terms of the number of datasets, the volume in exabytes, the number of API calls, etc. It offers digital amenities such as the possibility to monetise data or the possibility to integrate a third-party provider and thereby form a delegated service in the platform. The revenue model is based on licensing fees that are built based on these contractual agreements, with different tiers offering different terms and advantages suitable for different organisation sizes and origins. Given that the business model includes accreditation akin to a 'know your client' service, it builds de facto trust among participants in the data exchange platform.

The API-AGRO platform integrates all these heterogeneous sources into one single marketplace, through which multiple user categories, such as farmers, technicians and individual consumers, can obtain access, as can B2B software developers and other solution providers. In doing so, API-AGRO operates essentially as a multisided marketplace between data providers and data users that are active in the agricultural sector, giving access to data and agricultural decision support systems.

In 2019, API-AGRO and APPLIFARM settled on an agreement, enabling agricultural stakeholders to benefit from their consent management and data exchange technology for farms (Xavier, 2019). APPLIFARM is a data-sharing and valuation platform for upstream agriculture, whose goal is to make data accessible so breeder performance and animal production can be enhanced within the sector. Created in 2017 by eight livestock farming companies and initiated by a collaborative approach launched by Neovia and Evolution, APPLIFARM grants access to a catalogue of 1 000 different nominative datasets (farmer or animal) originating from 30 000 farms.

API-AGRO helps APPLIFARM display the data drawn from farms on its platform. The goal here is to encourage the secure exchange of data made available to stakeholders within the livestock farming sector. API-AGRO also offers its data exchange services to APPLIFARM's customers and benefits from APPLIFARM's expertise as the first technological service provider to join its network of top partners.

— **Public transport and traffic management.** The availability of open data from governments on public transport and transport infrastructure has generated substantial ecosystem growth across a range of transport and tourism related subsectors.

Open data made available via APIs that document infrastructure such as the location of public transport hubs (bus stops, train stations, etc.) are used to populate mapping, GPS and travel applications. The availability of these data, coupled with government API-enabled data on demographics and private industry data on aggregate spending patterns, is influencing the design and placement of new industries through the availability of more granular market research data. Examples of this include services established at bike and railway station hubs and food security. Data gathered from these services facilitates tourism-based travel, making it easier for travellers who are unfamiliar with a city to move around and spend. The availability of these data has spurred the development of new applications and enhanced ecosystem value chains, which have moved from information-richness to wayfinding to mobile transport payments infrastructure. Along this value chain, new economic activity is expected to arise from the ability to purchase venue and event tickets to further stimulate local economies.

An example from our case study work is the creation of a developer community in Madrid (Spain) around EMT Mobility Labs, which had more than 1 500 registered members who had created over 50 mobile apps (see also Figure 21). This example shows that APIs lead to new entrepreneurial possibilities and, in terms of the private sector, it suggests that APIs have been harnessed '... for a more transformative and disruptive end, giving rise to completely different business models' (Williams, 2018).

Data made available by TfL have been used to power an independent business, namely the TransportAPI platform (Mark Boyd, 2014). TfL attested to the creation of 600 applications by SMEs (see also Box 7). Mobility apps, built on government geospatial and transport data made available via APIs, have been soaring, with the appearance of more real-time train, bus and underground data, and the emergence of sharing services (cars, bikes, scooters, etc.).

The marketplace of the French national railway company (Société nationale des chemins de fer français - SNCF) APIs includes 30 apps. Captain Train, one of the biggest apps using SNCF APIs (O'Neil, 2013), was founded in France in 2009 and was bought for EUR 200 million by the UK company Trainline in 2016. It had no proper mobility data, mainly offered a good user experience in terms of selling train tickets and soon expanded to distributing tickets from 183 rail and bus carriers in 45 countries, allowing a user to book a trip across different operators. Today, Trainline sells tickets for 172 000 daily trips (Lunden and Dillet, 2016).

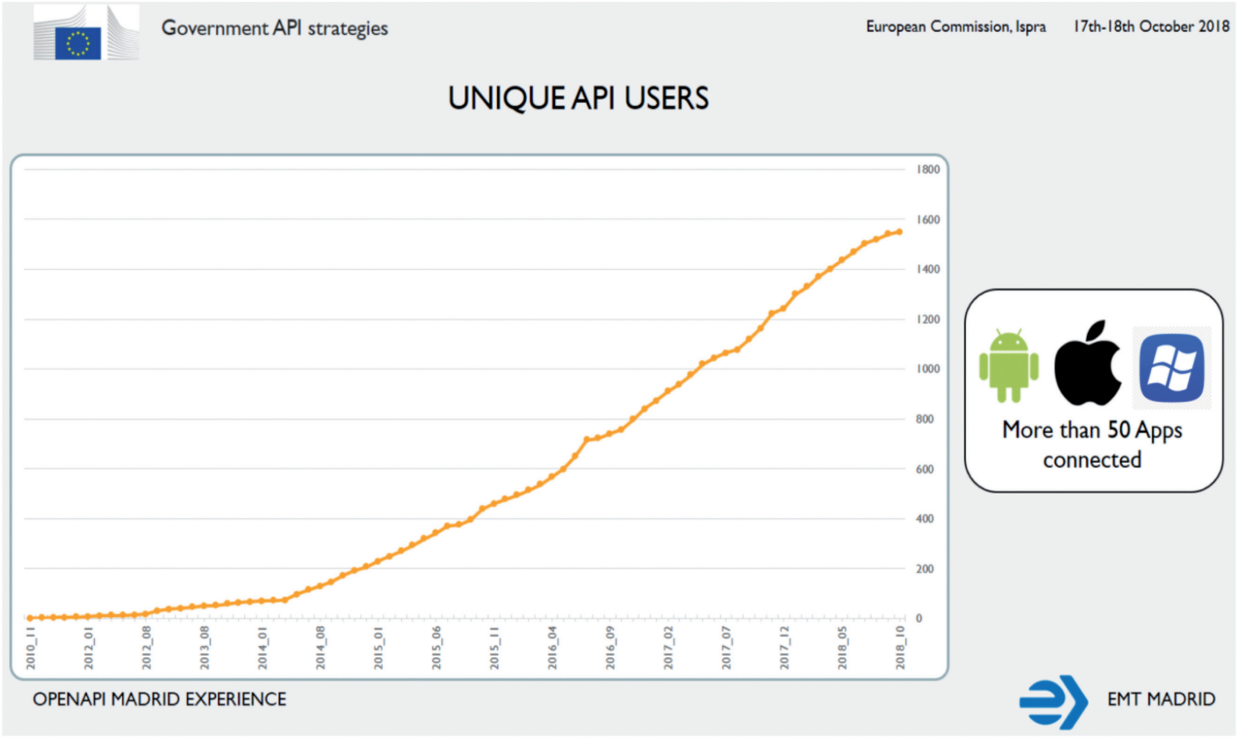


FIGURE 21: More apps from open government APIs (EMT case study).
Source: EMT, Madrid (European Commission, 2018f).

Box 7.
TfL

At a recent European conference (European Commission, 2017c), TfL detailed the investment that it had made.

- Through an API, 200 data elements are made available to some 12 000 developers producing some 600 apps that 40 % of Londoners use.
- TfL has formed partnerships with major IT players such as Apple (for mobile payment and the rental of bikes), Twitter (for pushing alerts out), Waze (a 2-way data-sharing agreement enriching the app with data from the road network that TfL manages while benefiting from data collected through Waze) and Google (enriching the map application with real-time data).
- The data can be consumed under the terms of the UK Open Government Licence with some minimal additions for free. This is done under a statutory requirement as part of UK legislation. Mechanisms are in place to ensure that consumption remains at an acceptable level. There is one single set of data at the base that is consumed both by TfL for its purposes and by third-party developers. Developers must give attribution to TfL for the fact that their apps include TfL data.
- In terms of the creation of additional economic activity, it has been calculated that, in total, the TfL open data policy generates GBP 100 million in direct value and has enabled the creation of some 1 000 jobs.
- For data acquired by a third party (e.g. Waze data), restrictions resulting from the partnership agreement apply.
- All of the data made available are data that TfL collect anyway for its own purposes. TfL is not collecting additional data merely to make them available to third parties.
- Mashing data provided by TfL with privately held data can bring additional insights (e.g. answering the question 'are there correlations between rainfall and collisions involving cyclists?').

The TfL API aggregator of public transport data is an example of the economic value generated from public transport APIs. This intermediary has not only created a business in which transport data is aggregated for use in wayfinding apps, but also stimulated economic development in other sectors including healthcare (in which maps and transport routes are provided on online booking pages for healthcare services) and in out-of-home advertising (with next transport departures displayed on kiosks and outdoor digital advertising). In turn, out-of-home advertising has stimulated local spending: commuters can spend more at venues until the moment their transport arrives, further enhancing local economies.

- **Location intelligence.** Government geospatial data offered via APIs have helped stimulate a broad range of economic activity. Maps and GPS navigation providers rely fully or in part on government geospatial data. This has stimulated the growth of new mapping businesses such as Carto and the investments of relevant private companies such as Environmental Systems Research Institute (Esri). Government geospatial data have enabled new start-ups such as the Portuguese-based Ubiwhere to create a range of smart city and mobility solutions, including the Urban Platform, which in turn has stimulated the creation of new apps and transport-related services (Ubiwhere, 2020).
  The location intelligence sector, often based on government geospatial data available via APIs, is estimated to generate approximately EUR 403 billion in 2020 (Grand View Research, 2018). Government geospatial API data have enabled GPS mapping products such as TomTom and car manufacturing software to develop, creating new economic activity. In turn, these products have been able to link to external infrastructure such as car parking bays. As a result, parking payments can be optimised so that drivers can purchase vacant car parking spaces from their GPS navigation and drive directly to their parking bay. This helps stimulate economic development by removing friction for travellers wishing to drive to spending destinations, and reduces carbon dioxide emissions by reducing the need for drivers to drive around searching for an available parking space. For parking bay operators, it optimises their

spaces in a similar way to how hotels can offer price discounts via booking aggregator apps to optimise their vacant assets (TomTom, 2020).

As the OECD's analysis of Argentina's digital government strategy found, the availability of geospatial data via APIs 'has helped to enable a user-driven and real-time approach for the standardisation of geodata in the country. These efforts have helped to ensure that data are being used both statistically and as a service for public sector systems that can generate quality data from scratch, thereby reducing the cost and burden of building value-added products and services resulting from low quality datasets' (OECD, 2019b).

— **Weather and agricultural data.** Weather APIs cover most parts of the world. Weather apps – which ingest weather APIs from government sources – are a growing business, generating millions in revenue each year from product sales and in-app advertising. Weather data via APIs are also used as a raw ingredient in digital agricultural products. Agricultural datasets and reports are also widely available from governments via APIs. Large ecosystems benefit have been expected from both these data.

Following the model of agencies that produce intelligence for commodities markets, a business of agri-intelligence is developing using the datasets available through APIs. Companies such as Gro-Intelligence use available APIs to produce intelligence for actors in the agriculture sector such as (Gro Intelligence, 2018):

- demand models for revenue forecasting, and the food industry and agribusiness;
- planting intentions forecasting for agribusiness and machines and equipment manufacturers;
- yield forecasting for credit risk management;
- drought indices for climate risk management;
- general scenario forecasting of price, climate, trade, supply and demand variations;
- farmers' financial health for banks;
- commodity demand models for insurance demand modelling;
- price forecasts for hedge credit;
- yield, area and production forecast models;
- demand models for investors in storage, handling and processing assets;
- historical and weather forecast data for supply estimates and price impacts.

— **Robo-journalism/quake-bot.** The existence of APIs can favour the development of digital ecosystems in a given industry – it can also be useful to other ecosystems. In their search for new offers, news media have started to experiment with bots and 'robo-journalism': the *Los Angeles Times*' Quakebot, followed by that of *Nice Matin* (French news media), automated article publication at each earthquake in its zone. The *Los Angeles Times*' Quakebot relies on an API from the US Geological Survey. As soon as a tremor meets set criteria, such as magnitude and geolocalisation, an article is produced automatically; in the case of *Nice Matin*, it is reviewed by a journalist before publication (BBC, 2014).

— **Vehicle registration data.** Vehicle registration data are collected by government authorities for licence plate use and to confirm that vehicles are roadworthy, meet safety standards and are within exhaust emission standards. Vehicle registration that is managed by a web service API can create efficiency gains for governments, citizens and businesses by reducing the friction in registering vehicles. For policing, digital management of vehicle registration can allow citizens to report abandoned vehicles (although, in some jurisdictions, governments have been reluctant to make these open data in the form of an API in case doing so increases the burden on policing services). However, beyond improved efficiency (which can have some ecosystem value added impacts in reducing administrative costs for businesses needing to register their fleet, as discussed above), the availability of vehicle registration data enables a whole range of new businesses and products to emerge that stimulate new economic activity and create new data-based industry ecosystems.

The UK Driver Vehicle and Safety Agency notes that vehicle registration data have enabled new use cases, including providing car details for prospective car buyers at auctions, car insurance companies using these data as an indicator of how well cars are being looked after (and hence influencing the price of insurance), validating car mileage for cars offered for sale, tracing potential mileage fraud, building apps to remind motorists when their registration is due and the reasons why that type of vehicle will most likely fail, and providing compliance data for companies with large vehicle fleets (UK Government, 2018).

— **National identity verification service.** This is an example of a government shared service delivered via an API that has stimulated ecosystem growth. Identity

verification services can enable new financial services, particularly loans, which in turn encourage new economic activity. Identity verification services can support businesses to grow their customer base and deliver more digital services once trust and consent have been established.

For example, the Singapore Government's national identity API, MyInfo, aims to provide all Singapore citizens with a secure, easy-to-use method to authenticate themselves and apply for a range of public and private services. The service is now available via APIs through the 'ndi.api' beta service. The service has been taken up across the banking and financial sectors as part of an initial ecosystem focus. To date, MyInfo has 104 partners, 163 production-grade integrations and 78 integrations that power instant data sharing. Bank users are already noting significant benefits in their use of these APIs including the following (Lee, 2019).

- One banking product for offering car loans was able to speed up the loan approval process, resulting in it taking less than 15 minutes. This, in turn, increased loan approvals by 15 %, bringing in new revenue to the credit providers and auto retail industries.
- Banks indicated they were seeing growth in new digital accounts triple, with 90 % of these accounts opened using MyInfo APIs. This created cost savings of 20 % as a result of reduced operational overheads for the banks.

Moreover, findings from the workshop and the survey reveal the opportunity of **innovative funding mechanisms** (e.g. although not common, there have been attempts to define co-funding models to fund ICT infrastructure among different stakeholders). In addition, there are beginning to be cases of co-payment in which partial and even full cost-recovery models are adopted.

4.1.6. Benefits when government assumes a regulatory role in application programming interfaces

As regulators, governments can mandate the use of APIs for given industries to encourage competition, break down monopolies, ensure consumer confidence and create innovative environments. The use of APIs can assist in the monitoring of regulation by facilitating the exchange of relevant data (e.g. metrics) with the regulating body. Examples from healthcare and banking demonstrate how new economic activity can be generated through government regulation and enforcement of the use of APIs. In Europe, the banking example has been proposed as a model for the future opening of digitised consumer services such as telecommunications, energy and utility services and insurance. The following are brief descriptions of these two cases.

— **Healthcare.** Global agreement under the Health Level Seven international organisation has created the fast healthcare interoperability standard (FHIR). This API standard ensures the security and standardisation of electronic medical health records data so that patients can share health records more seamlessly across borders and with various providers, especially at times of acute care. The FHIR sets a range of API standards for defining the electronic medical record dataset and proposes elements that should be considered compulsory for adoption by all healthcare organisations.

In Europe, the FHIR is encouraged through the Commission recommendation on a European electronic health record exchange format. This recommendation proposes investigating the adoption of the FHIR and the use of APIs more broadly to encourage innovation and citizen data security (European Commission, 2019l).

In the United States, the government has mandated the use of the FHIR as obligatory for all software and organisations seeking to work within the government's funded health system. Since 2015, software and other digitised healthcare providers must show accreditation and alignment with use of the FHIR to be eligible for Medicaid funding (Mark Boyd, 2015).

However, the regulatory environment often runs slower than technological advances and, as discussed above, this is a particular risk with APIs, for which the velocity of change and adoption increases exponentially, which quickly brings negative impacts to the forefront. In the United States, private technology companies have begun creating relationships with accredited healthcare providers to access patient data via APIs. Recent news reports show that Google now has access to large swathes of personal healthcare records due to partnership agreements that open data via APIs (Wikipedia, 2020b; Singer and Wakabayashi, 2019).

— **Banking services.** In Europe, PSD2 sought to open up the previously closed banking industry in order to generate new competition, improve customer experience and widen choice (European Union, 2015a). Governments are acting as regulators to mandate that banks must expose data and services to third parties at no cost and in a secure manner (where there is customer consent). This model, referred to as 'open banking', is seen by most as requiring the availability of APIs to ensure that exposing services and data occurs in a standardised and secure manner. Globally, there are some signs that such a move towards an open banking model is also resulting in access to a wider selection of services by those who had previously been underserved by banks, such as migrants, women and small and micro-businesses (an economic added value generated by government-regulated APIs) (Consultative Group to Assist the Poor, 2020).
At the same time as the creation of a regulated open banking environment in Europe via the PSD2 initiative, the United Kingdom also embarked on an open banking model in which standard APIs for exposing payments, accounts and banking product information were mandated (Open Banking, 2019). In Europe, legislation and implementation approaches have been less binding. APIs are not specifically mentioned under PSD2, instead requiring only that banks expose services in an automatic and no-cost manner to accredited third parties. Regulatory technical standards released by the European Banking Authority outline the requirements that must be addressed in a digital technology connecting the services, but API standards are not mandated.
LUXHUB is a start-up that has been made possible thanks to the emergence of PSD2 legislation. It is a platform that includes a marketplace for all bank (and Fintech) APIs. Owing to the lack of a regulated API standard for banks under PSD2, LUXHUB must invest resources in exposing and normalising all bank APIs so that they can work across individual idiosyncrasies in their design. At the workshop we organised at the APIdays conference in Paris in 2019, Jacque Pütz, CEO of LUXHUB, noted that **this complexity has created a new product opportunity for LUXHUB**: an integrated API that adapts individual bank APIs to a single uniform API that can be used by any third party to enable scaling and integration of all banks on the platform.

4.2 | Costs and challenges

API adoption carries both **technical** and **organisational costs**. Depending on the role that government takes when adopting APIs, these costs can vary greatly. Moreover, the adoption of APIs implies **challenges** such as those involved in overcoming the organisational mindset shift required, overcoming security vulnerabilities and adhering to current regulations (e.g. the GDPR). This section summarises the qualitative analysis of findings related to costs and challenges.

On the technical side, the sources of costs vary greatly depending on the level of API adoption. The **sources of costs** range from purely operational aspects, such as **software development**, **deployment and maintenance**, and tactical aspects, such as the **provision of digital infrastructures** and building capabilities, to strategic concerns, such as the **definition of strategic requirements** linked to the achievement of digital government goals.

On the organisational side, depending on the API strategy adopted by institutions, different sets of policy options (see Table 1) may have significant differences in terms of costs. Examples of these costs can be found in Table 6.

No main conclusions can be drawn at this stage on budgetary quantification owing to the small number of respondents who quantified their budget and the variety of ICT complexity of their API systems. However, from the results of our survey, it seems that the yearly budget used to maintain APIs, as illustrated in Figure 22, was rather low. Moreover, the allocation of the available budget was interesting in economic terms because two thirds of the API systems in the survey relied on the externalisation of resources, either by contracting services or through new public and private partnership models.

API adoption also carries **challenges** both at the organisational and the technical levels. The organisational challenges include the need to change organisational mindsets and to address new interoperability and organisational barriers. To overcome these organisational issues, the practitioners analysed in the study have (i) developed a common vision of their digital ecosystem and (ii) deployed cohesive coordination efforts (e.g. Regione

Name	Costs
Estonia's X-Road	— X-Road is a distributed system and therefore it is difficult to understand the true full total cost of ownership — The initial investment was in the region of EUR 300 000 (i.e. 6 full-time equivalent years of development
FIWARE	Public–private partnership funded by: — EUR 300 million from the EU — EUR 100 million from a private enterprise membership model — EUR 100 million from venture capital The FIWARE NGSI is open source and therefore there is no cost for the source code, but the configuration will no doubt be expensive
Amsterdam city data	— EUR 6 million over 3 years — Developers are the most significant cost — Infrastructure is less than 5 % of the cost – the hosting cost per month is around EUR 8 000
DAWA	— Initial development cost: EUR 270 000 — Operational cost: EUR 135 billion per year (includes Amazon Web Services)
Madrid Mobility Labs	— Maintenance: EUR 60 000 yearly (1 person year) — Development: 3 to 4 person months (first version) — Portal development: 6 person months
KLIP (Flanders)	Ongoing costs of EUR 1.9 million per year

TABLE 6: Multiple-case study analysis of costs.
Source: JRC, own elaboration, based on Williams (2018).

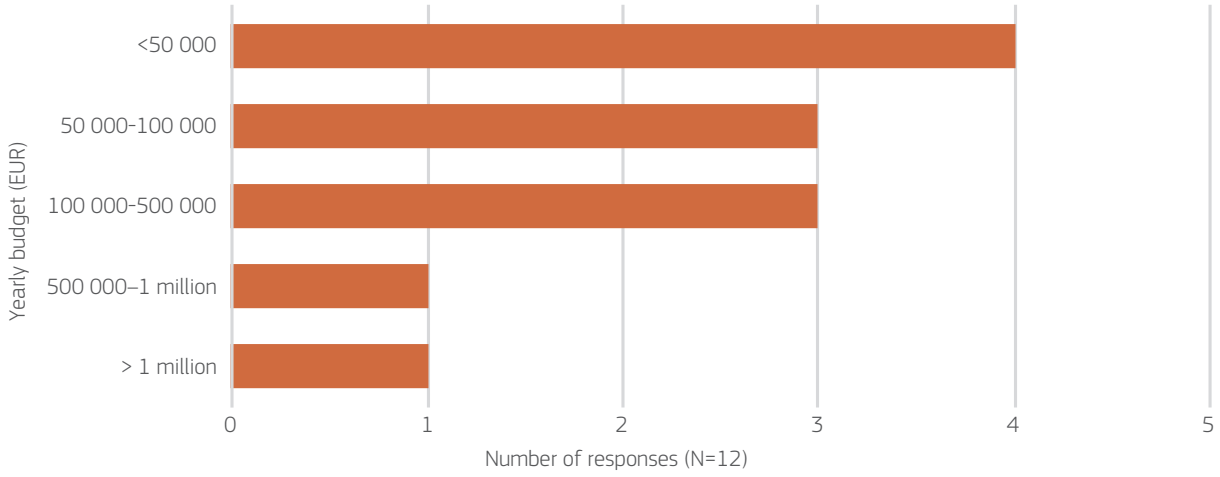


FIGURE 22: API yearly budget.
Source: JRC, own elaboration based on the study survey.

Lombardia). On the technical side, the main concerns regard increased IT vulnerability, the additional complexity in adhering to existing regulation and the lack of skills. The evidence we have observed in our study on these technical challenges includes the following.

— **Security.** As also highlighted in Section 3.2.2.4, cybersecurity is a major issue when dealing with APIs. APIs expose data, services and transactions to build new services. An API is a 'door' to an organisation's network. If not properly protected, this door could be used to get unauthorised access to the internal network and could be a free ticket to exploit internal vulnerabilities. Therefore, APIs must be appropriately secured to ensure data privacy and to ensure citizen confidence in the service delivery channel. APIs intended for access to public data must be protected from inappropriate use or abuse such as denial of service. A number of security solutions exist, such as OAuth and certificate-based authentication, which are used in conjunction with a wider cybersecurity strategy and cryptography (see also Section 3.3.2 and Santoro et al. (2019)).

— **Adhering to existing regulation.** For the most part, externally facing public-sector APIs involve the movement of data that are sensitive, as they often, in some way, refer to information about a citizen. APIs can play a significant role in the facilitation of government

transparency (Lathrop and Ruma, 2010); however, further regulatory considerations must be taken into account when adopting them. The publication of APIs, in fact, especially when sharing data, must/should adhere to a number of regulations, such as in the case of the EU GDPR (European Commission, 2018g), PSD2 (European Union, 2015a) and the Open Data Directive (European Union, 2019b).

— **Lack of skills.** The successful implementation of API strategies requires a whole new set of public-sector skills and knowledge. While policy stakeholders may not need to know the technical working of APIs, because of the mindset shift that APIs will generate in how governments function, some understanding of APIs in a wider context will be needed by most leaders in a digital government era. Stakeholders throughout the study argued for the need for more and better storytelling on the role of APIs and their value. For example, Regione Lombardia (Italy) has prioritised storytelling for all government decision-makers as an essential next step in creating the necessary buy-in to continue rolling out their digital transformation strategy (Panebianco, 2019).
Other essential skills that become imperative in a government in which APIs are widely adopted include the ability to measure value from technology enablers, user-centred design practices and ecosystem facilitation skills. Aligned with the above discussion on funding models, new collaborative work practices that break down entrenched departmental silo models would also be needed.

4.3 | Social impact highlights

In addition to the economic impacts listed in the previous sections, this section will focus on the social highlights that we have identified in our research. Our analysis is structured along the Tallinn Declaration principles (Estonian Presidency of the Council of the EU, 2017). The declaration covers the modernisation and digitalisation of governments and can be reviewed in terms of the possible application to APIs.

— **Privacy and cybersecurity.** APIs facilitate the exchange and sharing of government datasets, including those that could contain private information of citizens and companies. When correctly designed, APIs can provide mechanisms to ensure privacy- and security-related requirements are met. However, if data privacy and security are unattended, governments risk losing citizen confidence in the delivery channel and therefore weakening their authority. In this sense, APIs intended for access to public data must be protected from inappropriate use or abuse.
Some solutions to protect the privacy of citizens have been proposed at the global level, such as the Solid open-source platform and framework for application development, proposed by Tim Berners-Lee (Middleton, 2018). The Amsterdam Data Exchange (AmDex) is another remarkable initiative focusing on the protection of data, which was proposed by the Amsterdam Science Park and the Amsterdam Economic Board in cooperation with multiple partners, including Amsterdam Data Science. The project aims to provide broad access to data for researchers, businesses, governments and individuals in a secure marketplace for data. AmDex is inspired by the European Commission's Open Science Cloud (AmDex, 2019). Some initiatives, that let final users better protect their privacy have also been proposed. The MyData initiative favours the empowerment and participation of citizens and offers a citizen-centred consent-management API based on systems (MyData network, 2020). Another solution at the city level is that presented by the city of Amsterdam at our workshops. It consists in the creation of an ethics group for data privacy (Tada community, 2020).

— **Digital by default, inclusiveness and accessibility.** APIs help generate social value by making services more accessible, with less friction, as they can be accessed from any location, at any time, via digital means (e.g. on a mobile device or via the internet). This can create additional inclusiveness and accessibility, as citizens are not required to present at government offices in person, call within restricted hours or go to specific locations.
In addition, it can be noted that APIs can help monitor inclusiveness and accessibility. The Open Data Directive proposes that 'high-value' datasets be available as dynamic, real-time APIs and lists demographics as one area that should be pursued. The availability of demographics data via APIs can be a crucial tool in ensuring the inclusiveness and accessibility of a

government from the perspective of its citizens. Any project or service being implemented by a government could use a demographics API to embed population data into service access maps. At any given time, a service manager could see the distribution of access to their services and ensure that all populations are accessing the service equitably.

One of the best examples of digital by default, inclusiveness and accessibility is the availability of government-run public transport data via APIs. These data enable all citizens to access public transport in a way that reduces friction (shorter waiting times and more precise travel planning) (EMT-Madrid, 2019).

— **OOP.** In an API context, this model is being used to create moments-of-life pathways in which citizens and companies can register one aspect of their life or business and have an automated series of supports triggered as a result. For example, after the birth of a baby, a citizen should have the birth certificate registered, followed by automatically being provided with details of early childhood support, any available services for new parents, vaccination details, etc. Governments around the world, including those of Singapore (Smart Nation Singapore, 2020) and Australia (Digital Transformation Agency, 2019), are introducing APIs to address this principle.

— **Openness and transparency.** Open data APIs on government spending are described elsewhere in this report and demonstrate a clear example of the openness and transparency value generated for society by making data available via APIs.

City governments are also beginning to use APIs to enable consultation via digital means. This creates new social value in openness and transparency whereby not only are citizens informed of future plans, but they are invited via digital means to contribute via always-available consultation (combining openness social value with inclusiveness and accessibility social value). For example, in Barcelona, the digital platform Decidim links directly to Barcelona City Council's neighbourhood plans to populate discussion boards. In this way, citizens can provide feedback on upcoming neighbourhood amenity issues and see the feedback from their neighbours and how such feedback was responded to by the city government (Aragón et al., 2017).

— **Interoperability by default.** This principle proposes that citizen social value should be generated from digital services that function across borders and between various levels of government services. Identity verification is a good example of this principle generating social value via APIs. Identity verification services (accessed via APIs) can allow citizens to access services from various tiers of government or the private sector using the one identity system. This also demonstrates the OOP social value (Lee, 2019).

Government regulations that insist that health records use common API standards are also generating interoperability social value for citizens. Citizens can share their health data across various hospitals, including across countries, by using APIs (European Commission, 2019l).

— **Trustworthiness and security.** Citizens expect digital service provision to be secure and trustworthy. Failing to deliver on these requirements may weaken citizens' trust in institutions. APIs can help to enforce the traceability of transactions between government and different actors. For instance, API platforms at national levels, such as FranceConnect (European Commission, 2018f), provide users with a trusted identity, based on one of their existing accounts, to access national public services in a secure fashion.

— **User centricity.** The participants of our workshops saw citizens as an important factor in determining the satisfaction that can be achieved from resources exchanged via APIs. The user-centricity principle is increasingly being recognised by governments around the world when designing digital services for citizens and businesses. User-driven design is the primary principle guiding the OECD's digital government framework (OECD, 2019c). Principles established by Finland (6Aika, 2017b), Italy (Italian digital agency (AGID), 2018), France (Government of France (DINSIC/DINUM), 2020b), the Netherlands (Geonovum, 2019) and others include user-centric design. This follows best practices globally. The Western Australian Government, for example, clarifies the intention of its user-centred principle by stating the following: 'Start with needs: user needs, not government needs. Service design starts with identifying user needs. If you don't know what the user needs are, you don't build the right thing. Do research, analyse data and talk to users. Don't make assumptions. Have empathy for users and remember that what they ask for isn't always what they need' (Government of Western Australia, 2017).

5

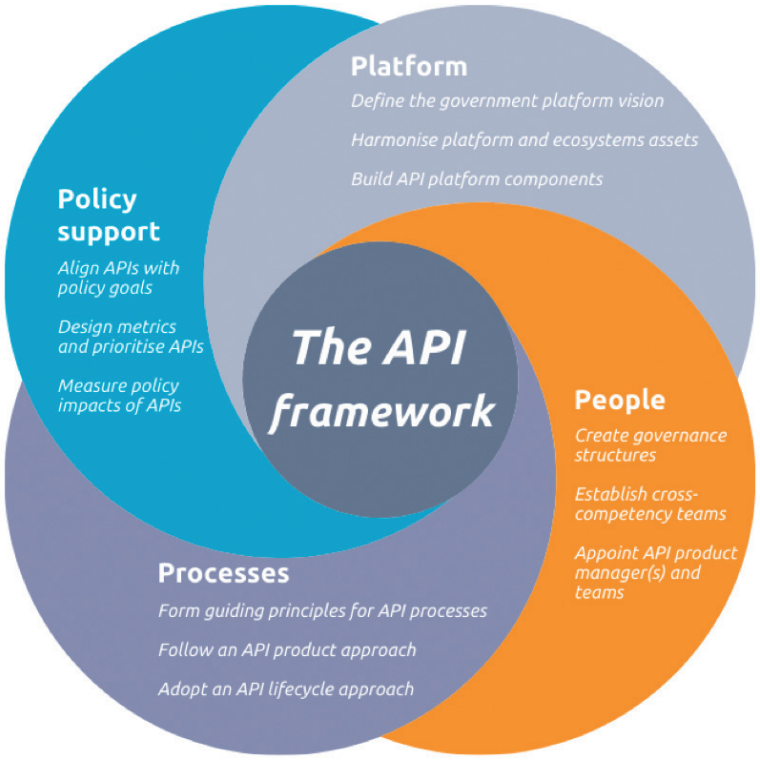
HOW GOVERNMENTS SHOULD ADOPT APPLICATION PROGRAMMING INTERFACES

SUMMARY

Based on the analysis of the landscape (in particular of the best-practice literature), and the costs, benefits and metrics identified in the study, a robust 'basic digital government API EU framework' is proposed within the study and presented in this section. The framework comprises three levels of action for different target users (i.e. at **strategic**, **tactical** and **operational** levels). For each level, the framework gives recommendations related to four different aspects, namely (i) **policy**, that is, align, prioritise and measure the adoption of APIs with policy goals; (ii) **platforms and ecosystems**, that is, define government platforms, harmonise actions of different digital ecosystems and build the API platform components; (iii) **people**, that is, create governance structures, establish cross-competency teams and appoint products managers; and (iv) **processes**, that is, form guiding principles and follow API product and API life cycle approaches. To assess the level of maturity in the adoption of the proposed API framework, a self-assessment maturity tool is also proposed. The tool lets governments track the level of maturity of their API framework and identify their next actions to address the maturity gap.

Regarding the more operational aspects (i.e. the selection of the tools to implement APIs in government), the general principles include (i) choosing tools that support agile and iterative development, (ii) choosing open-source tools by default and (iii) choosing modern, cloud-based and commodity tools. Specific components for API life cycle management must cover all stages of the API process, namely strategy, design, documentation, development, testing, deployment, security, monitoring, discovery and promotion, and change management.

Legal and licensing issues were one of the most underdeveloped areas identified in the best-practice literature review, when analysing existing government API use cases and in workshop discussions. For this reason, efforts have been made to classify the legal aspects analysed in our research, by analysing them from strategic (e.g. European Union regulation), organisational/tactical (e.g. SLAs) and operational (e.g. licensing aspects) perspectives.



5 HOW GOVERNMENTS SHOULD ADOPT APPLICATION PROGRAMMING INTERFACES

In the previous sections, we have analysed and illustrated the relevance of APIs in digital governments, analysed government API landscapes and tried to answer the first question of our study: why should governments invest in APIs? In particular we have outlined:

— the relationship between the digital government policy agenda and the use of government APIs;
— the methodology for a literature review to identify government API best practices;
— the current policy and implementation landscapes in the European Commission and the Member States;
— the benefits (including added value) and the challenges of adopting APIs by government bodies.

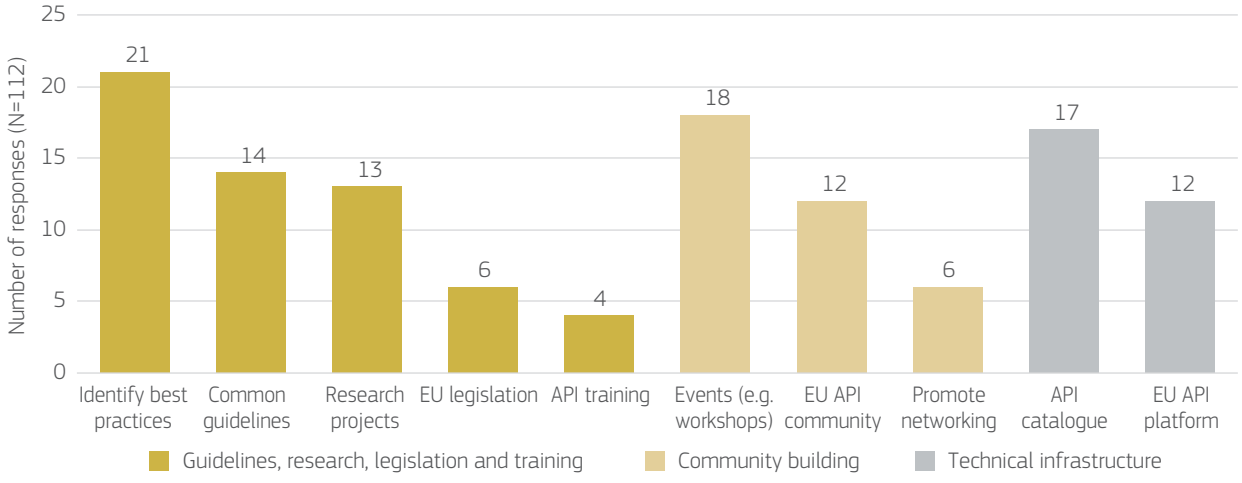


FIGURE 23: European Commission requested actions.
Source: JRC, own elaboration, based on the study survey results.

The overall goal of this section is to answer the second question: how should governments adopt APIs? The importance of this question was confirmed many times during our activities with the API stakeholders. Indeed, from our survey on European Commission requested actions, the stakeholders gave the highest priority to the need to identify best practices (see Figure 23). Together with the request to provide some 'common guidelines', this represented a clear indication of where to focus our research.

Based on the analysis of the best practices we collected within the study (see Section 3.4), in this section we first present our proposal for a robust API framework for governments, including a tool to self-assess the degree of maturity of its adoption. We then summarise the key considerations for governments when selecting API tools. Finally, we analyse a series of current available solutions for potential licence model(s) for APIs.

5.1 | A basic application programming interface framework for governments

While working on the list of best practices that governments should follow when adopting APIs, we found that the majority of best practices related to operational-level concerns. That is, there is a fairly clear understanding of industry best practices that can be utilised to design, develop and publish government APIs, from a technical perspective.

The challenge at the European and Member State levels is that APIs are rarely mentioned in strategy and overarching policy documents. Looking at the private sector, it is worth reflecting on the experiences of industry when the use of APIs began to mature. After single use-case adoption of APIs, private industry found that as more APIs were introduced in an ad hoc manner, they created additional complexity. Governments are now facing a similar experience when implementing APIs. Private industry has shown that, to be used effectively, APIs require implementation that can ensure they maintain alignment with broader business goals. APIs can also be used to increase interoperability within the organisational structures they are intended to support. APIs must also be used consistently as a common technology across operations (Vaughan and Boyd, 2018).

> *"The API framework helps governments reorient towards a more coordinated API approach across all of their operations over time"*

It is also not sufficient to simply rely on private industry practice when designing a framework for government API adoption. For example, while private industry is often driven by a profit motive, governments must create social value and provide services to all citizens. In addition, while private industry companies can focus on relationships that will benefit them the most, governments must focus on fostering economic development and creating level playing fields for all business entities. Moreover, private industry businesses tend to focus on the role of delivering products and services to the marketplace, while governments have to balance multifaceted roles that include being a provider, consumer, facilitator and regulator. Given these unique challenges, we propose an API framework that:

— addresses the risk of generating complexity through ad hoc API creation;
— facilitates EU cross-national interoperability of data and digital services;
— reflects on governments' broader functions and unique roles.

The framework has been created by using a robust methodology, shown in Figure 24. The methodology began with a literature review stage, moving on to distilling best practices and then organising them into a framework. This framework was then discussed with government stakeholders at three workshops, with the project advisory board and via an online survey. Moreover, a pilot project was conducted in partnership with the government of Regione Lombardia, Italy, to validate the framework in its initial phase. The pilot project tested and refined the framework based on a concrete case. In addition, within the pilot project, we created a self-assessment tool to measure maturity in implementing various framework components (see section 5.2). An extensive description of the framework has also been published (Mark Boyd et al., 2020a).

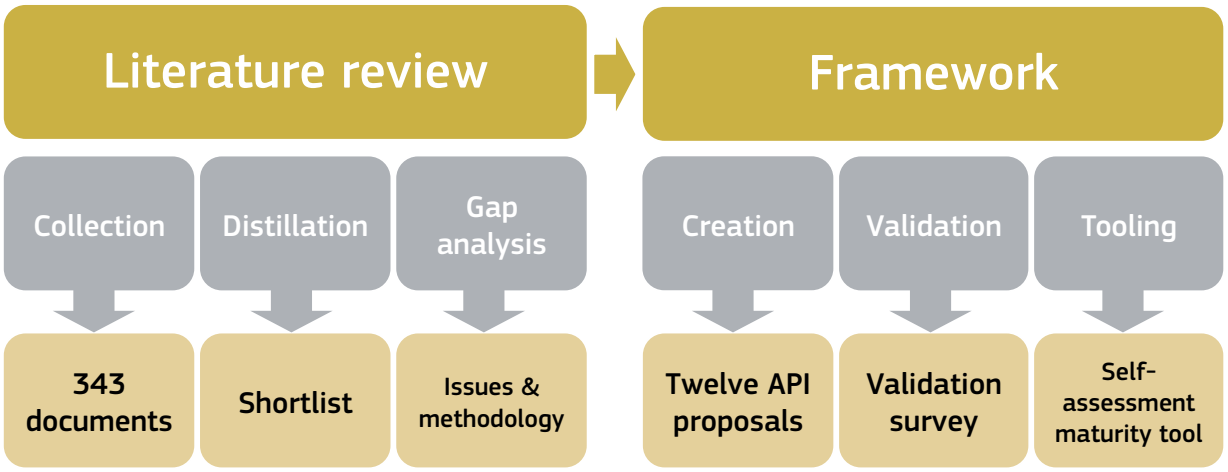


FIGURE 24: Overall methodology for the API EU framework.
Source: JRC, own elaboration.

To build the framework, we have considered four aspects or 'pillars' that reflect the capabilities available to governments to carry out action.

1. **Policy support.** Governments set policies and legislation to guide all actions across their operations. APIs are an enabling technology and approach that can help governments achieve their policy goals. This pillar describes how APIs should support policy goals.
2. **Platforms and ecosystems.** APIs enable platform models and ecosystem networks to develop. This pillar describes the core platforms and ecosystem components that need to be in place to make government APIs effective.
3. **People.** APIs require new, or updates to, organisational and team structures within government and new skills among public-service and other stakeholders. This pillar describes how people should be organised and supported to manage API activities.
4. **Processes.** Best-practice processes are available to design, implement and manage APIs. This pillar describes the processes that can ensure high-quality, effective and useful APIs.

These pillars should be considered at three levels, as proposed by Owyang (2013).

1. **Strategic.** This level involves identifying clear, broad, goals and visions to advance society and community. The first four proposals within this level describe an ideal scenario in which a whole-of-government approach is taken, even if, actually, much of this work is not yet done by the governments at international, national, regional or city levels. That is why there is a need to follow the foundational elements in place. Without them, governments will only ever create ad hoc APIs that will eventually generate complexity, reduce interoperability and reinforce existing siloes. This strategic work can be done before APIs are created or while current API activities continue.
2. **Tactical.** This level involves setting actionable targets to be achieved by allocating resources (time, people and budget). Once there is an understanding of APIs as a technological enabler that facilitates the achievement of government policy goals, with the proposals within this level, governments can then better set actionable targets and allocate resources.
3. **Operational.** This level involves implementing actions to reach targets using best practices and available tools within the available resources. With policy alignment and resources allocated, governments can work on the technical and day-to-day operational elements of adopting and managing APIs.

Ideally, strategic actions should guide tactical actions and, in turn, operational activities. But, as many situations start within an ongoing digital transformation environment, a bottom-up or, more commonly, a hybrid bottom-up/top-down process can also be applied.

Drawing from the methodology of Figure 24, the **12 proposals** illustrated in Table 7 were developed ([17]) within the framework.

	Policy support	Platform and ecosystems	People	Processes
API strategy	1. Align APIs with policy goals	2. Define the government platform vision	3. Create governance structures	4. Form guiding principles for API processes
API tactics	5. Design metrics and prioritise APIs	6. Harmonise platform and ecosystems assets	7. Establish cross-competency teams	8. Follow an API product approach
API operations	9. Measure policy impacts of APIs	10. Build API platform components	11. Appoint API product manager(s) and teams	12. Adopt an API life cycle approach

TABLE 7: API framework proposals.
Source: JRC, own elaboration.

5.1.1. Align application programming interfaces with policy goal

There are several key EU-wide and country-, regional- and city-level policies that focus on reorienting governments towards a digital model. There are also clear cross-cutting targets documented in the sustainable development goals and Europe's commitment to these goals is outlined in the document *A Sustainable Europe by 2030* (European Commission, 2019m). An API framework ensures that government APIs can be introduced to support these existing policy goals. A similar process is observed in private industry, where companies are encouraged to 'prioritise API development based on the business's strategy, business and modernisation impact, and ability to execute' (Iyengar et al., 2019).

At present, some European Commission policies explicitly mention APIs as being an enabling technology to achieve goals. However, this leave room for the adoption of alternative solutions and can lead to a duplication of efforts. Policy and funding goals are also distributed across government operations at the European Commission and Member State levels (and also within regional and city government organisations). When policy goals and funding environments are siloed, there is little incentive to encourage collaborative work. APIs can assist in encouraging collaborative work as multiple departments work together to share data and services, for example. An added benefit is that, when two departments are pursuing separate but similar goals, APIs can assist in fostering joint action. For example, transport departments may be responsible for using data to better manage traffic congestion and environmental goals may focus on reducing consumer-based carbon dioxide consumption. Therefore, APIs that assist governments in developing more direct driving routes or the use of public transport help to achieve both transport and environmental departmental goals.

For each government policy goal, APIs should be considered to support the achievement of these goals. If APIs are implemented, the API framework should be used to ensure the cohesive design, creation and management of APIs.

Once it has been identified which policy goals can be achieved through APIs, an impact assessment can be carried out to ensure that APIs will not have any detrimental impacts when being leveraged as an enabling technology.

> *"Policy support, platforms, people and processes have been considered at strategic, tactical and operational levels"*

5.1.2. Define the government platform vision

Without a defined platform model, governments risk simply replicating existing paper-based services as digital services, continuing siloed approaches and reinforcing current market barriers to participation that exist in traditionally organised systems (Margetts and Naumann, 2017).

When governments step back from a purely 'digital government' agenda (in which the government provides 'digital services'), a different approach to government can be considered. For example, in Australia, the national Digital Transformation Agency reimagined government services as being automated and evoked at key life

transition stages (also known as life events-based actions). These events include birth, marriage, the completion of education and starting a business (Digital Transformation Agency, 2019). The Singapore Government has introduced a similar model as part of its API and digital government strategy, entitled the 'Moments of life initiative' (Smart Nation Singapore, 2020).

This type of new paradigm of joined-up and automated service delivery by government is not imaginable if the starting point for API creation is to simply convert the paper-based service into a digital service. Evaluations and reflections by policy leaders involved in the digital government transformation agenda have noted that the biggest failure has often been that governments have not been 'bold enough' in envisaging new platform models of government (Loosemore, 2018).

Governments introducing APIs are embracing platform-based models in which services and data assets are shared internally between departments and can also be exposed securely to external stakeholders. This approach alters the current government model, including current budgeting processes and cross-collaboration approaches. As discussed above, in an API-enabled government platform model, governments are producers, consumers and regulators at the same time and a consideration of how these roles intersect is an important visioning exercise to undertake before embarking on a whole-of-government API strategy (Koponen, 2018).

By articulating a platform vision for government APIs, new opportunities to leverage APIs to deliver on this vision emerge naturally (Dastur, 2018). For example, in the European Commission's digital strategy, one of the goals is to co-create value with external parties (European Commission, 2018b). By acknowledging that this is part of the process of adopting a platform model, it is easier for strategic implementers to see the role that APIs could play in enabling co-creation. This vision could inspire new thinking around common data models and identifying priority ecosystems, which, in turn, could trigger discussions around future viable private–public partnership business models.

The four proposals suggested at the strategic level (i.e. proposals 1–4 of this API framework) do not seek to create policy for governments. Digital government leaders who are responsible for overseeing the implementation of API activities at the whole-of-government and departmental leadership levels are not creating policy. They must ensure that API activities align with strategic decisions. This involves first understanding the whole-of-government policy goals and identifying where APIs can play an enabling role.

In particular, digital government leaders need to understand the level of support for platform models. For example, some governments are focused on reorienting themselves towards a platform model in which internal departments share resources and work more collaboratively. Other governments may have a platform vision in which partnerships are extended primarily to local businesses, research institutions and community groups. Others may be looking at platform models with larger industry partnerships. This proposal asks digital government leaders to research and understand what platform model their government has chosen to pursue.

5.1.3. Create governance structures

Enabling APIs for reuse and interoperability, within a platform approach, requires agreement on how to enhance interoperability, including on adhering to common API standards, considering which shared data models must be commonly defined, defining the common architectural choices and determining which service components can be reused. Oversight needs to ensure that appropriate access is secured for APIs to prevent the exposure of data on citizens and businesses. Governance structures can:

- help ensure standardisation;
- address and manage risks;
- encourage interoperability;
- ensure adherence to wider government policy principles.

The European Commission EIF (European Commission, 2017a) gives a set of recommendations for public administrations on how to improve governance of their interoperability activities, establish cross-organisational relationships, streamline processes supporting end-to-end digital services and ensure that existing and new legislation does not compromise interoperability efforts. The EIF includes four interoperability layers (see proposal 6), an integrated public service governance layer and a 'interoperability governance' layer to: (i) ensure holistic governance of interoperability activities across administrative levels and sectors, (ii) identify and select standards and specifications and (iii) ensure that

standardisation work is relevant to the needs of the organisation.

There are several factors that will influence the establishment of appropriate governance structures, including:

— skill sets and an understanding of APIs among potential governance committee members;
— the availability of resources such as risk assessments and API style guides to assist oversight;
— government visions of a platform model, which may influence the degree to which a governance committee is a facilitator that encourages action or a prescriptive regulator that approves or rejects the API-focused activities of various government departments and teams (OECD, 2019c).

Another challenge will be to create sufficient governance structures to encourage knowledge sharing, prevent duplication and ensure the use of interoperable and standardised methodologies without generating too many additional committees or reallocating project resources to the creation of new governance structures.

5.1.4. Form guiding principles for application programming interface processes

The literature review of government API best practices found that one key best practice when aligning APIs with a whole-of-government strategy is to identify and clarify a core set of principles to guide API action. The European Commission and governments of many Member States have defined charters of core principles to guide their work, either in creating APIs specifically or more generally to guide the development of digital government or digital services.

A set of core principles helps guide government actions when implementing digital government models. Principles help governments maintain accountability and transparency by providing all stakeholders with a clear means of assessing the motives of and commitment to government action. Governments can share and, if needed, review their core principles and ensure that they are understood by the teams responsible for overseeing digital government, cybersecurity, interoperability and API-focused activities across all of government.

The European Commission EIF can be considered within these principles (European Commission, 2017a). They establish 12 interoperability 'underlying principles of European public services' that are fundamental behavioural aspects for driving interoperability actions: subsidiarity and proportionality, openness, transparency, reusability, technological neutrality and data portability, user-centricity, inclusion and accessibility, security and privacy, multilingualism, administrative simplification, the preservation of information, and the assessment of effectiveness and efficiency.

5.1.5. Design metrics and prioritise application programming interfaces

Individual departments or agencies will need to identify which APIs are the priority. Collaboration across them will also need to occur to identify common platforms needs among all of them that can be budgeted for and created collaboratively. Once priorities are set at the whole-of-government level, departments or agencies can allocate resources to adopt API activities or share resources to collaborate across departments on common elements.

To ensure that APIs are achieving policy goals, metrics need to be introduced that measure the policy impact of APIs. When governments prioritise which API activities they will work on, they need to also define how success will be measured. Metrics need to be defined that will assess and check if APIs are enabling policy goals to be achieved (i.e. figures on connections with external actors (G2B, B2G, G2C), figures on the reduction of the digital divide, figures on the overall efficiency gains of the organisation and, in the case of platform environments, figures on networking effects).

5.1.6. Harmonise platform and ecosystems assets

API platforms require a range of stakeholders to agree on a set of minimum common choices to enhance interoperability (including to adhere to common API standards, considering which shared data models must be commonly defined, and to define common architectural choices) and to agree on which service components can be reused and, sometimes, even the use of common tools. Implementing a government API framework requires the following components.

— Prioritised ecosystems. These ecosystems should be made up of networks of stakeholders that participate in a domain area of expertise, such as transport, agriculture, etc., to identify common use cases and industry needs for APIs.
— Data registries. Shared data should be selected and analysed. A minimum set of common syntactic, (e.g. format) and semantic (e.g. terms, properties and relationships) characteristics should be discussed and agreed upon. To avoid ad hoc outputs, the reuse of existing and recognised models should be considered, such as Schema.org (Schema.org community, 2020)). Single-source-of-truth datasets/core vocabularies can be reused to avoid complexity and duplication.
— Shared services. These are common digital services that are reused as components in value chains. For example, an identity verification capability or a payments functionality can be built once and used in multiple departments' websites and mobile apps.
— Single inventory point, such as an API catalogue or an API portal. This allows internal or external stakeholders to access the documentation about shared services and data registries via APIs at a unique point in the web.
— Shared technology standards. Agreements on standards ensure that APIs are easily understood and replicable because they share nomenclature and other design elements (Hong Kong Monetary Authority, 2018).

The European Commission EIF gives fundamental guidance on implementing interoperability among and within public administrations through a set of recommendations on how to improve governance of their interoperability activities, establish cross-organisational relationships, streamline processes supporting end-to-end digital services and ensure that existing and new legislation does not compromise interoperability efforts. The EIF proposes an interoperability model that is applicable to all digital public services and may also be considered as an integral element of the interoperability-by-design paradigm (European Commission, 2017a). It includes:

— four layers of interoperability: legal, organisational, semantic and technical;
— a cross-cutting component of the four layers, namely 'integrated public service governance';
— a background layer, namely 'interoperability governance'.

Moreover, the European Commission has launched a series of initiatives within SEMIC of the ISA[2] programme. SEMIC has developed a number of semantic specifications and interoperability solutions that are available to public administrations, namely the e-government core vocabularies ([18]), the Data Catalogue Application Profile for Data Portals in Europe (DCAT-AP) and the Asset Description Metadata Schema (ADMS). The *Handbook for Using the Core Vocabularies*, in particular, describes how the core vocabularies can be used by public administrations when creating APIs to attain a minimum level of semantic interoperability for e-government systems (European Commission, 2020i).

The French government's modernisation strategy has proposed mobilising ecosystems and using web standards to encourage common data models, standardised APIs, a unique inventory point and collaborative efforts within government departments and with external stakeholders (French Secretary-General for the Modernisation of the Public Action, 2020).

In Italy, domain-driven ecosystems (i.e. networks of stakeholders that share expertise in a common sector subject area, such as transport) are seen as central to assisting with prioritising and delivering API activities. In particular ecosystems:

— support a citizen- and business-oriented vision, leading to the creation of services that simplify interactions with public administrations;
— standardise the approach to the development of public administration services;
— stimulate interoperability;
— capitalise on the experiences gained by individual public administrations through the enhancement of best practice (Agenzia per l'Italia digitale, 2019).

Ireland's Chief Information Officer has noted that challenges with the country's current data architecture have resulted in a lack of data sharing across public bodies. It has also

led to duplication in data storage and collection. Ireland's vision for a more efficient data ecosystem is based on improving government operations by utilising APIs. It is currently introducing base registries (i.e. single authoritative sources of data that are mandatory for public bodies to reuse, accessed by APIs), encouraging discoverability by publishing all APIs to a single catalogue and creating an interoperability platform approach so that data and services can be reused across silos (Warren, 2018).

Approaches to creating domain-driven (vertical) ecosystems are still in their infancy, and best-practice methods have not yet been identified. Furthermore, some governments are focusing on cross-collaborative internal ecosystems that only involve government departments and public authorities working together in a given domain area, while others are creating ecosystems that involve external partners and stakeholders. The communication *A European Strategy for Data* has identified the importance of establishing domain-level data spaces in areas including industry (manufacturing), the green deal, mobility, health, finance, energy, agriculture, public administration and skills development.

Despite long-standing initiatives such as the INSPIRE Directive (European Commission, 2019n) and Eurostat collaborative work by governments to develop shared data models (Grazzini et al., 2019), the idea of API standards for them could be considered innovative (Geonovum, 2019) and this framework suggests to further develop it..

5.1.7. Establish cross-competency teams

API adoption requires multidisciplinary teams. Typical team compositions should include an API team leader who can act as a product manager to drive usage and ensure alignment with user need. The team leader can also communicate with policymakers to ensure that APIs serve policy goals. When APIs are built, engineers can make decisions based on appropriateness or technical best practices. However, sometimes, these inadvertently change the focus of the API slightly.

A product manager ensures that these changes both satisfy the requirements in a flexible, efficient and effective way and ensure that APIs remain aligned with the original policy-oriented intention.

Other team members required include an IT architect and developers/engineers. As the team grows, a developer advocate or evangelist will be needed to encourage use and to create resources that help internal and/or external users to integrate the government APIs into their workflows and digital services.

Multidisciplinary teams and an API approach will also require new public-sector skills. APIs need to be built to meet needs, so design thinking or user-centred design skills will be needed (Fujitsu, 2015). Other skills needed will include negotiation and collaboration skills, as team members will increasingly need to reuse and share APIs across departmental silos (Varteva, 2016).

Training resources on understanding APIs and their role in government policy and service delivery will need to be prepared and delivered across government operations. Digital skills competencies will also need to be updated to better reflect API knowledge (6Aika, 2017a). For example, it could be useful to further develop and use initiatives such as the Interoperability Academy, which is an 'eLearning platform, accessible 24/7, aimed at improving the knowledge of public servants on the reuse of ISA^2 solutions and supporting the implementation of the EIF' (European Commission, 2019a).

5.1.8. Follow an application programming interface product approach

Governments often deliver services in the form of programmes. Short-term pilot projects or time-limited projects are also conducted to meet specific targets or address other short-term needs. When introducing APIs into government, departments need to think of APIs as being akin to programmes or, in private industry terms, products. This means that they are treated as medium- to long-term assets that must be maintained, rather than as one-off or pilot projects with a definitive end date. They will require documentation for a range of user groups. They will need to be regularly reviewed, improved and updated. Their usage will need to be tracked to ensure

they are providing value and meeting organisational goals. If they are not proving useful or creating value, they will need to be deprecated.

Clear permissions and rights of use for an API are also part of API product management (6Aika, 2017b). Once APIs are available as reusable components for workflows, products and services (either within government or exposed to third parties), users need to be confident that the API is available, performant and permissible: availability means that it is able to be found, for example, in a government's API catalogue and that it does not stop working unexpectedly; performant means that it feeds data or services in a timely and consistent manner; and permissible means that end users understand their responsibilities and have an appropriate level of security and authorisation to use the API functionality for their use case. For example, external users will need to know if they are allowed to use government APIs in a commercial product and will need to be strictly checked and authorised to access private or internal government data.

Few governments are resourcing and managing APIs in an ongoing, programmatic way at present. While there are some examples of mature APIs being delivered by governments, the main issue at present is that, for some governments, creating and making APIs available is seen as a 'pilot' project that is not yet resourced rather than as a programme/product approach that is managed through ongoing and budgeted resources.

All government APIs should first be used internally. When identifying use cases for creating service and dataset APIs, internal use should be prioritised. That is, the API should be used internally to drive information flow or enable functionality within or between departments. This will help to ensure that APIs deliver value and that they are robust and performant.

Each API should define service-level objectives or expected standards of performance for internal stakeholders and, eventually, when opened to wider audiences, how they are expected to perform and be used when exposed to third parties. Service-level indicators can be used as measures to ensure departments are achieving their objectives or are addressing shortfalls when they are not.

APIs should be budgeted and resourced for ongoing use, including budgeting and resourcing for a product manager and associated tooling.

5.1.9. Measure policy impacts of application programming interfaces

At a tactical level, it is proposed that governments work with ecosystem stakeholders and across government to identify API activity priorities and to define the high-level value that is expected to be generated from the APIs being created (see proposal 5). Following this, at an implementation level, it is important to ensure that there are ongoing mechanisms that allow governments to monitor and measure that value. This monitoring can also ensure that no harms are inadvertently being introduced. As industry use of APIs has matured, analytics have been introduced to monitor the impacts of APIs. The three main types of metrics introduced for APIs are as follows.

1. **Performance.** Metrics for APIs were initially introduced to ensure that APIs were robust and performant. Uptime, security and response rate, for example, helped API technicians ensure that their service-level objectives were met. This is the most common form of measurement and is often carried out by businesses, as well as in government.
2. **Strategic value.** As APIs increasingly became recognised as a way for businesses to deliver on their strategic goals, key performance indicators were introduced to better measure API impacts on business goals, such as the ability to bring in revenue or to increase engagement with particular target markets. This is emerging in private industry as an important metric for ensuring that APIs are built with organisational value but there is not, as yet, a similar common approach within government.
3. **Ecosystem impact.** In line with a product management approach to APIs, alongside measuring the business benefits of APIs, new measures were introduced to ensure third-party adoption, for example measuring the time it took for a new developer to start using an API (referred to as the time to first hello world or TTFHW). Other measures included developer satisfaction and the likelihood of developers recommending an API to their peers (i.e. the net promoter score). These

metrics are often collected by both businesses and government, particularly by measuring adoption uptake of an API or by sharing examples of how the APIs are being used by external stakeholders.

Government API teams can measure these three types of metrics, but must also consider a fourth area: are APIs avoiding causing any detrimental impacts?

For example, when governments use APIs to expose large datasets to machine learning, they need to measure if the resulting algorithms are introducing any bias that creates inequality or marginalises any particular population. Also, if APIs are being used to create new digital services, there is a need to analyse usage data and ensure that populations without digital literacy still have available forms of access to government services. Sharing external unrestricted APIs should also be carefully considered to create a fair digital economy that supports SMEs. Monitoring the potential for negative impacts of APIs should be an essential part of a government API policy impact measurement system.

5.1.10. Build application programming interface platform components

A key challenge for the European Commission when encouraging the uptake of digital government goals is to find the right balance between being overly prescriptive on technology choices and building common interoperability platform components, such as the CEF building blocks. The CEF approach reinforces the necessity to build standardised IT infrastructure components that can ensure interoperability and sustainability.

In the case of national governments, there are some cases that are developing in that direction. The Estonian government, for example, identified several necessary steps, including (Kütt, 2016):

- adopt an API-first policy of enabling things rather than providing things;
- take control of the architecture;
- build an authorisation solution to enable APIs to handle sensitive data;
- invest in data protection, audits and fraud detection;
- discuss with end users;
- treat open data as APIs;
- build open data into new systems;
- develop prototypes and reference architectures.

When needed, platform components should be built following more flexible and sustainable approaches, such as, for example, the REST architectural style. The Italian government's Digital Transformation Team has affirmed the use of RESTful APIs based on government experience and interaction with third-party users. In 2005, Italy created the SPCoop standard for interoperability in the public sector. This was a SOAP-based, four-corner integration approach, and, 12 years after its introduction, 200 agencies were able to deploy and afford this common infrastructure, while smaller organisations and cities were not. The largest barriers to widespread adoption were the closed nature of this approach, that it required 1:1 contracts to be signed for each implementation and the fact that this 'mandatory infrastructure' was designed only around government-to-government use cases. The government reviewed the technical literature and noted that REST was the 'de-facto standard in the private market' and that various agencies started implementing REST-based APIs in 2013, which were opened to the private sector (Italian digital agency (AGID), 2018). They found this to be a successful pilot project, as REST was easier and cheaper to implement of the SPCoop solutions, and enabled engagement with private-sector actors. In 2017, this model became central to the Italian government's 3-year whole-of-government strategy, which included REST APIs written with OAS, where possible; market-driven API standards; iterative upgrades and versioning of government APIs; a public API catalogue; and self-serve access to appropriately secured APIs. The architectural model remains bimodal and allows existing SOAP services to continue operating (Piunno, 2017).

The Belgian government has created REST guidelines in recognition of the following factor: 'The main benefit for choosing RESTful services is to increase flexibility and to offer web service support to client platforms not able to communicate using SOAP web services' (Belgium Government, 2020). It noted that:

- REST is the de facto standard to communicate with web services from JavaScript and native mobile applications;
- while SOAP is strictly linked to XML and needs complex standards (a message transmission optimization mechanism, SOAP with attachments) to work with other media formats, RESTful services can support this natively;

— web service specifications added to SOAP are often overly complex;
— REST has become the industry standard for developing APIs on the web.

The Netherlands government has released an API strategy that states that the government 'aims to describe a set of design rules for the unambiguous provision of RESTful APIs. This achieves a predictable government so developers can easily start consuming and combining APIs' (Geonovum, 2019).

While governments may be challenged to mandate REST APIs for all government operations, best practices suggest that developers should consider building new APIs using modern web standards such as the REST architectural style. Regular monitoring of existing legacy architecture can then calculate if there are any efficiency or cost gains that could be achieved by moving existing SOAP approaches to REST, or if this would introduce unnecessary costs.

Leadership governments are creating style guidelines that document internal practices and standards for the creation of APIs. These style guidelines often propose REST, the use of an API specification file, naming conventions, security requirements and approaches to versioning.

5.1.11. Appoint application programming interface product manager(s) and teams

After an API-as-a-product mindset has been adopted at the departmental level, department staff members will need to be appointed as API product managers to help decide resource allocation (see proposal 8 above). These product managers will be responsible for creating developer resources (e.g. documentation) and for ensuring that support for developers consuming the government APIs is delivered in line with service-level objectives. The product manager would work closely with the API technical lead to ensure that APIs can achieve the intended policy goals and match use cases. The product manager would implement processes to collect and report on metrics (see proposal 9). An API product manager could also assist with maintaining communications with the domain ecosystem of stakeholders (see proposal 6).

The optimum organisational structure within government for such an approach is not unique. For example, some governments have multiple APIs that are managed together by a service manager (i.e. someone who manages or 'owns' multiple APIs together by focusing on how they work in combination as a whole). Also, a service manager could manage multiple APIs or an individual API could need a product manager. In any case, each department offering government APIs would need to appoint a staff member to be product manager for each API or group of APIs. Job descriptions, tasks and performance indicators will need to be prepared that reflect the product management duties to be performed.

The product manager should have overall responsibility for ensuring that APIs are discoverable, easy to use and documented, and see increasing adoption among those who can receive value from the APIs. The product manager works with technical leads and technical teams to ensure that APIs are performant, are used efficiently within resource constraints and maintain high security and data privacy standards. The product manager communicates with policy managers to identify use cases and new features, and monitors how the APIs are creating value in line with expected policy goals, without increasing detrimental impacts on communities and local economies.

5.1.12. Adopt an application programming interface life cycle approach

API life cycle management components should cover all API aspects, namely: strategy, design, documentation, development, testing, deployment, security, monitoring, discovery and promotion, and change management (Mehdi et al., 2018).

An API life cycle approach ensures that government APIs are built in line with best practices for authorisation and authentication, security, versioning and test-driven development.

API life cycle approaches also ensure that best-practice web development and software design is followed (Google, 2019). Moreover, API life cycle approaches ensure that API design matches policy needs and use case descriptions (through metadata specifications) throughout an iterative development cycle. API testing ensures that APIs function as intended and are robust and performant. API security and privacy measures can be included within the development stage and ensure that whole-of-government cybersecurity practices are followed (e.g. using the privacy-by-design principles documented in World Bank (2018)). Finally, API life cycle approaches ensure that APIs can be monitored and maintained at the desired efficiency, sustainability and performance-level requirements.

Work on API design guidelines is one of the most advanced areas of API activity by governments worldwide. Several governments within Europe have defined their API life cycle approaches. Design (or style) guidelines, once agreed, can then be used by governance structures to assess new APIs and ensure that they meet organisational requirements (see proposal 3).

5.2 | Application programming interface framework self-assessment

The above API framework is proposed to support governments in continuing and extending their current API activities in a cohesive and structured manner. The framework seeks to assist governments in aligning to a broader policy context, introducing metrics that measure the value and impact of APIs, and making use of best practices at all levels of government work (including policy and strategy, tactical decisions and individual API implementation). Reorienting existing government work to make use of the proposed API framework raises two key questions:

1. How does a government department build on its own API-initiating efforts while also moving towards adopting government-wide best practices and a more cohesive model that aligns with the whole-of-government and with the local, national and international agendas?

2. How does a government continue its API activities but also move towards a more structured model that avoids duplication and fosters collaboration, reuse, interoperability and industry innovation?

To answer these questions, within the study, we created a self-assessment maturity tool. The tool lets governments track their level of maturity against the API framework and identify next actions to address any gaps. Maturity models are used by governments in the European Union and around the world to help guide a reorientation process towards new paradigms for government operations. In designing and developing this maturity tool, we have considered some of them, namely (i) the open data maturity model (Cecconi and Cosmina, 2019), proposed by the European Commission; (ii) the DIGIMAT – eGovernment Maturity Assessment (CITADEL H2020 project, 2018), proposed by the CITADEL H2020 project; and (iii) the South Australian government's digital maturity assessment tool (Government of south Australia, 2019). These models aim to help governments assess their progress in transforming their key digital capabilities.

These three instruments each propose a set of dimensions by which maturity can be measured. A similar approach has been taken with the API framework maturity tool, which requires that government actions be aligned across the following dimensions:

— organisational infrastructure
— organisational leadership
— resource allocation
— skills
— metrics.

> *A self-assessment tool support governments tracking their level of maturity wrt the API framework and identify next actions to address gaps*

The self-assessment maturity checklists provided by the tool are intended for the digital transformation policy and IT leader(s) of a government's digital transformation, digital strategy, digital government or interoperability agenda who need to align APIs with wider policy goals and prepare common IT architecture and platform components for delivery of APIs, open data and shared capability services across the whole of government. This/these leader(s) may choose to complete the checklists with the cross-departmental collaborative body champion or other members of their whole-of-government management team.

For each of the proposals, we have prepared a checklist of a maximum of 10 questions. Depending on the answer, a weighted score is assigned and totalled for each proposal. This overall score represents a self-evaluation of the degree of maturity that that government has with respect to the suggested proposal. The tool and the checklists have been extensively described in (Mark Boyd et al., 2020a) and published online (Mark Boyd et al., 2020b).

5.3 | Tools selection in application programming interface life cycle

This section describes the key technical considerations for governments when selecting API tools. These tools often reflect operational concerns and could be utilised as part of the implementation of proposals 11 and 12 of the proposed API framework, when taking an API life cycle and product management approach.

The API industry offers a wide range of tools that support every aspect of the API life cycle, including design, deployment, implementation and management. Some are proprietary, while others are free and open source. Some tools are tailored towards single API deployments, while others are built to facilitate the development of an organisation's entire API ecosystem ([19]). As the API industry increasingly matures, governments may use a range of tools available to assist them in creating, deploying and managing APIs.

Several governments around the world have created technology codes of practice and procurement policies that guide them when selecting these tools and technologies for operational tasks ([20]). From our analysis of a set of documents about these practices, we have identified the following recommendations.

— **General principles.**

- **Choose tools that support agile and iterative development.** APIs should be deployed using modern software best practices, including version control and continuous integration. Tools that support APIs should therefore easily plug into a continuous integration and delivery pipeline (US Digital Service, 2020).
- **Default to open source.** Governments often make decisions to choose open-source tools whenever possible. Many companies offer products and services while the code they run on remains open source. Defaulting to open means governments can contribute back to the code to make the changes wanted, allowing internal engineers to understand how the tool works and maintaining infrastructure that is public, accessible and collaborative (Government of Canada, 2019b).
- **Choose modern, cloud-based and commodity tools.** A government's API engineering team should be able to work efficiently and an API should be able to scale quickly. Therefore, tools should be selected that are widely adopted by successful consumer-focused private-sector companies. Governments can seek to avoid vendor lock-in by choosing open-source, cloud-based and commodity products (Government of Canada, 2017; US Digital Service, 2020).

— **API life cycle management tools should cover the following life cycle stages** (Mehdi et al., 2018).

- **Strategy.** Like for other products, having a strategy for APIs is fundamental to guarantee that APIs are successfully adopted. In the API framework illustrated in Section 5.1, we have clearly identified how a government should proceed when adopting and implementing APIs. The framework suggests 12 proposals at three different levels for driving the activities of governments in their API journeys. In particular, at the strategic level, the framework identifies four main actions to be considered: (i) align

APIs with policy goals, (ii) define the government API platform vision, (iii) create API governance structures and (iv) form guiding principles for API processes.

- **Design.** When developing a new API, a design-first approach enables a team to focus on building solutions for end users from the beginning. A government's API life cycle should involve sketching out an API idea, designing resource and endpoint structures, and choosing response formats before beginning development. Lots of decisions must be taken when designing an API. At least the following aspects should be considered: semantics (e.g. vocabularies and data models), styles (e.g. protocols and patterns), interactions (e.g. the workflow of the API calls), safety (e.g. procedures to avoid use mistakes) and consistency (e.g. with other institutional APIs) (Mehdi et al., 2018).
  Tools exist to help design and prototype APIs, which allow engineers to write the API in a less technical language such as Markdown or YAML, generate interactive documentation and create mock servers, all without writing a line of code for the API itself.
  Governments can engage with end users using these tools and can get early feedback on the design of APIs, with real users testing out the usability by reading the documentation and writing client code against the API. APIs can also be explained using an API definition (e.g. OAS, API Blueprint or RAML) and sharing that document with users for feedback (Mark Boyd, 2017a). The API definition can be used as the backbone for much of this testing. Incorporating an API definition in the design process enables to use that definition in later stages of the API life cycle, such as documentation and testing. Many tools also integrate into the continuous integration pipeline, so that the API can be tested as part of the build process.

- **Documentation.** A machine-readable API definition should be part of the documentation because of the ubiquity of tools helping developers use API definitions/metadata to discover, understand and consume APIs, and because that definition can be used for other aspects of API management such as design and testing. However, the documentation should not just be the definition file. Documentation represents the learning experience for an API and therefore should also contain content explaining the context and purpose of your API, set expectations for versioning and support, and provide use cases or tutorials for getting started or achieving common workflows (Mark Boyd, 2017b).
  Documentation is extremely important for discoverability purposes. Currently, many web registries, directories and marketplaces are available to allow API providers to describe their APIs and to let API users search for and use the APIs that fit their needs. At the moment, all of these initiatives are based on manual contributions from both the publishers (which have to expose and register their APIs) and the users (who have to search for and select the APIs they are interested in). However, to our knowledge, there is no automatic way for a final user to discover the right API that fits his/her requirements ([21]). Documentation is the key element that could allow current practices to develop towards a situation in which APIs are automatically proposed to end users by, for example, matching his/her research criteria.
  It is important to note that documentation needs may be different for internal and external users, and should be created for each user type. For external users, documentation is just one part of the developer experience, which also consists of discovery and promotion, which are covered below. In a government context, it is often helpful for all users to make sure documentation includes context on policy and compliance.

- **Development.** The development of an API includes all of the decisions that a developer must take when implementing an API. This part is behind the interface the user of the API considers for the development of her/his application. Thus, it is invisible to him/her. To make the development of the API fast and flexible and so to be able to respond to user feedback and market needs, government engineering teams need to adopt good software development patterns, practices and principles, such as maintaining the 'separation of concerns', 'low coupling' and 'information expert' (Larman, 2004).
  Code should be version controlled, with Git being the most popular version control system. Version control not only is a software development best practice, but is helpful for governments bound by

policy or legislation to keep archives of technology or content (Australian Government, 2019a).

The API source code should also be hosted on a platform that allows collaboration, team access and continuous integration. Continuous integration is the practice of automatically running tests, linters or other build tools with every change to code that is pushed to the source repository. This ensures that all new code is tested and adheres to the team's conventions and requirements (Victorian Government, 2020).

- **Testing.** The quality of an API strongly depends on it being tested. Tools must be selected to test the API on multiple levels, namely the following:
  - usability testing – identify usability issues in the interface, documentation and discovery;
  - unit testing – test the software code (both the interface and the implementation) itself;
  - integration testing – test the implementation and interface issues by invoking the API for each of the use cases;
  - performance and load testing – test the non-functional requirements of an API such as the simulation of the use of the API under particular conditions (e.g. a huge number of applications that call the API);
  - security testing – identify cybersecurity vulnerabilities in the interface, implementation and instance of the API;
  - production testing – identify usability, functionality and performance issues in the production environment;
  - standards and compliance testing – verify that the API conforms to standards or technical specifications, that can be required, for example, by a European Union directive.

  This list is certainly not exhaustive, as lots of other tests could be performed in any software development life cycle. For example, in addition, some tests could be performed to satisfy formal agreements, such as SLAs.

- **Security.** As highlighted in this report many times, cybersecurity is the major risk when publishing APIs. A new 'door' is opened onto the assets and related IT systems of the institution that shares them through an API. Therefore, the management of security must be the first priority of the institution that is implementing APIs. Security must met the following goals: (i) protect the system, API client applications and end user from threats, (ii) guarantee that the API works for authorised and, when needed, authenticated users and (iii) protect the privacy of the shared assets (e.g. on personal data).

  Meeting these goals not only is linked to technical solutions, but also requires a holistic approach that involves a decision-making process for all of the API life cycle aspects. In addition, it requires a cultural change towards a 'security first' mentality among all of the actors involved in this cycle.

- **Monitoring.** Once an API is live, government teams should carefully analyse and observe its usage and behaviour. Indicators of API use, status and security vulnerabilities should be regularly monitored. The metrics used to monitor API should include:
  - problems (e.g. errors, failures, warnings and crashes),
  - system health (e.g. the central processing unit, memory, input/output and container health),
  - API health (e.g. API uptime, API state and total messages processed),
  - message logs (e.g. request and response message bodies, message headers and metadata),
  - usage data (e.g. number of requests, endpoint/resource usage and requests per consumer).

  As also observed in the 'Development' bullet above, an API gateway tool could provide a solution to collect, analyse and use many of these metrics.

- **Discovery and promotion.** Government APIs should be available in a single institutional portal or at least indexed in a single catalogue for discoverability. Multiple public-sector organisations and national governments require new APIs to be added to a central registry; this process can be done in many ways: manually by using specific API documentation editors or with more sophisticated and semi-automatic ways, such as a pull request in GitHub.

  When making catalogues available, to facilitate the search, it is recommended that multifaceted searching functionalities be enabled that let the final user search, for example, by keyword, asset (e.g.

data), API provider, etc., as application developers often need to know the asset they are seeking but may not know the API provider responsible for publishing a particular API (Government of New Zealand, 2016).

As also observed above, documentation is key element to improve the discoverability of an API. However, only documenting an API might not be sufficient to make it discoverable by the right users. External registries and catalogues can be used to publish and advertise the existence of the API. In addition, adopting an internal discovery solution and utilising internal newsletters or events to promote APIs to other teams within the organisation may be helpful.

Making an API discoverable does not necessarily mean that developers will discover it: promotion is also a key part of an externally facing API strategy. Investing in a developer relations programme and assigning a dedicated developer evangelist role is incredibly valuable in ensuring government APIs are found and used. This includes identifying government projects and initiatives that can be related to the use of the API, collaborating in the publication of reports, speaking at conferences, hosting events, using the institutional social network facilities, building communities around the API (Van Hoytema, 2018) and getting coverage in the press (Mark Boyd, 2017c). APIs should also be promoted via additional actions, such as their description with storytelling, and this will also promote them both internally and externally to the providing institution (see, for example, the work of Regione Lombardia (2020f)).

- **Change management.** An API is likely to need to change at some point in its lifetime and the chances are that some of those changes will be breaking changes (i.e. changes that require the client application to be changed). Usually, even if designed with great attention, an API must be changed or even deprecated for valid reasons, such as changing business requirements, industry standards or user needs. Iterating based on user feedback early in the design and development stage and appropriate management of the versioning of the API will help mitigate breaking changes that will be required later down the line.

  Principles to keep in mind when managing change (Government of United Kingdom, 2016) include the following.
  - Avoid backwards-incompatible changes whenever possible.
  - Use semantic versioning or only version major releases with backwards-incompatible changes. A good practice is to put the version number in the URL ([22]).
  - Create new endpoints for significant changes.
  - Provide notices for deprecated endpoints.

5.4 | Legal aspects of application programming interface adoption in governments

In general, there is no legal framework specifically dedicated to APIs, but this does not mean that APIs function in a legal void. In considering the legal aspects relevant to APIs, in this section we look at the potentially applicable laws and analyse the arising issues, aspects, problems and/or questions from the API point of view. The frameworks and laws from areas such as privacy, cybersecurity, interoperability, standardisation and ownership seem to be directly relevant to APIs.

We highlight that legal and licensing issues are one of the most underdeveloped areas identified by the different methodological approaches, namely in the best-practice literature review, when analysing existing government API use cases and in workshop discussions. Focused work is needed to identify the best models and approaches that governments should adopt to ensure a balance between enabling API adoption and minimising risks and adverse impacts from government API availability.

In Section 4.3, we identified the legal aspects linked to privacy (i.e. sharing datasets via APIs that could contain private information of citizens and companies). We listed some solutions that can mitigate this risk, such as the Solid open-source platform and framework for application development (Middleton, 2018), AmDex (AmDex, 2019), the MyData initiative (MyData network, 2020) and the ethics group for data privacy (Tada community, 2020).

In addition, in Section 3.3.2, we identified and analysed standard approaches to licensing. In this section, even for cases in which no particular legal approach was applied, we highlight the diverse legal aspects of APIs from strategic, organisational/tactical and operational points of view (Jacobson et al., 2011).

5.4.1. Legal and licensing issues at the strategic level

As far as the strategic level is concerned, the alignment of different legal policies in the context of APIs should be considered. Binding laws on government APIs can help ensure the interoperability of APIs within a government's jurisdiction. Some Member States have already chosen legislation as a key enabler to ensure industry-wide commitment to API standards. Finland, for example, has established a law to ensure that transport providers all share data via APIs and has also enacted a law to oblige government services to share one IT architecture (Government of Finland, 2017).

Protecting personal data is one of the main concerns in the European Union. As presented in Section 3.1.1, the European Union has regulated such data protection through the **GDPR**. When using APIs to share personal data among different parties, specific measures need to be implemented to record which parties have obtained these data. But APIs can also help in maintaining the consistency of this information among different information systems, as they can be used among the parties if information needs to be corrected or removed.

Moreover, the highly decoupled nature of APIs could be key to GDPR compliance as personal information begins to be shared both within and outside the boundaries of the European Union. Therefore, organisations should be looking to accelerate their plans to break their monolithic stacks into reusable API-led services (Berlind, 2018).

The EU has also leveraged legislative frameworks in order to manage its role as a regulator mandating the use of APIs. **PSD2**, as transposed and enforced by Member States, ensures that banks use integrative technologies (i.e. APIs) to open payments and account information services, in order to drive greater competition, facilitate economic development and enable greater consumer choice (see Section 3.1.1).

In general, from an organisation point of view, legislating for the mandatory use of APIs is a strict approach that forces stakeholders to make use of APIs. In private industry, some API strategies have faltered in large enterprises because individual lines of business chose to take their own approach. This is often reflective of a business culture in which lines of business might compete with each other for enterprise resources, budget and internal influence. Whole-of-business API strategies have been most successful when a CEO has mandated that all lines of business must use internal API standards, when governance structures are established to guide whole-of-government action or when the management team has introduced key performance indicators for APIs that ensure each line of business reports on API progress (Axway, 2019). This mandated approach in private industry could be considered analogous to a government legislative approach that enforces the use of APIs by government departments.

From our interviews and workshops, we have observed that legislative instruments need to be accompanied by more specific resources to support the adoption of APIs. Governments mandating that specific internal departments must expose datasets and services using agreed API standards, as in Finland, often do so alongside providing support to make it easier for departments to follow this approach, with clear explanations of the value of doing so (Panebianco, 2019).

The successful implementation of API legislation is usually tied to providing incentives for private stakeholders. For example, in the United States, while healthcare agencies are legally forced to use API standards for sharing electronic healthcare records, they also benefit from getting access to specific government funding programmes (Mark Boyd, 2016a).

5.4.2. Legal and licensing issues at the tactical level

At this level, legal tools can help oversee the allocation of resources to manage and implement APIs. In private industry, SLAs are used to create commercial arrangements that reflect business budgeting processes. Individual lines of business may 'buy' the internal API services offered by other lines of business and agree to an SLA. The cost to one

department is compensated by penalties if the API does not match the SLA terms, such as agreed performance standards and he uptime level of access. This model is then also replicated with external stakeholders, whereby APIs are made available either to trusted partners and suppliers or more openly in an ecosystem model to any third party that pays for access.

APIs could require governments to work in new collaborative models to share data registries and shared services across government departments. A model in which departments 'pay' the department custodian via budgetary reallocation may be one way to understand the future requirements of new departmental funding models for a digital government infrastructure in which the reuse of API resources is prioritised and encouraged.

For example, the most recent Italian government IT plan has considered some of these issues and the relevance of SLAs for internal government APIs. As this model is still in its early stages, the government is implementing a model in which it focuses on service-level objectives ([23]). SLAs, as demonstrated by private industry, focus on penalty schemes for deficiencies in performance and uptime, which can lead to the need for conflict models to resolve challenges in the availability of APIs.

At present, the majority of government-provided APIs available to third parties do not have SLAs that confirm what third parties can expect in terms of performance, availability, consistency and/or uptime. Governments are increasing their work in fostering ecosystems in which government APIs are made available to third parties. The lack of SLAs for government APIs may limit interest in adoption in the future. In addition, the lack of clarity on and confidence in businesses and non-profits making use of APIs can be considered a cost of external usage.

A product management approach to government APIs is encouraged in a number of best-practice documents (6Aika, 2017c). Product management tasks include managing service-level expectations by API consumers. New models for establishing, negotiating with, monitoring and reporting on service-level objectives and SLA with internal and external users should be adopted by governments.

5.4.3. Legal and licensing issues at the operational level

At the operational level, when making individual APIs available for consumption, terms of service agreements are required to ensure that API consumers are using government digital assets as intended. For internal government APIs, authorisation and authentication mechanisms should guide access to governments' assets (e.g. datasets and fields within datasets) or rights of access, such as read-only or the ability to transact or edit data. Privacy (as required by the GDPR), citizen rights and other legal requirements can be 'baked in' to the APIs rather than documented in a terms of use agreement between internal government stakeholders (Poikola et al., 2015).

As far as the role of an API provider is considered, public organisations will need to ponder APIs in terms of both the resources they share among themselves and the assets (e.g. data) to which they provide access. This includes issues such as licensing and (personal) data sharing. Final API users (which could also include governments) will need to carefully examine these licencing issues but also their obligations in maintaining (personal) data-sharing requirements.

Government APIs that are exposed publicly may require, depending on their degree of openness (see Figure 7), licensing agreements at different levels: the data layer, the API source code and the API access layer.

— **Licensing data.** Regarding sharing APIs that expose internally produced open datasets, some government API catalogues specifically define the terms under which the data and APIs are available and accessible (6Aika, 2017d). Others have open data catalogues that have built-in, automated APIs available for each dataset, and these are often offered under blanket licensing terms that apply to all of the data portal's underlying data.
  Licensing API data collected by contractors can present additional issues. Several governments are currently facing challenges in historical contracts with third-party suppliers that are now able to collect data on government-funded service delivery without sharing the underlying data with the government contracting them. As a result, the contractor is able to create new services and products targeting citizens or businesses, or otherwise maintain a competitive advantage over

its competitors. Some city governments in particular are rewriting government contract templates to ensure that contracted suppliers make service data available via unrestricted APIs (Catapult – future city, 2018).

Licensing API data collected by private businesses using government infrastructure should also be considered. At a city government level in particular, several governments are introducing new requirements for emerging technologies to share data with the cities and the public via APIs (Hardinges, 2019). Contractors in transport and utilities often note there is a need for balance, as some of these data reflect competitive advantage or risk security exposures (European Commission, 2018h). Tourist apartment rentals, ride sharing, and scooter and other integrated mobility operators are, at times, required to share data on service usage with local governments. As Daniel Sarasa Funes from Zaragoza City Council stated at the APIs4DGov Paris workshop and information-sharing event, these providers are often fundamentally changing the dynamics of a city and, without licensing agreements for API-enabled access to data, city governments are unable to plan city amenities and safety (Sarasa Funes, 2019). At regional and national government levels, energy and utilities data will be increasingly needed to help plan and manage climate risks and ensure adaptation to climate crises.

— **Licensing the API source code.** In addition to the abovementioned approaches to managing terms of use, there is also the need to consider exactly what part of an API is being exposed. An API is an integration that enables a consumer to link to a resource. For example, when a government has published open data, an API can allow those open data to be integrated into an external system. However, this presents a challenge for API licensing. While the open data may have their own licensing arrangements allowing reuse, there is not necessarily any evidence to show that the API is not manipulating the data and changing the original dataset through the integration capability. Government publishers may consider opening the source code, or software, that defines how the API works or consider using APIs that have the source code openly released. This will ensure that end users can track what the API does and that the underlying dataset is preserved during the integration process and is not manipulated in any way at its source. This is also useful, for example, to check the content of AI algorithms in various fields, such as in e-democracy, facial recognition and autonomous cars.

There are a number of licences that can be used to release a software code (Open source initiative, 2020). For example, the European multilingual classification of skills, competences, qualifications and occupations has licensed the libraries or software that have been used to develop its API (European Commission, 2020j).

— **Licensing API access.** Because APIs often make data also available in bulk format, it may be necessary for APIs to have specific usage constraints in terms of service. This may be necessary to encourage the efficient use of APIs so that government data system infrastructures are not flooded with API requests for data and services, which would increase the costs of government infrastructure management. Open and free access to data and services may also inadvertently create market barriers for SMEs competing against global multinational companies and technology giants. Larger enterprises may have the resources to consume a greater API pipeline from government, which gives them competitive advantage to create products, such as machine-learning algorithms, at a faster rate, than local SMEs.

While terms of use licensing agreements may need to differ depending on the legal jurisdiction, private and government stakeholders are seeking to create uniform approaches where possible. Across emerging markets, the World Bank's Consultative Group to Assist the Poor (CGAP) has published a guide on legal risks and concerns for financial service providers opening APIs to foster the creation of new financially inclusive services and products (Lovells, 2020). This guide recognises the European Union's GDPR and PSD2 legislative environments and makes recommendations for common terms of use agreements that could be used by providers, even in jurisdictions outside Europe. Similar work is needed for government agencies.

The Swedish government has supported and funded a similar model and released an API licence template that can be used by all Swedish government departments when releasing APIs. The licensing template explains the valid uses of an API for external stakeholders (Swedish Governmental Agency for Innovation Systems, 2020).

New risks are emerging in relation to APIs that may need to be considered when formulating terms of use. The growth of misinformation is a key concern for many democratic governments. Terms of use licensing agreements may, in the future, need to deny the use of APIs to those using data and services to spread misinformation. While this may be difficult to enforce, the licensing provision may give future prosecutors a new avenue to address misinformation agents.

Choosing a licence

A relatively complete collection of licences, and information on how to specify them in a structured way, is provided by the Software Package Data Exchange (SPDX) (SPDX Workgroup-Linux Foundation, 2019). SPDX is an open standard for communicating software bill of material information (including components, licences, copyrights and security references). The uniqueness of this approach is that it is possible to codify the appropriate licence in each module of the software code. It also reduces redundant work by providing a common format for companies and communities to share important data about software licences, copyrights and security references, thereby streamlining and improving compliance.

The European Commission provides a couple of assistants for choosing the right licence: the JLA and the EDP licensing assistant. The JLA is a tool that allows everyone to compare and select licences based on their content (European Commission, 2019h). The EDP licensing assistant provides a description of the available licences. It also gives an overview of how to apply licences as a re-publisher/distributor of open data and how to combine multiple licences (European Commission, 2020k). Creative Commons (Creative Commons, 2019b) also proposes a web tool that allows the user to select the appropriate Creative Commons licence. The user can specify many licence features, including sharing adaptation of the work and allowing commercial use of the work. The system returns the licence that best fits the user's needs (Creative Commons, 2019a).

Regarding open-source licences in particular, a community of GitHub developers has proposed a guide for understanding the legal implications of open source and explaining which open-source licence is appropriate for a specific project (GitHub, 2019b). In addition, GitHub supports developers in choosing an open-source licence for their source code (GitHub, 2019a). The website does not provide a comprehensive directory of open-source licences but instead lets the user choose from a set of the most commonly used software licences and has an appendix that allows the list of licences it proposes to be checked.

The Open Source Initiative proposes a set of frequently asked questions that help the user to choose the right licence from a set of open-source software licences. Questions are related to choosing the best open-source licence and how to apply the source licence to the software released. It also gives some advice on what to do if the user violates a copyleft licence and on the meaning of 'contributor agreements' (Open Source Initiative, 2019).

The Free Software Foundation recommends steps for and illustrates differences when choosing licences for software developer work. It recommends choosing different licences for different projects, depending mostly on the software's purpose, and in particular for small programs, libraries and server software (Free Software Foundation, 2018).

6

WHERE GOVERNMENTS SHOULD PRIORITISE APPLICATION PROGRAMMING INTERFACES

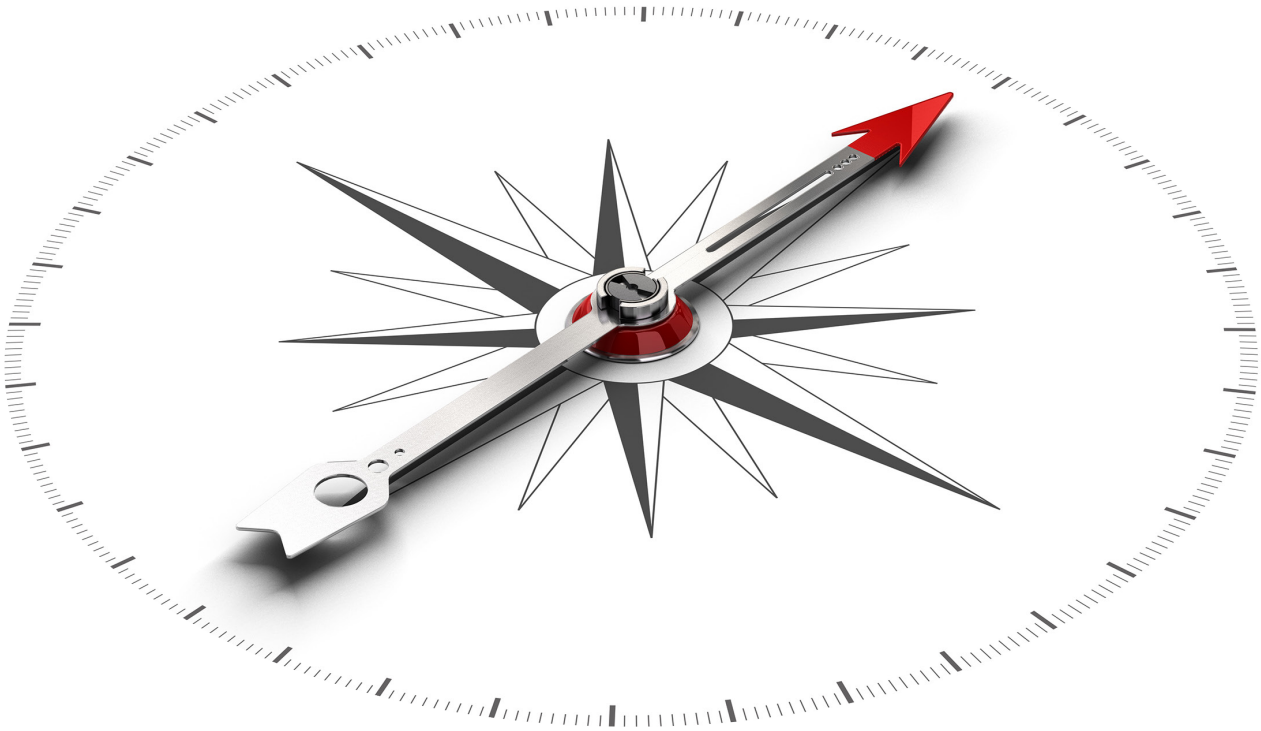
SUMMARY

APIs are a general purpose, domain-neutral technology that support the machine-to-machine exchange of data and services in digital governments. They can be applied to a huge number of thematic areas and can support many technological domains.

The European Commission broader policy goals highlight the need for priority setting for APIs. Policy directives such as the Open Data Directive are explicit about ensuring that 'high-value' datasets be treated as priorities. These 'high-value' datasets comprise the following: geospatial, earth observation and environment, meteorological, statistical, company and company ownership, and mobility datasets. In addition, the communication *A European Strategy for Data* announced the creation of sector- and domain-specific 'data spaces' in the following areas: industry (manufacturing), the green deal, mobility, health, finance, energy, agriculture, public administration and skills. These sectors should be treated as priorities when moving towards an API-enabled infrastructure for government. Particularly, for key high-level priorities, any opportunity to build APIs that help achieve the related policy goals should be considered.

To be noted that health APIs have been largely adopted but it must be considered that prioritising health as a domain for API activity will require specific measures to strongly protect citizens' privacy, implement cybersecurity and adopt correct licensing systems.

As regarding the technological domain, emerging and early adopted technologies or, currently, disruptive technologies (even if well known) that use APIs to perform and reach their goals include AI, autonomous things, the IoT, big data, smart cities, citizen science, blockchain and microservices.



6 WHERE GOVERNMENTS SHOULD PRIORITISE APPLICATION PROGRAMMING INTERFACES

6.1 | Thematic areas

Existing and recent European Commission policies show an increasing move towards working in an ecosystem model, in which internal stakeholders collaborate across European Union institutions, European Commission directorates, individual governments and departments, and external stakeholders, including private-industry, research and community groups. There is an increasing need for ecosystem approaches, given the need for much more collaborative action, to implement the programme of work outlined in the Commission priorities (European Commission, 2020l) and also in the light of the need for environmental protection and the recent health emergencies.

Two key European Commission policy documents, in particular, highlight the need to leverage domain-level ecosystems. The Open Data Directive focuses on internal government (public-sector) datasets and explicitly sets out that the use of APIs for 'high-value' and dynamic datasets is mandatory (European Union, 2019a). 'High-value' datasets include geospatial, earth observation and environment, meteorological, statistical, company and company ownership, and mobility datasets. In addition, the communication *A European strategy for data* announced the creation of sector- and domain-specific 'data spaces' and focuses on the interplay between public, private, research and community datasets. The data spaces

include those in the areas of industry (manufacturing), mobility, health, finance, energy, agriculture, skills and public administration (European Commission, 2020a).

Even though this report focuses on government APIs, which mainly share government digital assets, all of these sectors must be treated as priorities when moving towards an API-enabled infrastructure for government.

The study identified some overlapping domains that will require collaborative action to reach governments' goals. Therefore, we consider these domains in our list of thematic areas, which we classify into two categories: 'transversal' thematic areas, which cover and can be used in many societal sectors, and 'vertical' thematic areas, which cover specific societal domains.

6.1.1 Transversal thematic areas

Besides the provision of digital public services and the publication of government open data, the prioritisation of APIs should focus on the areas illustrated below.

Smart Cities

From the analysis we have conducted, we have identified web APIs implemented by a number of cities, and networks of cities, around the world. We have strong evidence that APIs are a fundamental building block in supporting smart cities in publishing open data, in providing better digital public services, in making flexible and interoperable digital government platforms and in improving the digital economy of countries, regions and cities. They also provide mechanisms to guarantee the ethical use of personal and private data, and they help to fight against cyberattacks.

The JRC's Future of Cities initiative identifies the challenges influencing the future of cities in Europe and beyond. The main aim is to raise open questions and steer discussions on what the future of cities can, and should be, within both the scientific and the policymaker communities. Examples from the associated publication suggest that web APIs have been implemented by a number of cities, and networks of cities, around the world (Vandecasteele et al., 2019; European Commission, 2020m).

> *Specific sectors must be treated as priorities when moving towards an API-enabled infrastructure for government*

Relevant examples from the abovementioned initiative include the cities of Helsinki, Santander and Madrid. They shared with us their experience (European Commission, 2018f), which is summarised here.

— The city of Helsinki, which is part of the OASC community and the 6Aika strategy for sustainable urban development, highlights the role of APIs in increasing interoperability and supporting the OOP, open data initiatives and data catalogues.

— For the city of Santander, which is part of the Synchronicity IoT network of 49 cities in Europe, the publication through APIs of data coming from the IoT can be an important contribution to data markets within the broader European DSM.

— The Madrid Mobility Lab ecosystem of APIs and portal brings information to citizens through multiple channels and transportation applications for buses, parking, public bicycles, traffic levels, city hall sensors, third-party sensors and data. The case of Madrid also shows interesting non-financial benefits, such as the ability to use data from sensors to inform citizens about the levels of pollen and other allergens that exist on various transport routes, thus enhancing people's comfort and health when on the move.

Geospatial

Motivations for public-sector organisations to publish and consume APIs may be linked with geospatial data sharing and related developments. Among all public-sector data that can be made available through APIs, geospatial data may be particularly important as Geospatial data are, together with statistical datasets, the 'backbone' of datasets in the public sector. There are particularities of geospatial data due to their means to integrate, and be integrated with, data from other sources and their means of providing complementary information that other data sources or processes would not be able to do, or would do so somewhat inefficiently. This can be seen from the perspective that 'everything happens somewhere' and can be represented in information systems for analysis and presentation, for example through geographical information systems.

The INSPIRE Directive identifies 34 main themes that datasets throughout the European Union Member States need to address in a harmonised way to implement the directive (European Union, 2007a). The INSPIRE geoportal (European Commission, 2020g) shares thousands of datasets gathered from each EU Member State. The deployment and exchange of spatial web services operated by the Member States of the European Union are at the foundation of INSPIRE. Because of the latter, increasing numbers of research projects have been performed at the JRC to consider APIs as a central building block not only for the future of INSPIRE itself but in general, for the evolution of spatial data infrastructures, as they allow for better data-sharing practices in terms of availability and accessibility (Kotsev et al., 2018; Lutz et al., 2019).

The ELISE action, also part of the ISA^2 programme, is a package of legal, policy, organisational, semantic and technical interoperability solutions to facilitate more efficient and effective cross-border or cross-sector digital public services and processes involving location information and the insights gained from that information (location intelligence) (European Commission, 2016j). Combining layers of location data and other data provided via APIs can provide powerful use cases. For example, knowing the location of an individual or device connected to the internet (or via another locational tracking system, e.g. a global positioning system (GPS)) is now commonplace. The known location can be associated and combined with geospatial, meteorological and sensor data to enhance both administrations' and citizens' interactions with the world around them. Location intelligence, which combines the use of analytics, geospatial information and location-based services, has many use cases in government (Williams, 2018).

Another example of such data sharing can be seen in Eurostat's map services via the data distribution API of the geographical information system of the Commission (GISCO). This service allows any user (public services, policy units or external developers) to use these data in combination with their own data to help display those data on a geographical base or produce new data products (European Commission, 2020n).

Geospatial data are also particular in their potential relevance for decision-makers. In some instances, access to real-time and up-to-date geospatial data can be pivotal in reducing the 'uncertainty of decisions' by visualising the extent of a phenomenon or supporting the management of particular events, such as a natural disaster or major man-made incident. For example, the European Facilities for Earthquake Hazard and Risk (EFEHR) provides its data and documentation for APIs and web services, allowing users to build their own applications directly on top of them (EFEHR, 2017).

Geospatial data may also power online services, whereby data and mapping APIs are integrated into many online services, offering users relevant local information related to the services they consume. Some common examples include parking applications for citizens (e.g. parking space availability), checking the availability of retail items in certain locations and checking the location of specific shops.

Significant work has been identified on managing open geospatial data as APIs in the public sector. The OGC API family of standards is being developed to make it easy for anyone to provide geospatial data to the web. These standards define resource-centric APIs that take advantage of modern web development practices. During the 2019 Inspire event in Helsinki (Inspire Helsinki team, 2019), the trend was to move from the traditional geospatial services required some years ago by the INSPIRE Directive (European Union, 2007a) to the new API specifications proposed by the OGC (OGC, 2020).

Geospatial APIs are also used significantly in the private sector. One of the most popular examples are the APIs

provided by Google, which are now used by a large number of applications, as also indicated by the number of developers (currently 2 574) that follow them in the ProgrammableWeb directory (ProgrammableWeb.com, 2020b).

Geospatial APIs are also used in geospatial communities. The OpenStreetMap initiative has also counted many developers who use APIs to access and update the OpenStreetMap datasets (OpenStreetMap foundation, 2009), download datasets (OpenStreetMap foundation, 2020a) or investigate usage statistics (OpenStreetMap foundation, 2020b).

Statistics

Many public-sector statistical institutions make their datasets available via APIs. The European Commission Eurostat data contain many indicators (short-term, structural, theme-specific and others) on the EU-28 and the euro area and the Member States and their partners. The Eurostat database always contains the latest version of the datasets, meaning that there is no versioning on the data. Datasets are updated twice a day, at 11.00 and 23.00, in case new data are available or because of structural change. The JSON and UNICODE Web Services offer programmatic access to Eurostat data, with the possibility of downloading a subset of a given dataset. This operation allows requests for data to be customised, whereby a user can filter the data based on certain dimensions to retrieve specific data subsets (European Commission, 2020o). Grazzini et al. (2019) highlight that 'the proposed approach revolves around the provision of "Do-It-Yourself" (DIY) services on top of open data (e.g., disseminated through online database, web-services and/or REST Application Programming Interfaces)'.

The creation of APIs that assist with improving the analysis of different outcomes based on socioeconomic background should be prioritised. For example, some jurisdictions, such as Victoria in Australia, have aligned high-value datasets with their government policy priorities and distributed them via APIs. In Victoria, this includes being able to analyse data by the gender of populations to ensure that goals to address violence against women are maintained across all government action areas.

Citizen science

Citizen science, powered by a series of digital devices, offers an effective way to connect citizens and policymakers. Citizens can get involved by taking part in science-related processes and by understanding and guiding the changes taking place around them. The potential benefits that citizen science can bring to policy formulation and implementation range from providing evidence for assessments and supporting regulatory compliance to community empowerment and awareness raising. In the environmental policies domain, for example, the number of citizen science activities is huge, covering an extensive range of policy areas and being implemented in many parts of the world (Nascimento et al., 2018). At the European Commission, a partnership between the Directorate-Generals for Environment, Research and Innovation, Eurostat and Climate Action, the European Environment Agency and the JRC particularly addresses the relationship between people and data (European Commission, 2020p).

The JRC is also examining the use and practices of citizen science for EU policies (European Commission, 2019o). This initiative aims to contribute to the understanding of possible roles of citizens and the (power) relationships that are emerging owing to data governance and the ongoing digital transformation of society. While keeping a holistic view across the different possible types of citizen-generated and citizen-contributed content, this work should help to advance our understanding of people's intentional engagement in authentic scientific investigations (citizen science) and the possible interplays of this with European policy. One of the recommendations resulting from the workshops organised by the participants (citizen science practitioners with experience in mobile application and web platform development and implementation) was that, in governments, 'platforms, portals and apps should have an API to share data, and API standards should be followed where possible' (Sturm et al., 2018).

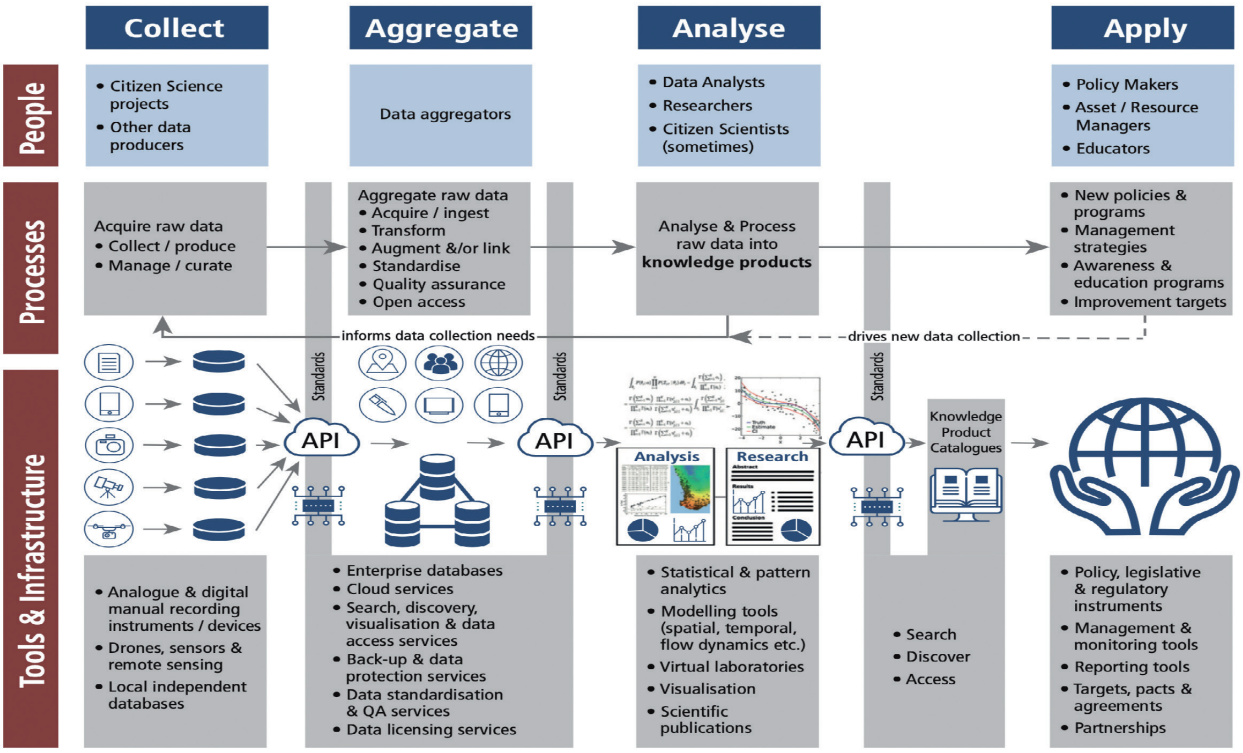


FIGURE 25: A conceptual model for a digital information supply chain.
Source: Brenton et al. (2018).

The JRC has also launched a web community page on citizen science, which includes the identification and development of methodologies and tools that connect citizen science with selected policy areas and demonstrates their use and usefulness in the different phases of the policy cycle (European Commission, 2019o). One of the JRC projects within this initiative is MYGEOSS (European Commission, 2016k). MYGEOSS has developed a mobile application for monitoring alien species. It investigates the use of the app in the field and the validation processes required to allow it to feed data into the official European Alien Species Information Network (EASIN) (European Commission, 2020q).

Applications like MYGEOSS rely on a series of distributed networks of information that must be supported by a proper IT infrastructure. Historically, data generated by citizen science projects were often used only within the context of the project for which they were collected. Because, nowadays, projects on citizen science (as well as others) gather and aggregate data from many and heterogeneous sources, IT infrastructures that support citizen science in a broader and distributed context need to be considered. Brenton et al. (2018), for example, propose an infrastructure based on 'a conceptual information supply chain model in which citizen science projects are involved in data acquisition and analysis processes' (see Figure 25).

Data and procedural standards provide a common language that allows similar information from disparate sources to be efficiently aggregated and exchanged, thus giving raw data potential value, utility and impact beyond the purpose for which they were originally collected. APIs provide a simple mechanism for exchanging data between different electronic systems, facilitated by growing access to high-speed internet technologies (Brenton et al., 2018).

Public sector

This thematic area is quite large, as it could easily include all of the APIs that are discussed in the other thematic areas. However, within this area, it could be useful to restrict attention to the APIs that share digital assets specifically related to public-sector administration. These APIs can contribute to enhancing the dissemination of these digital assets (and thus to improving transparency, accountability and trust), to addressing law enforcement needs, to supporting the effective application of EU law and to enabling innovative 'gov tech', 'reg (compliance) tech' and 'legal tech' applications.

This report has already given some mature examples of the use of public administration data for improving accountability and enabling new 'reg (compliance) tech'. In particular, the OSF's use of APIs to display local government budgets and expenditure to enable transparency has been detailed in this report. Another example involves tax systems. Globally, tax systems around are moving towards API-first infrastructure to enable automated financial reporting by businesses and citizens. While the goal is to reduce friction and automate tax reporting, additional benefits include a reduction in corruption and fraudulent tax reporting and a reduction in government costs in auditing and regulation (OECD, 2019a).

It should be noted that governments have also begun experimenting with using APIs to expose decision-making processes. In law enforcement environments, for example, the use of facial recognition AI will require an underlying API infrastructure (European Commission, 2020r). For example, the Innovative Public Services project is a joint activity of the Directorate-General for Informatics (DG DIGIT) and the JRC, run as part of the framework of the innovative public services action of the ISA² programme. Its purpose is to gain an understanding of the innovation potential and framing conditions of emerging disruptive technologies such as blockchain and distributed ledgers, AI- and IoT-related infrastructures, and technological solutions and platforms that are already at a mature stage in the private sector, such as APIs (European Commission, 2018d). In this way, it aims to better assess the impact of these features, namely if they lead to more efficient and improved public services and improved interaction between governments, citizens and business.

Another JRC initiative is the Digitranscope research project (2018–2020), which was established at the JRC Centre for Advanced Studies, focusing on the governance of digitally transformed human societies (European Commission, 2018i). The project has two main streams of work related to the following questions: Is there a European-specific pathway to digital transformation and, if so, what should it look like? What are the new forms and scales of governance enabled by digital transformation? Digitranscope contributes to the EU policy agenda by studying the different data governance models emerging for sharing data between the public sector, the commercial sector and civil society. It also analyses different ways in which the value generated through the integration and analytics on these data is distributed among the stakeholders, which can also be enhanced by the use of APIs (Micheli et al., 2019).

6.1.2 Vertical thematic areas Health

Health is a complex domain area that requires managing the consumption of data, heightened security as regards access, standardisations to ensure interoperability, and regulation. Personal healthcare records, for example, which often start as written notes in a doctor's office or on an ambulance form, need to be passed to diagnostic testing professionals, back to primary care physicians and on to insurance agencies, then specialists, then allied healthcare professionals. These records are then integrated with data from medical and fitness devices and used in hospital discharge or to fill prescriptions (Mark Boyd, 2015).

Some governments are experimenting with making data and content available via APIs for health benefits. For example, the Victorian government in Australia notes that it is unable to provide all niche diabetes information services to all populations in the area. By opening up health information content and research data via an API, the government is allowing innovators to create additional digital resources specifically targeting subpopulations with specific needs. Such resources are often beyond the resourcing capacity of governments, but allow niche market entrants to either provide a commercial offering add to existing work by working with community groups to serve specific population needs. Government-provided healthcare information that is available via APIs acts as a raw input for the creation of the digital product.

In 2015, US government policy advisors Huckman and Uppaluru noted in the *Harvard Business Review* that 'Efforts to "liberate" health care data for third-party applications have progressed slowly, because the sector lacks the robust APIs and app developer programs common in other industries' (Huckman and Uppaluru, 2015). This is often still the case today. They noted a range of beneficiaries of health APIs, including:

— patients and caregivers, who benefit from interoperability and easier access to services, as data are shared with appropriate health professionals;

— healthcare providers, who can create innovative solutions on top of common healthcare data;

— researchers, who can engage in citizen science or analyse health trends using large population sets of anonymised data – this already occurs with the use of privately held data; for example, social media API feeds and bulk search results can help epidemiologists identify routes of transmission and exposure (Fung et al., 2015).

The health domain draws in elements from economics, policy and regulation. Regarding economics, in this section, we have briefly presented the healthcare domain as an example of the economic value that can be generated through governments taking a regulatory role.

From a policy perspective, the European Commission's *Recommendation on a European Electronic Health Record exchange format* (European Commission, 2019l) proposes the use of APIs to share health records across various systems. Globally, work is progressing on defining standard APIs for electronic health record exchange as part of the FHIR initiative. This would enable interoperability of health data when a citizen consents to his/her health records being shared between service providers. The European Commission has recommended that API standards be investigated as a priority mechanism for the sharing of data automatically. In addition to the emergence of API standards, which can be pursued at the European Commission and Member State levels, some jurisdictions have also created social service catalogue APIs that track the availability of related health and community services and eligibility criteria. These APIs could, in the future, interact with health data to automatically allocate services to citizens in need. This has implications for AI and machine-learning initiatives and ethical algorithms will need to be developed whereby, if APIs feed data into such resource decision-making systems, rights of appeal and insight into the decision-making processes are clarified.

From a regulatory perspective, global challenges in using APIs for health data are creating new concerns. In the United States, large technology giants have made agreements with healthcare providers with limited citizen consent, with large tracts of individual health records being shared via APIs (Pilkington, 2019). The US National Public Radio (NPR) also reported on the danger of private providers, such as dating apps, exposing health data of their users (including HIV status data, which are shared openly with third-party partners in some apps), while fitness applications apply a range of terms of use that may result in health activity data being shared with third parties (NPR.org, 2018).

Therefore, prioritising health as a domain for API activity will require specific measures to address interoperability priorities, ecosystem priorities and regulation for managing emergent technologies, but also to strongly protect citizens' privacy and adopt an appropriate licensing system.

Earth observation and environment

This domain would align well with European policy-wide priorities, particularly the green deal, which recognises that European policy must address the single greatest issue facing society today: the impact of the climate crisis, which is seeing increased temperatures and more extreme weather events, more population health challenges and the depletion of available energy and production resources. The European Commission's green deal (European Commission, 2020s) recognises the importance of Europe becoming a carbon-neutral continent by 2050 to avoid the 'greatest challenge of our times': the risk of major catastrophic impacts from the climate crisis. Given the gravity of the potential negative impacts of the climate emergency, governments must consider the potential to use their full operational resources in new ways. APIs represent one opportunity to use an enabling technology to support these wider policy goals.

Such a move would also align well with proposed actions outlined by the UNEP, which proposes the creation of a digital data ecosystem supported by common APIs to drive data collection, sharing and exposure (David Jensen and Campbell, 2018). The UNEP has also published a discussion paper on building a digital data ecosystem to encourage new global collaboration using real-time evidence of environmental impacts in order to better address climate crisis needs. The UNEP's discussion paper highlights the potential of leveraging APIs to encourage knowledge sharing and reduce duplication. It recognises that 'compliance with open APIs and other emerging standards is important. For this reason, all actors contributing to the digital ecosystem will be obliged to publish information on the infrastructure they are using together with information about their open source and commercial software' (David Jensen and Campbell, 2018).

Satellite data are one of the main assets in reaching these goals. APIs are important for accessing worldwide satellite data, such as the data published by the Copernicus programme (European Union, 2020b). The Copernicus Open Access Hub provides complete, free and open access to Sentinel-1, Sentinel-2, Sentinel-3 and Sentinel-5P user products, starting from the in-orbit commissioning review (IOCR). Sentinel data are also available via the Copernicus Data and Information Access Services (DIAS) through several platforms. The API Open Access Hub is recommended to those users that access Copernicus data on a regular basis (ESA, 2020). As part of the EU's Copernicus earth observation programme, the European Centre for Medium-Range Weather Forecasts (ECMWF), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and Mercator Ocean have joined forces to implement a DIAS platform called WEkEO (ECMWF, 2019) that offers appropriate APIs to access its data and services (European Union, 2020c).

There is also major potential in the use of data to support of the green deal priority actions on climate change, the circular economy, zero pollution, biodiversity, deforestation and compliance assurance. The UNEP's paper on creating a digital data ecosystem is also highlighted in this report's shortlist of best-practice documents, given the role that APIs will play in ensuring the flow and exchange of data to enable action in this priority policy area.

Earth observation and environment APIs and data are also closely aligned with energy APIs and data, as discussed further below.

Mobility

Public transport data are often one of the first real-time, dynamic datasets opened as an API (Mark Boyd, 2014). There are many examples of governments offering various kinds of APIs in the transportation domain (Vaccari, 2020), all for many different reasons. Traffic congestion data and related transport datasets including on parking bays are often opened, although more work could be done to open traffic congestion data that are aligned with air quality impacts. One of the biggest challenges for many cities is that mobility data are increasingly owned by private companies and technology giants including Google, as well as start-ups in ridesharing and electronic scooter and bicycle sharing, that do not then share data with cities, creating an uneven view of key city urban planning challenges (Sarasa Funes, 2019).

Our case study on the transport in the city of Madrid (EMT) was specifically selected within this domain. The EMT is an ecosystem of APIs and a portal bringing information to citizens through multiple channels and applications for transportation-related APIs such as buses, parking, public bicycles, traffic, city hall sensors, third-party sensors and data. One of the key findings of the case is its success in the economic value created by the adoption of APIs (see Section 4.1).

Transportation is also one of the FIWARE interoperability data models, which adopts NGSI for linked data APIs to exchange information among data providers and consumers (FIWARE Foundation, 2020).

Meteorological

While they are closely linked to earth observation data, it is worth mentioning meteorological data specifically. Meteorological data are often already exposed as APIs, driving the creation of a consumer app economy. Weather conditions have an impact on nearly every area of our lives, including commutes to work, other travel and our health and safety. Thanks to satellites, radar, remote sensors, our own mobiles and other weather-monitoring technologies (e.g. national weather service alerts), we now have a better understanding of weather conditions and phenomena. APIs allow applications to connect to large databases of weather forecast and historical information and also to smartphones with built-in GPS. Thus, we have access to mobile applications that provide hour-by-hour forecasts, severe weather alerts and other relevant weather information for just about every place we go. There are many examples of private-sector APIs available on the web (RapidAPI, 2020). However, the public sector also represents a good source of information to be incorporated in applications via APIs. For example, the ECMWF produces and disseminates weather forecast data for the national meteorological and hydrological services. Its web API enables data to be programmatically requested and retrieved from the ECMWF data archive

for use in web, mobile or desktop applications (Setchell, 2019). However, there are also some initiatives at the local level, such as the one of Regione Lombardia, that require a specific agreement to be accessed (Regione Lombardia, 2020g).

Agriculture

Agriculture data and APIs can enhance the sustainability performance and competitiveness of the agricultural sector through the processing and analysis of production and other data, allowing for the development of precise and tailored applications of production approaches at the farm level. APIs will be an essential component of such systems in order to draw in real-time data feeds from a wide range of sources (including weather, pesticide use, IoT sensor data for soil and air, produce market prices and equipment availability, among others). Some national governments are already prioritising agriculture as an area for API-first approaches, as described in this report in the example of API-AGRO, illustrated in section 4.1.5. Emerging start-ups across Europe are also leveraging FIWARE's NGSI API CEF building blocks to create agricultural products (Rodriguez et al., 2018).

Energy

Energy data and APIs can promote a stronger availability and cross-sector sharing of data, in a customer-centric, secure and trustworthy manner, as they can facilitate innovative solutions and support the decarbonisation of the energy system. It has been suggested that the knowledge gained from leveraging APIs to open highly regulated, consumer markets such as banking can be used to drive similar models in energy. For example, the availability of identity verification and customer onboarding systems via APIs can enable greater utility switching among the market and enable consumers to move towards more sustainable energy providers more quickly. Access to aggregated energy consumption data via APIs, when used in apps, has also been shown to be effective in reducing household energy consumption. APIs can be an enabling technology in helping EU Member States reach decarbonisation goals by enabling open innovation (allowing a variety of organisations to better work together to support a transition to a low-carbon energy system); by creating new approaches to optimise increasingly complex (and decentralised) energy networks; and by creating better outcomes for consumers by encouraging innovation in the marketplace, through the delivery of new products and services. To date, one known example in Europe is the Finnish government's public–private enterprise Fingrid. It has created APIs for the energy sector, releasing real-time feeds for a range of electricity consumption datasets, including the use of renewable energy, and has forecast usage patterns (Fingrid, 2018).

Companies and company ownership

These datasets will be imperative for the European Commission and Member States to ensure that SMEs are supported through policy action. In addition, work on open business registration and tax services via APIs will require alignment with company data. Company ownership data are an important dataset for transparency and anti-corruption, as evidenced by the work of key agencies such as OpenCorporates, which shares its own APIs (Opencorporates, 2020)

Some Member States also offer this kind of API. This is the case, for example, of Estonia, which offers a company registration API and a set of X-Road services that, upon implementation, enable users to submit applications to the business register for establishing a private limited company through a simplified procedure (Government of Estonia, 2020).

This domain overlaps with the public administration API and data domain area in two significant ways: they both work to avoid corruption and promote transparency and they both enable automated taxation and other regulatory oversight to be managed optimally.

Industry (manufacturing)

To support the competitiveness and performance of the EU's industry, ecosystem work in this domain would better capture the potential value of use of non-personal data in manufacturing, which is estimated to be EUR 1.5 trillion by 2027 (European Commission, 2020a). It will be crucial that APIs help manage the flow of information in industrial and manufacturing spaces. In the study examples were found of APIs already being used to help manage manufacturing processes. For example, the European Chemicals Agency uses APIs to share data among industry and government stakeholders on the use of chemicals that potential have hazardous impacts. Often, these APIs are created for one-off use cases. Work to ensure IoT API standardisation, the use of APIs in autonomous things technologies (both discussed below) and the availability of FIWARE interoperability building blocks could be the backbone of an effective industrial data space. Under strategies proposed in the European green deal, there will also be a regulatory role for governments in supporting industry to move towards cleaner manufacturing processes.

Financial data

Financial data can stimulate, through enhanced data sharing, innovation, market transparency, sustainable finance and access to finance for European businesses and a more integrated market. Governments are beginning to take steps towards opening finance ecosystems following the initial successes of PSD2. The PSD2 initiative has encouraged global action to open banking and financial systems so that more stakeholders can offer secure digital financial products, and has inspired other countries to create similar regulations (Mehdi and Boyd, 2019). Canada, Israel, Mexico, New Zealand and the United Kingdom are all currently considering open banking and finance models (Muir, 2019).

In an open finance approach, financial services and other stakeholders open up financial services and data via APIs in a way that enables new products to be built. It is similar to the open banking model of PSD2, but encourages integration of services and data between other financial actors. This has proven effective in emerging markets in creating new financial inclusion opportunities and assisted in enabling third parties to create consumer-facing and small-business-facing financial products that help users to generate savings, apply for loans and/or create wealth (Consultative Group to Assist the Poor, 2020). Already, some examples from transport ticketing are emerging in which commuters can pay for parking, public transport travel and venue entry tickets when planning their travel routes (Almeida Santos, 2018).

Skills and employment

Skills and employment APIs and data can reduce skills mismatches between the education and training system, on the one hand, and labour market needs, on the other. The API catalogue and portal of the French governmental agency Pôle emploi is an excellent example of how governments can act as a central repository for both training and employment data in a single platform. Emploi's model seeks to share API from datasets owned by external partners in the education space. This enables partners and external stakeholders to create new products, services and calculation methods to address disparities between labour market needs and the workforce population's skill sets (Pôle emploi, 2020).

6.2 | Technologies

In this section, we will give a short overview of the advantages of a selected set of emerging and early adopted technologies or, currently, disruptive technologies (even if well known) that use APIs to perform and reach their goals. As in the rest of the document, the focus here is on government API adoption. Nevertheless, some of the areas identified in the previous section (e.g. the geospatial domain) have been considered, and those technologies can be used to support the new industrial strategy of Europe: AI, cloud computing and 5G.

Artificial Intelligence

AI is an EU strategic domain within the priority *A Europe Fit for the Digital Age* (European Commission, 2020t; Craglia et al., 2018; European Commission, 2020u). AI refers to any machine or algorithm that is capable of observing its environment, learning and, based on the knowledge and experience gained, taking intelligent action or proposing decisions (Craglia et al., 2018).

Many AI functionalities are now offered on the web via APIs (ProgrammableWeb.com, 2019a). AI is not a new concept, as its origin dates back to the 1940s and 1950s, but it is only recently that it has passed out of academia and specific research fields and arrived into our everyday life. Roughly, we could classify AI into at least two categories.

1. Machine/symbolic reasoning. This refers to semantic modelling AI and logic, in which data are represented as a discrete set of facts about concepts, their instances and their relationships. These objects can be semantically modelled and, by using well-defined logic languages and graph theories, logical deduction is used to derive new knowledge from the initial status. Machine reasoning AI systems are systems that deconstruct 'tasks requiring expertise into two components: "knowledge base" ([24]) and a general-purpose "inference engine" that described how to manipulate and combine these symbols' (Kaplan, 2016). Reasoning and semantic AI solutions can be utilised in many fields, such as the creation of 'digital universities' (Maltese and Giunchiglia, 2017) based on the use of a semantic technology (Giunchiglia et al., 2014).

2. Machine learning. This refers to a technique in which a program or system can dynamically change its behaviour based on ever-changing data. For this reason, the system has the ability to learn without being explicitly programmed. In doing so, algorithms enable systems to make data-driven decisions or predictions by building a model from sample inputs. A system then does not just simply memorise the samples but recognises patterns and regularities. The goal of machine-learning algorithms is to find specific patterns in (large) datasets, such as the use of machine-learning systems in the medical field that can diagnose skin cancer better than dermatologists (Haenssle et al., 2018).

Jerry Kaplan summarises the pros and cons of machine reasoning versus machine learning as follows: '... symbolic reasoning is more appropriate for problems that require abstract reasoning, while machine learning is better for situations that require sensory perception or extracting patterns from noisy data' (Kaplan, 2016). To obtain better results from the techniques that these two categories of AI offer, the trend is now to combine them (Bottou, 2011). APIs can efficiently share the AI services of both categories that have been developed by third parties, making a set of powerful and updated solutions available to API users allow them to build their final application or service (ProgrammableWeb.com, 2019a). These functionalities can be used but also published by governments and can be used to create new innovative business. Avoiding ad hoc API solutions for AI and instead adopting standards and best practices to implement them is also essential for the development of AI in the DSM. The adoption and sharing of these functionalities via APIs offers the possibility (and probably a unique way) to combine them in a number of different ways and to build completely new and innovative future-oriented solutions.

However, the reverse is also true: not only can AI digital assets be shared via APIs, but also AI techniques can be used to improve the current API challenges faced. Intelligent algorithms could provide solutions to automatically discovering APIs on the web. Reasoning and matching systems can also be used to combine web APIs without, or with limited, human intervention, to create, for example, multiagent systems that use interaction protocols to deal with emergency situations (Vaccari et al., 2012) or to build complex collaborative swarms (Barret, 2018).

Ongoing research on the impact of AI on society is being performed by the European Commission. The JRC's AI Watch initiative aims to monitor the development, uptake and impact of AI in Europe: 'AI is experiencing a period of intense progress, due to several key technological enablers: faster processing, increased amounts of data, and better algorithms' (European Commission, 2018j). APIs can be a fundamental key enabler for the development of AI in Europe and beyond. If correctly implemented, APIs allow AI-empowered applications to exchange information with each other in a flexible and loose-coupled way.

Internet of things

ISO defines the IoT as 'an infrastructure of interconnected physical entities, systems and information resources together with the intelligent services which can process and react information of both the physical world and the virtual world and can influence activities in the physical world' (ISO and IEC, 2016b). In the digitalisation age, the growth in the IoT is going to affect all aspects of the digital society in a significant way. The IoT is a key enabling technology for building local data ecosystems.

Through the use of standards, smart cities can use the IoT as an important technology to perform and implement their digital transformation. Nelson et al. (2017) highlighted this relationship: 'The pervasive instrumentation of the physical world with sensors and actuators provides an unprecedented level of information granularity that is useful in decision-making processes. As municipalities and the public sector at large begin to leverage the Internet of Things (IoT) for civic solutions, there exist greater necessity and impetus to maintain a certain level of standardization in the platform and data architecture.'

Today, it is possible to distinguish between the old IoT generation, taking care to connect as many 'things' as possible, and the new IoT generation, namely IoT 2.0, which deals with generating actionable intelligence from devices and their data. Empowered by billions of connected devices, sensors and actuators, IoT 2.0 will be bigger, more powerful and much more settled than the old IoT generation. IoT 2.0 will allow for the digital transformation of a hyper-connected society and, for this reason, it is also called the 'internet of transformation'. IoT 2.0 will deal with related IT technologies, processes, people, benefits, outcomes and significant real-life opportunities, rather than just device technology and gateways aspects. Naturally, they include microservices and API technologies as solutions.

IoT data offer the potential to consider the real world and better manage resources. This includes activities involving the automatic update of data. For example, devices make use of APIs to connect mobile apps to the provider, sending data for storage/processing and/or retrieving information. Similarly, sensors communicate through a provider's backend infrastructure using API calls. Specific data-management techniques and technologies may be needed to ensure that such data are well organised and accessible for other purposes, especially the geospatial component of sensor data.

To manage processes and provide access to data from devices and sensors, some support is provided by IoT API-based platforms, with the following five core capabilities: the connection between the device and the internet; securing IoT devices, data and identity; managing and controlling the provisioning, maintenance and operation of IoT devices; analysing and transforming the data into timely and relevant actionable insights; and building and sharing applications that can be integrated with third-party systems.

Most of these capabilities are achieved using APIs and require solid API management, where IoT interoperability comes through based on widely accepted standards (API-based services). As interoperability is likely to be one of the most important barriers to the widespread integration of IoT ecosystems between domains, standards and technologies, projects such as FIWARE (one of our case studies, see also Williams (2018)) and VICINITY (VICINITY consortium, 2020) are building platforms linking various ecosystems providing 'interoperability-as-a-service' for infrastructures in the IoT. An API helps develop an adapter to the platform and other APIs manage data access for others outside the platform.

The European Commission's communication on ICT standardisation (European Commission, 2016l) also prioritises the creation of API standards for the IoT: 'Foster an interoperable environment for the Internet of Things, working with ESOs and international SDOs. This will develop consensus under the umbrella of the Alliance of IoT innovation (AIOTI17), targeting reference architectures, protocols and interfaces, the promotion of open application programming interfaces (APIs), support of innovation activities related to reference implementations and experimentation and the development of missing interoperability standards'. This will be essential to ensuring that IoT data are able to feed into AI initiatives such as digital twin projects, smart cities' infrastructure and predictive modelling algorithms that serve a variety of use cases.

The proliferation of the IoT and the success of rich cloud services are pushing the boundaries of the new computing paradigm, including edge computing, and new virtual applications, such as digital twins.

Edge computing

Edge computing calls for processing data at the edge of the network. Edge computing is very important because it has the potential to address the following concerns: response time requirements, battery life constraints, bandwidth cost savings, and data safety and privacy (Shi et al., 2016). API supports the implementation of edge computing, which is seen either as decentralised AI (Rausch and Dustdar, 2019) or more generally as an emerging technology that lets operators host content and applications close to the edge of the network. The European Telecommunications Standards Institute (ETSI) is currently producing standards for multiaccess edge computing (MEC) (Natalie Boyd, 2017). Figure 26 illustrates an example of the deployment of a MEC enterprise network consisting of several 'zones' (ETSI, 2018):

— the headquarters, where the core business services are located;

— satellite offices, with local enterprise networks being connected with the headquarters cloud through secured backhaul networks, which allow enterprise employees to access the enterprise services – an enterprise network may use 4G/5G small cells for outdoor coverage, Wi-Fi networks for indoor coverage and fixed access for static devices;

— remote employees, who access enterprise services using a virtual private network (VPN) over public Wi-Fi or cellular networks.

5G networks are expected to significantly reduce latency and vastly increase capacity for delivering high-bandwidth data streams between high densities of people and things at low energy and with high reliability. 5G will allow a huge amount of data to be transported much faster, reliably connecting an extremely large number of devices and processing very high volumes of data with minimal delay (ITU, 2018). According to Ericsson, programmability in 5G core networks will allows providers to open up telecommunications network capabilities and services to third-party developers, allowing them to create new use cases thanks to standardised APIs on the new network architecture for 5G (Manocha, 2019). 5G can bring disruption to the network level by opening up the mobile network's operating system and exposing core network capabilities to external parties, so they can program their applications to use mobile connectivity and edge computing. In 2017 and 2018, ETSI released a set of edge API standards and announced a collaboration with the OpenFog Consortium to build fog-enabled edge technologies for 5G and the 'Cloud-to-Things continuum'. Seven standards define mobile edge APIs: principles,

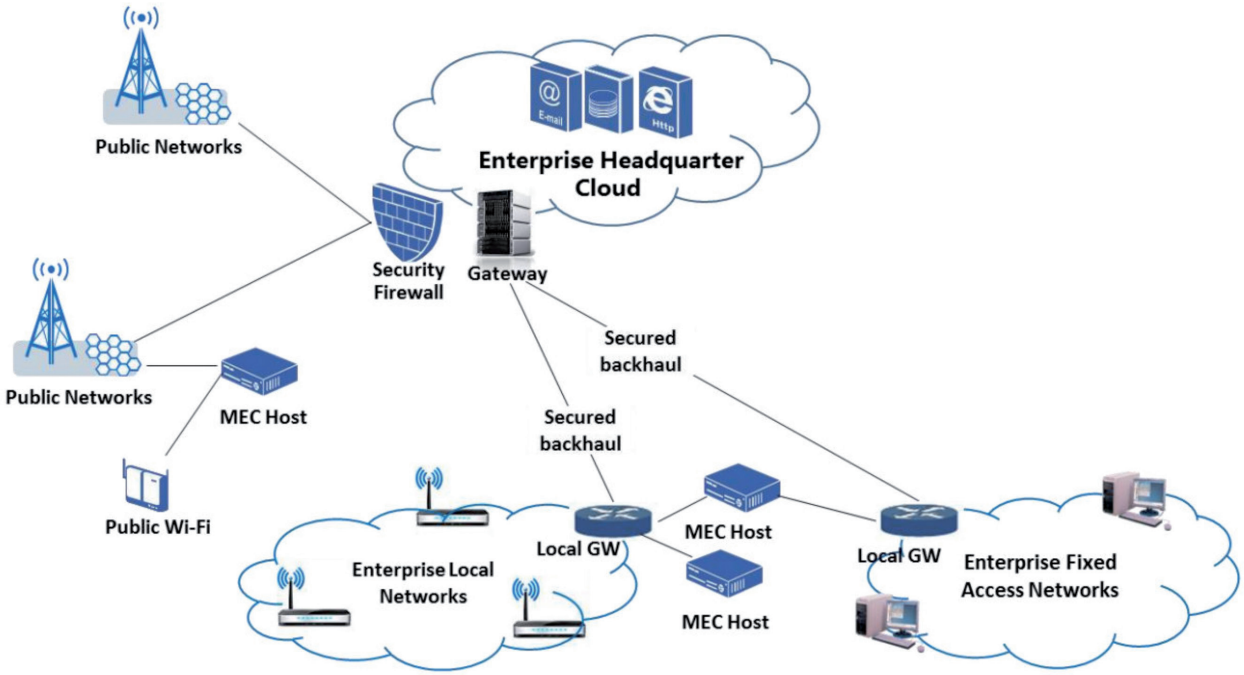


FIGURE 26: MEC deployment across different enterprise networks.
Source: ETSI (2018).

management, platform application enablement, a radio network enablement API, a location API, a user equipment identity API and a bandwidth management API (Natalie Boyd, 2018).

Digital twins

The idea of a digital twin is to create a digital replica of a physical object and use the twin as the main point of digital interaction. A well-defined digital twin becomes the interface and integration point for an IoT solution. A digital twin platform could provide an API that allows systems to interact with the digital twin. For instance, machine learning and analytics services should be able to interact with a digital twin through an API.

The role of digital twins has recently been recognised by the European Commission and digital twins are considered one of the key trends for the IoT (Gartner, 2018). According to the Commission communication *A European Strategy for Data*, the 'investment track for the Commission initiative for data spaces will bring together private actors with public support to develop common platforms offering access to a large diversity of cloud services for secure data storage and sharing as well as applications ranging from artificial intelligence to simulation, modelling, digital twins and high performance computing (HPC) resources' (European Commission, 2020a). The communication clearly commits to concrete actions on these investments. For example, within the common European green deal data space, the Commission will launch the 'Destination Earth' initiative. This initiative will bring together European scientific and industrial excellence to develop a very high precision digital model of the Earth. This ground-breaking initiative will offer a digital modelling platform to visualise, monitor and forecast natural and human activity on the planet in support of sustainable development, thus supporting Europe's efforts for a cleaner environment as set out in the green deal. The digital twin of the Earth will be constructed progressively, starting in 2021, and will rely on the use of APIs (European Commission, 2020a).

Autonomous things

Autonomous things technology represents a link between AI and IoT technologies. Indeed, AI-powered IoT elements, such as industrial equipment and consumer appliances, are a type of autonomous thing. Autonomous things are often in the form of a physical device operating in the real world. Examples include robots, drones and autonomous vehicles.

Autonomous things also include things that operate solely in the digital world without any physical manifestation. Autonomous things were identified in 2019 by Gartner as the top strategic technology trend of the year (Gartner, 2020a). Gartner predicted, for example, that 'by 2021, 10 % of vehicles will have autonomous driving capabilities, compared with less 1 % in 2018'. Gartner also predicted that, as communication become multidimensional and multimodal, new forms of interactions, including virtual assistants and independent agents, will facilitate the exchange of data. Autonomous things also rely on the use of the web as a programmable platform to connect things on the web or the 'web of things' (WoT).

An analysis of research has been done to predict the future of services on the web (i.e. the vision of the WoT) that leverage web standards to connect all types of devices and real-word objects. 'Smart web services', for example, could provide remote access to resources and functionalities by relying on standard communication protocols, but also by encapsulating 'intelligence' (Maleshkova et al., 2016). This intelligence includes capabilities in terms of context base adaptation, cognition, inference and rules to implement autonomous decision logic in order to provide services that automatically perform tasks on behalf of the user, without requiring the user's specific involvement. Regarding providing remote access to functionalities and resource over the web, the trend is to develop and use APIs, a simpler approach with respect to the traditional web services approach. Automatic composition and a combination of services on the web, including APIs, can be then enhanced in general through the use of semantic matching techniques (Vaccari et al., 2012) and semantic web services (Fensel et al., 2007).

Big data

Big data and big data analytics contribute to the API economy in three main ways that are of interest to the public sector. First, the generation of additional volumes of data has meant that APIs are not the exclusive territory of developers but that laypersons are now using APIs indirectly through API-powered apps. This increase in the usage of data through apps has accounted for a huge growth in big data (Kaushik, 2016). Second, social media platforms make data publicly available through APIs, resulting in third-party developers contributing more apps and data (Vis, 2013). Such data and applications, again powered by APIs, may be of use in policy development or to improve service delivery activities by public-sector actors. Third, as noted above, service-generated data are becoming of particular interest to digital platforms and big data analytics, as trace logs, quality-of-service information and service invocation relationships can be used to enhance system performance and increase technical efficiency. APIs can also be provided to users to access service-generated big data and the associated results (Zheng et al., 2013).

Analysis possibilities can also become much more efficient through APIs. For example, AI cognitive APIs rely on the use of a huge quantity of data and are capable of processing complex, unstructured data and delivering related analytics. Many organisations use such APIs to create their own products and services. In addition, APIs can provide big data applications with faster access to stored data, thus offering more efficient processing and computing resources.

In most sectors of society, including the public government domain, data interoperability has traditionally applied the 'discovery and access' paradigm, which consists of discovering/finding a remote dataset, downloading it to a local server and using it locally (e.g. by visualising it or processing it to generate new data or information). In extreme synthesis, datasets have been moved though the network to be ingested in local data systems that support independent and monolithic applications. Digital transformation and its 'datafication' paradigm disrupted this model, introducing a new IT approach that was more efficient, addressing the challenges that emerged with the advent of big data (i.e. large and/or heterogeneous data, characterised by diverse levels of maturity, quality and velocity). This new model, commonly called 'distributed application', aims to implement the full datafication value chain (depicted in Figure 27) by utilising the web as the computing and analytics platform for building applications that are then distributed. This approach builds on the capacities offered by the significant developments in virtual computing and the hyper-connectivity that characterises our society (Nativi et al., 2020; Giuliani et al., 2019; Craglia et al., 2018).

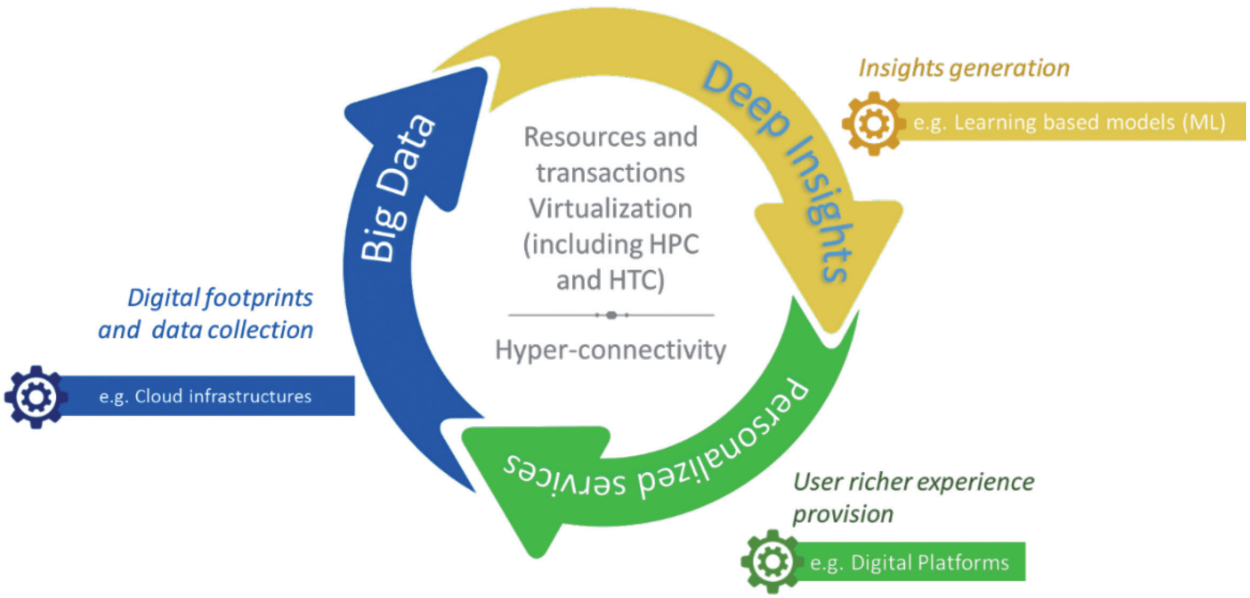


FIGURE 27: Datafication paradigm.
Source: JRC, own elaboration.

From an engineering viewpoint, the distributed application model applies software ecosystem architectures. As regards interoperability technologies, the model implementations make use of microservices, container-based solutions and APIs to connect distributed components and services and develop applications. In this instance, datasets are not moved around, but application algorithms are deployed in place of datasets, working out a virtual collection of independent services that work together. On the other hand, the orchestration of the components is controlled 'locally' by the application owner. The key technology for such a complex application environment is an API, as it lets all the components exchange information in a modular way.

The rise of the datafication paradigm (in all sectors of our society) introduced big data challenges, including the need to use high-performance computing for generating intelligence. This moved applications from our powerful personal desktops and local servers to the digital cloud, making irrelevant the location of the components/services utilised to develop an application, instead using the web-as-a-platform paradigm (Shelly and Frydenberg, 2010). While this allowed application developers to theoretically utilise thousands of possible components/services, it introduced a serious problem of interoperability. APIs, along with other technologies such as microservices, address most of these problems by (i) exchanging machine-to-machine information from multiple sources for content collection and (ii) chaining heterogeneous services managed by different platform infrastructures on the web.

Microservices

The case of microservices is different from the previous cases. While, in the previous cases, APIs play a role in supporting them to improve their efficiency and efficacy, microservices support the creation of APIs.

No official definition of microservices is available. In Fowler and Lewis (2014), the authors define microservices as 'an approach to developing a single application as a suite of small services, each running in its own process and communicating with lightweight mechanisms, often an HTTP resource API'. This definition implies the idea that microservices provide a way of structuring an application into loosely coupled, independently deployable components that communicate over the web utilising lightweight interfaces, such as APIs. Therefore, microservices deal more with how an application is structured internally than with how it is presented externally to its potential users.

We observe, however, that the ideas of modularity and loose coupling, as well as the concurrency with which microservices are built, are also inherent to the so-called Unix philosophy, one of the most successful paradigms in modern software engineering. Microservices can be seen to be the networked, web-enabled analogue of specialised applications running over an operating system, in this case the web or any other network built over a specific protocol. Following this philosophy, microservices-based APIs are useful in helping to design government applications in a more efficient and flexible way.

In addition, microservices become valuable only when they can communicate with other components in a system (i.e. when each of them has an API as its interface). These interfaces also play an essential role in emerging architectural application styles such as the one proposed by using microservices. It is important that, to maintain some fundamental characteristics of the software code (including separation, independence and modularity), APIs are also loosely coupled. The key design practices required to reach this goal are well described in Nadareishvili et al. (2016) and include the hypermedia-driven or HATEOAS implementation.

Owing to the important role that microservices architectures play in API implementation, governments should invest in an analysis of if APIs can be supported with the adoption of microservices architectures and, if so, how this can be done.

Blockchain

Blockchain is the most well-known and -used distributed ledger technology. Blockchain is the type of ledger in which value-exchange transactions are sequentially grouped into blocks. Each block contains a signature that is based on the exact content (string of data) of that block. The next block contains this signature as well, linking all previous blocks to each other until the first block. Blocks are immutably recorded across a peer-to-peer network, using cryptographic trust and assurance mechanisms. In the context of digital government, blockchain technology has the potential to facilitate direct interactions between public institutions, citizens and economic agents. At the most basic level, this implies improved public services in information registration and exchange processes (Allessie et al., 2019).

The use of blockchain APIs (i.e. APIs that let users access blockchain functionalities) presents both advantages and drawbacks and, for this reason, their use has to be evaluated, depending on the specific use case. Use cases of blockchain APIs include enhanced connectivity and security, allow processing to be orchestrated and improve collaboration, accountability and trust (Sandoval, 2018). Standard blockchain can be used to make adopting blockchain technology more flexible, in terms of the wide range of competing blockchain options today. As proposed by Aikon, for example, blockchain APIs can be used to standardise the interface for multiple blockchains to make the access to different solutions flexible (Aikon, 2019).

However, the use of blockchain APIs also presents some drawbacks, such as the fact that blockchain is often very wasteful, as many nodes repeat a task over and over for a single verification. In addition, once a transaction is registered in the ledger, it is immutable. This makes it impossible to correct errors.

6.3 | Prioritisation strategies

The examples illustrated in the previous sections suggest areas in which government APIs should be prioritized. APIs should also be prioritised when they help avoid duplication in the creation and delivery of digital services, something that is often observed during ecosystem building and in collaborative work by governments across departments. National identity verification, application form filling (in line with the OOP) and payment infrastructures are examples of services that are often replicated by each government department (Eaves and McGuire, 2019; Thomson, 2015).

The innovation S-curve concept (Sawaguchi, 2011) suggests that innovation occurs in waves, in which new ideas are first taken up by small-scale innovators while existing trends reach their peak. As existing trends become optimised based on existing innovation, their impact falls. This occurs at the same time as the new innovation by small-scale participants grows and reaches mainstream trend acceptance. This observation can also help in making prioritisation decisions, namely encouraging a focus on investment in fast-growing, mainstream ideas while also seeding investment in small-scale innovators.

Applied to government APIs, this concept could see the bulk of priority decision investment being allocated to current high-value, high-impact domains such as health, geospatial and transportation, while also initiating investment in the near future wave of innovation such as in AI, digital twins and IoT.

Governments' regulatory role suggests yet another set of API priorities. Governments' regulatory role can also help in setting API priorities. The European strategy for data notes the following: 'Sector-specific legislation on data access has also been adopted in some fields to address identified market failures, such as automotive, payment service providers, smart metering information, electricity network data, or intelligent transport systems. The Digital Content Directive contributed to empowering individuals by introducing contractual rights when digital services are supplied to consumers who provide access to their data' (European Commission, 2020a).

These areas may suggest the need for API prioritisation based on regulatory needs. Key informants to the APIs4DGov study, as well as other studies (High-Level Expert Group (HLEG) on Business-to-Government Data Sharing, 2020; European Commission, 2020v), noted the importance of creating business-to-government data sharing via APIs for particular domains. For example, mobility start-ups and tourist accommodation platforms

have an impact on city planning, civic amenities, traffic congestion and population levels (Sarasa Funes, 2019).

Regulatory frameworks and legal enablers such as standard contract templates mandating the sharing of business data with governments via APIs may assist in enabling cities to better plan for local populations. In addition, emergent technologies such as IoT sensor and camera surveillance data may be funnelled into a data pipeline via APIs to enable AI and machine-learning programs. These may also need regulatory frameworks that regulate API access in order to manage the potential negative impacts of API adoption.

To summarise, there are a number of ways that governments can set priorities on exposing APIs.

— Governments can prioritise the exposure of data.

— Governments can focus on exposing horizontal functionalities for reuse in government services.

— Governments can try to find a balance between high-impact domains and investment in the next wave of innovation.

— Governments can regulate industry sectors and mandate API standards.

7

POLICY RECOMMENDATIONS

SUMMARY

APIs are a key enabler for supporting the European Commission priority *A Europe Fit for the Digital Age* and support the priority of Europe being a leader in the data economy. Indeed, APIs help to exploit the potential of data by allowing them to be accessed in an easier, a more coordinated and a faster way. They are also a crucial technological solution in the development of next generation digital infrastructures that will empower the EU to grab the opportunities of the data economy.

The evidence collected from our research for this study recognises the significant value of APIs in enabling governments to deliver on digital transformation goals, to enhance interoperability and form digital ecosystems, and to move towards more platform-based models in which value is co-created with a range of external and internal stakeholders. To achieve these benefits, our recommendations include:

— explicitly adopting APIs to support the new Commission priorities and policies at the EU level, specifically governments at different levels in the European Union and the European institutions, in particular the European Commission;
— increasing the 'API culture' in governments;
— becoming digital ecosystem aware and engaging public- and private-sector stakeholders (e.g. by creating specific working groups and mixed public/private workshops);
— creating best-practice operational guidelines and standards to assist governments in implementing product management and life cycle approaches – the focus should be on the following aspects: giving significant attention to cybersecurity and privacy aspects, analysing API legal and organisational aspects, and providing a set of technical recommendations on API discoverability and access;
— reorienting government API and digital government strategies to consider the adoption of the proposed API framework.

7 POLICY RECOMMENDATIONS

APIs are a key enabler for supporting the new European Commission priority *A Europe Fit for the Digital Age*, which aims to make data more accessible while bringing the benefits of digitalisation to European society. The Commissioner for the Internal Market, Thierry Breton, said: 'Our society is generating a huge wave of industrial and public data … I want European businesses and our many SMEs to access this data and create value for Europeans – including by developing Artificial Intelligence applications' (European Commission, 2020w). As APIs can facilitate access to data, they greatly increase the possibility of reaching all of these goals.

Within the communication *A European Strategy for Data*, the adoption of APIs in EU governments also supports ensuring the EU's leadership in the global data economy, in which 'The amount of data generated by businesses and public bodies is constantly growing. The next wave of industrial data will deeply transform the way we produce, consume and live. But most of its potential remains unfulfilled … That data should be available to all, whether public or private, start-up or giant' (European Commission, 2020w). Once again, APIs help to exploit the potential of data by allowing them to be accessed in an easier, more coordinated and a faster way. Moreover, APIs have to be considered as a key element in 'the development of the technological systems and the next generation of infrastructures, which will enable the EU and all the actors to grasp the opportunities of the data economy' (European Commission, 2020w).

These new policy initiatives are already supported by the fact that APIs are being recognised as essential to implementing the requirements of the Open Data Directive on 'high-value' and dynamic datasets. In addition, the recently published communication *A European Strategy for Data* (European Commission, 2020a) indicates that ensuring that the datasets of data spaces are shared within and among the diverse domains is crucial, as this helps to avoid them becoming 'siloed' environments, pointing to a role for APIs.

To achieve these benefits and support ongoing policy efforts, some key recommendations, presented in the following sections, are made. Following the trends illustrated in this document and these recommendations, we imagine that API adoption in governments will explicitly be sustained in the next policy provisions, with investments probably made under the next digital Europe programme (European Commission, 2018e). As we also propose in Section 5 and following the abovementioned recommendations, this could be a good opportunity to adopt APIs across the whole of the European Union in a uniform, consistent and coherent way.

7.1 | Explicitly adopt application programming interfaces in governments

Our main recommendation is to explicitly adopt APIs to support the new Commission priorities and policies at the EU level. We recommend that governments at different levels in the European Union and the European institutions, in particular the European Commission, adopt APIs.

The Commission should lead by example, namely by building on the European Commission digital strategy, which already includes APIs among the elements listed for the collection, acquisition, management, storage, curation sharing, reuse, publication, archiving and preservation of data. It is suggested that the Commission opts for an API-based architecture in the design of internal and trans-European applications. Where possible and applicable, microservice- or API-based design should also be encouraged wherever software systems are created as part of Horizon 2020 and future Horizon Europe research projects.

APIs can also be an integral part of the European government interoperability strategy proposed for 2021. The use of APIs is essential to implementing the requirements of the Open Data Directive on 'high-value' and dynamic datasets (European Union, 2019a). In addition, guaranteeing that the datasets of the data spaces identified by the communication A European Strategy for Data (European Commission, 2020a) are shared within and among the diverse spaces is crucial, as this helps to avoid them becoming 'siloed' environments. Both policy initiatives offer a chance for the first steps to be taken towards a European governance framework for APIs.

From the analysis of these documents, we observe that APIs are explicitly mentioned by the most recent policy legal instruments. In many cases, these documents require the mandatory use of APIs to implement their specific goals (European Union, 2019a; European Commission, 2020a). However, the implementation of instruments such as the programmes and activities identified in Section 3.1.2 still rarely explicitly mention the adoption of APIs in governments. This might mainly be the result of the recent formulation of the policy legal instruments and the time needed for the implementation phase of these policies.

When developing legislation applicable to reuse, data and metadata formats, technical arrangements for the dissemination of 'high-value' datasets (as set out in the Open Data Directive) and the design of the proposed common data space for the public sector, the adoption of APIs will allow the proposals of the framework proposed in Section 5.1 to be followed. The following recommendations will help to make this process more efficient, cohesive and structured and, thus, will help to avoid ad hoc implementation.

We recommend that a number of areas and technologies be prioritised, namely those that are expected to generate the largest positive effects. Key high-level priorities, such as the health domain, provide a significant opportunity to build APIs that help achieve the related policy goals, and we have identified these priorities in Section 6. They include some horizontal domains (e.g. smart cities, the geospatial sector, statistics, citizen science and the public sector) and vertical thematic areas (e.g. health, earth observation, mobility, meteorology, agriculture, energy, companies, industry, finance and jobs/skills). Emerging and early adopted or disruptive technologies that use APIs to perform and reach their goals should also be prioritised. These include AI, autonomous things, the IoT, big data, smart cities, citizen science, blockchain and microservices.

Administrations at all levels of government are encouraged to start looking beyond the use of APIs in managing data. APIs are equally well suited to managing other digital assets (e.g. transitioning from 'electronic' forms to real digital interactions): 'Connectivity through the ecosystem makes it easier for citizens to comply with their obligations while making it harder not to. APIs facilitate conditionality, making sure a transaction can only progress when certain conditions are met, such as a valid business registration. Data can flow through to multiple endpoints ensuring integrity and consistency across

> *APIs should be adopted to support the new Commission priorities and policies at EU level*

the system' (OECD, 2019c; OECD, 2019a). Only through such 'transaction APIs' can the public sector fully connect to future ecosystems in which machine-to-machine exchanges, where possible, replace, to make them faster and reduce errors, some of the current human to human, human to machine or machine to human interactions (a recent example would be the transmission of positive test results for infectious diseases directly from laboratory software to the health authorities). European cooperation or regulation on standards for such APIs can help establish a common market for conformant software. APIs can also usher in new models of service delivery, enabling the integration of digital public services into targeted offerings for special user groups or situations.

We also suggest that governments focus on the risks and challenges identified in the study, including cybersecurity threats, cultural barriers (e.g. the need to increase the recognition of the importance of APIs at the senior management level), operational and technical barriers (e.g. the change management of the legacy existent IT systems and the need to adopt common guidelines at the whole-of-government level), legal barriers (e.g. the need to define common legal instruments to define licences and SLAs for the use of APIs) and economic barriers (e.g. the fact that APIs are more expensive than plain/bulk data exchange, and the long-term commitments that API systems require). Overcoming these challenges requires further recommendations and the adoption of a proper API framework for governments, as discussed in the following sections.

7.2 | Create and improve the 'application programming interface culture' in governments

The majority of stakeholders do not need to know the particulars of APIs, but understanding the basics is important. As APIs are a key technology enabler for policy, for citizen and business interactions with government, for the creation of platform approaches and for enabling technologies such as AI and IoT, there are many government stakeholders who need to understand both the value and the risks of APIs. This implies improving a specific set of (advanced) digital skills among public-sector actors, including speaking the right language to ensure that projects and public procurements achieve the results demanded of service providers and contractors.

Adopting APIs also requires changes to departmental budgets and organisation, and adjustments to resource allocation. Policymakers and key decision-makers therefore need to understand the importance of APIs in digital government models at a high level. Departmental leaders need to understand the value, challenges and resource implications of APIs and operational teams need to understand privacy, security and best-practice implementation approaches. All of this will require API introductory and specific training.

In addition, many of the benefits that are sought from APIs require new ways of working within government. In particular, negotiation and collaboration skills for public-service workers to allow them to work across departmental siloes and with other tiers of government are needed. In other situations, user-centric skills such as design thinking and user experience approaches are needed to focus development on demand-driven approaches that avoid overinvesting in infrastructures that are not fit for purpose, even when agile approaches are in active use. The abovementioned emphasis also implies improvements in external facing skills, including working with external stakeholders in ecosystem models. Such skills will be essential for a digital public-sector workforce in which APIs are used to achieve interoperability, reuse services and develop new digital services. Moreover, the partnership working involved in such ecosystem approaches may also lead to fundamental transformations in the organisations themselves and this will require management from the relevant leaders within those organisations.

Training should also focus on storytelling, sharing some of the examples of success documented throughout this report as a way to encourage understanding and action, especially through those activities that draw on real experiences and help to develop a European Union API community. We suggest that these activities be implemented in strict alignment with the European Commission Interoperability Academy and the European Support Centre for Data Sharing to create training materials on APIs.

7.3 | Create best practices and guidelines

Best-practice operational guidelines and standards should be created to assist governments in implementing product management and life cycle approaches. This study found that a range of best practices were being implemented by governments and the private sector. There is sufficient agreement on architectural styles, security minimum standards and API design that they can be collected into standards and shared across European governments. While there is almost total agreement among governments and the private sector that a product management approach should be taken, fewer resources are available to guide government stakeholders when implementing best practices and tools to help support this new skill set. We recommend that the focus should be on the following aspects:

> *"Best practices, guidelines and standards should be created and shared to assist government in implementing product management and lifecycle approaches"*

— technical aspects:
  - the provision of a set of recommendations for governments to manage the semantic versioning of APIs;
  - tools to improve the discoverability of government APIs and the composition of government API services – ways to improve the discoverability of APIs by using established methods (e.g. API catalogues) and technical specifications for API publications (e.g. the OAS) need to be identified and trialled;

— cybersecurity and privacy aspects:
  - investigate security solutions and security standards for handing security requirements, including the authentication and authorisation of users;
  - investigate specifications for ensuring data traceability that would help support citizens' trust in public-sector APIs, while ensuring the ability to document compliance with legal requirements;

— legal and organisational aspects:
  - an analysis of the legal conditions for handling ownership, rights of use and liability for data in/from different governments related to handling the transfer of responsibility for data across organisational, sectoral and national borders, which could include checking if access-management solutions have been set up for data access and any digital rights management in key Open Data Directive areas (relevant studies have been developed by various Directorate Generals of the European Commission, including the studies on 'high-value' datasets of the Open Data Directive);
  - an analysis of the current available and possible solutions for SLAs for APIs to help API providers take all of the relevant considerations into account and to improve the consistency and recognisability of terms across different API providers – this should be done by also engaging key users to ensure that possible solutions have a lightweight/appropriate level of complexity.

7.4 | Adopt the application programming interface framework proposed in this study

In our study, we provide a framework on how to adopt APIs in governments, which will help them to better reach their policy goals, including the aforementioned priorities of the European Union. This framework provides a cohesive, coordinated approach to APIs that overcomes the challenges of complexity that can result from ad hoc implementations. The framework model recognises that governments are already implementing APIs and digital government strategies in a variety of ways, as the proposals aim to accommodate existing efforts.

The framework is based on a robust analysis of the best-practice literature on APIs, on the discussions with and feedback received from the participants of our workshops, on the interviews with a number of API experts from both the private and the public sectors. Moreover, it has been tested in a pilot project with the government of Regione Lombardia in Italy. Nevertheless, we still consider it as a tool in its early stages that must be further tested, validated and refined, as well as continuously adapted to presently unexplored current and future requirements. This is why we suggest that the adoption of the framework be considered and that, if it is adopted as a tool by the European Commission, its implementation as a tool supporting the CEF building blocks or supporting the implementation of policy instruments such as the Open Data Directive.

> *"Digital government agendas should consider the proposed API framework for designing their API strategies"*

In support of this effort, it would be useful for the European Commission to further develop our (online) maturity toolkit to allow governments to perform self-assessments and to guide them through the API framework's implementation. In this study, the pilot project involved preparing a set of maturity assessment checklists for all of our proposals, and also included a testing pilot. This resource could be further tested and refined, aiding governments in changing their approach to become more cohesive, while still gaining value from their current API-related activities. The online tool could be used both to score maturity and so help governments to prioritise future actions, and to benchmark governments' status and find organisations facing similar challenges or that have already developed reusable solutions.

7.5 | Become digital ecosystem aware

Knowledge transfer from/to the private sector has been found to be fundamental in supporting the findings and conclusion of this study. It is suggested that private-sector involvement in digital government efforts related to APIs be continued, including in partnerships with company-neutral organisations similar, for example, to the APIdays series of conference (APIdays global, 2019). The following ideas could be applied in future API industry and Govtech events to augment the reach and the depth of sharing knowledge.

— Webinars on APIs could be organised on digital government topics and public-sector API managers could be encouraged to share their stories as compelling short articles. Conferences could be held to host the webinars to increase the number of online community members and reach a wider audience while encouraging collaborative working between groups at onsite events. The articles could be published on platforms such as ProgrammableWeb.com, apiscene.io, nordicapis.com or a dedicated blog hosted by European Commission platforms, such as JoinUp.

— Other government APIs workshops on specific topics could be organised. While previous workshops have dealt with general topics about how to build and manage APIs, a future series of events could be dedicated to APIs and data-sharing technologies for public policy-relevant topics such as healthcare, personal data, smart cities, security data or cultural heritage, among other topics appropriate to the location and the local ecosystem. These events could also be organised based on the best practices adopted in other European Commission initiatives related to APIs. The events would attract speakers from the private and public sectors and would allow them to learn from each other and discover new ways of partnering on data collection, refining and exposition, API-related best practices and community engagement.

— A specific government API conference event could be organised, focusing on digital government and public-sector APIs, possibly located in Brussels and organised by the European Commission. This event would attract speakers from the most advanced public-sector initiatives and attendees from the public and private sectors.

It is also suggested that a specific working group be created with experts from the Member States working

on the specific topic of APIs and, if possible, that this be connected with the CEF building blocks initiatives of the European Commission (particularly the e-delivery building block). The working group could also focus on specific, concrete pilot activities on the topics of interest of the participating members.

A European knowledge hub on the web is also needed. It could be implemented as one of the collection hubs of the JoinUp initiative and linked with the Science Hub of the JRC and with the European Support Centre for Data Sharing. Transforming the one-off activities performed by the APIs4DGov project into a periodical set of activities that involve the whole European Union government API community should also be prioritised. The presentations given at conferences and other work identified during this study (or further future studies) could also be widely distributed. The Science Hub could also act as a centre of excellence of government and industry knowledge about APIs. European and international governments at all levels could share examples of their API activities, so that everyone can learn from emerging best practices and collectively solve some of the more challenging aspects of API adoption in governments. The platform could also be used for cross-border project scoping, so that testbeds could be put in place and reusable solutions developed.

8 CONCLUSIONS

8 CONCLUSIONS

Digital transformation has affected the entire public sector in many ways. Governments have passed from digitalising their back-office tools, to using the internet to make their processes and services more efficient (e-government), to integrating digital technologies and user preferences in the design and receipt of services (digital government). The digital government transition, in particular, requires a noteworthy investment of public resources. Therefore, technological solutions that trigger, enable and facilitate this transition must be adopted, considering their maturity, their impact and the best way they can be implemented. APIs are one of these solutions and have had growing attention from governments in the last few years. An API is, in brief, a machine-to-machine interface, different from a machine-to-human interface, such as a web browser. Through APIs, the information managed by digital governments can be exchanged and governed with a large number of stakeholders including other governments, companies and citizens. APIs can be used by governments, similarly to (but with different goals from) what happened in the private sector for both small and large players such as Amazon, Google and Twitter. To better understand how to follow this trend, 2 years ago, the European Commission initiated the 'APIs4DGov' study, the aim of which was to analyse the state of the art in, the value added by and the way forward in adopting APIs in governments.

This final report has presented the main outcomes of the European Commission APIs4DGov study. This document provides a concrete tool for governments to use to determine the status of their API strategies and, eventually, how these strategies should be designed or adopted. The document focuses, in particular, on the role of governments as API providers, whereby they share their APIs with different target groups that are both internal and external to the organisation. Other documents published as part of the study present the case studies analysed, API web standards and the proposed API framework for governments.

8.1 | Main results

From our research, we have identified that the definition of **API strategies** can **assist governments in their digital transformation by regulating the necessary organisational change management process**. APIs can provide crucial information on the use of resources, on actors and dynamics of digital interactions and on processes' performance and, ultimately, can support budget allocation decision-making. APIs can help automate access to government digital assets, including data and service transaction, and increase their reach potential.

Access to digital assets is key to designing the transformational roadmap and ultimately improving government efficiency and effectiveness by means of **increasing the innovative potential of public service provision**. Moreover, APIs enhance policymaking by facilitating access to virtually any relevant information required in all phases of the policy cycle.

Inherent **features of APIs**, such as their **reusability and modularity**, fundamentally **increase the reach potential of digital assets to both internal and external players**. Digital solutions can be composed of a highly flexible assemblage of APIs involving several actors. Owing to these enabling characteristics, **the definition of API strategies is crucial for the wiring of a functioning digital ecosystem**.

For many years, the European Commission has worked on a series of initiatives and activities that deal, in general, with the digital transformation of governments and that could be supported, through improved efficiency, by the adoption of APIs in governments. The **Open Data Directive** makes the adoption of APIs for 'high-value' and dynamic datasets mandatory. In addition, the communication **A European Strategy for Data** specifically requires the use of APIs in digital governments. To concretely implement the adoption of APIs in governments, current initiatives, such as the EIF, the ISA[2] programme, the EU e-government action plan 2016–2020 and the CEF building blocks, and future initiatives within the next digital Europe programme should then explicitly consider the implementation of APIs as suggested in this study.

The main finding of the preliminary analysis of the cases studied is that **APIs strongly support the digital**

transformation of governments and that **when API strategies and solutions are implemented, their uptake is rapid and extensive**. Nevertheless, **API strategies in EU governments are in their early stages, with the oldest having only been implemented in 2014, and a significant number are planned to be deployed within 2020**.

Regarding API technical standards, this study has clarified some disputed topics, such as the **difference between web services and APIs**, the **definition and adoption of the REST architectural style** and the classification of the degree of maturity of the technical adoption of APIs. Moreover, this study has collected, analysed and classified the most relevant documents for supporting governments in their technological API journeys, also considering the advantages and drawbacks of the adoption of standards.

The deployment of functional API systems has positive effects on performance in private organisations, such as increasing flexibility, reducing costs, allowing easier access to digital assets and, with marginal costs being close to zero, allowing the reach potential to be virtually unlimited. All of these characteristics have intrinsic economic implications, however, and it is not yet clear how these effects would transfer to government environments. As noted above, APIs support government goals and public service provision. In addition, internal and external benefits have been identified for governments when sharing their digital assets. **Internal benefits include innovation triggering, efficiency gains and improving the access to and use of government (open) data digital assets. External benefits include the enablement of digital ecosystems, the rewiring of interactions with society actors, new economic opportunities and the possibility of orchestrating digital ecosystems.** API adoption also carries both technical and organisational costs. No main conclusions can be drawn at this stage on budgetary quantification. Nevertheless, from the results of our survey, it seems that the yearly budget used to maintain APIs is rather low. Moreover, the adoption of APIs implies challenges, such as those involved in overcoming the organisational mindset shift required and the potential lack of skills, overcoming cybersecurity vulnerabilities and adhering to current regulations (e.g. the GDPR). Social implications include the possible impact on **privacy and cybersecurity issues**, the augmented exchange and use of government datasets, and the help provided in generating social value by making services more accessible, which, in turn, can create additional inclusiveness and accessibility.

This study looked at emerging government best practices and guidelines from around the globe, with a specific focus on the EU. Over 3 900 links were found and scanned for their relevance to APIs, in addition to the best-practice documents and guidelines. Of this combined pool of documents, 968 documents were reviewed and 343 were chosen as relevant for government API best practices. Based on the analysis of this literature, discussions with many stakeholders and a pilot project, a robust **basic digital government API EU framework** is proposed within the study. The framework gives the following recommendations: (i) align, prioritise and measure the adoption of APIs with policy goals, (ii) define a government platform, harmonise actions of different digital ecosystems and build the API platform components, (iii) create governance structures, establish cross-competency teams and appoint product managers and (iv) form guiding principles and follow API product and API life cycle approaches. Regarding the selection of the tools to implement APIs in government, general principles include the following: (i) choose tools that support agile and iterative development, (ii) choose open-source tools by default and (iii) choose modern, cloud-based and commodity tools. Specific components for API life cycle management must cover all stages of APIs, namely strategy, design, documentation, development, testing, deployment, security, monitoring, discovery and promotion, and change management.

APIs are a general purpose, domain-neutral technology that can be applied to a huge number of areas. Nevertheless, based on the evidence found through our research, we suggest prioritising the following domains: health, earth observation, mobility, geospatial data, statistics, meteorological data, agriculture, energy, company registrations, industrial manufacturing, financial data and skills/jobs data. Moreover, the following thematic areas would greatly benefit from API adoption in governments: smart cities, citizen science and all of the public sector data in general (e.g. open data). Because of their disruptive impact, APIs of the following technologies should also be prioritised: AI, the IoT, big data, edge computing, digital twins, autonomous things, microservices and blockchain.

8.2 | Recommendations

Our concrete key recommendations include the following.

— **Explicitly adopt APIs to support the new Commission priorities and EU and Member State policies.** APIs should be adopted to implement the European Commission digital strategy (including the design of internal and trans-European applications). APIs should be adopted by EU governments to implement the Open Data Directive and the European government interoperability strategy, as well as legislation on technical arrangements for the dissemination of 'high-value' and dynamic datasets and the design of the European Union data spaces of the European strategy for data.

— **Create and improve the API culture in governments**, including the creation of best practices and guidelines in specific fields. The alignment of training activities with the Interoperability Academy and the European Support Centre for Data Sharing must be considered.

— **Adopt the proposed API framework to orient government API and digital government strategies.** The API framework presented considers the adoption of APIs not only at the operational level, but also from tactical and strategic points of view. The framework is based on a robust analysis of the literature on API best practices, on the discussions with and feedback received from the participants of our workshops and on the interviews with a number of API experts from both the private and the public sectors. Moreover, the framework has been tested in a pilot project with the government of Regione Lombardia in Italy (Mark Boyd et al., 2020a).

— **Become digital ecosystem aware.** Engaging both EU governments and the private sector is fundamental to developing and designing interoperable government IT platforms that link multiple stakeholders.

8.3 | Limitation of the study

We tried to extend our investigation into many aspects related to API adoption in governments, but we are conscious that the research area in this field is vast. Some aspects, such as the quantitative socioeconomic impact of APIs, are currently quite difficult to analyse for various reasons, including the relatively recent and rare adoption by governments of API strategies, the problems in discovering available government APIs on the web and the difficulty in objectively measuring the impact of APIs on the distinct institutional goals of governments (which are society oriented) compared with their impact on private sector goals (which are profit oriented). For these reasons, there is a lack of data that can be gathered and analysed and so the results of such analyses cannot be considered solid enough to produce quantitative results. This study investigated and presented these aspects in a qualitative way, but our wish is that, in the near future, API strategies will be embraced more by governments than is currently the case. In this way, there will be an increasing availability of data about government APIs and so their discoverability will increase enough to allow researchers and policymakers to better evaluate the use and impact of the adoption of APIs in the public sector.

In the study, efforts were made to classify the legal aspects analysed in our research, by classifying them from strategic (e.g. European Union regulation), organisational/tactical (e.g. SLAs) and operational (e.g. licensing aspects) points of view. Legal and licensing issues were some of the most underdeveloped areas identified in the study. More focused work is needed to identify the best models and approaches for governments to ensure a balance between enabling API adoption and minimising risks and adverse impacts from government API availability.

The proposed API framework is at an early stage. It has to be further tested, validated and refined, as well as continuously adapted to currently unexplored present and future requirements. For this reason, it could be useful to consider its further implementation as a tool supporting the CEF building blocks or supporting the implementation of policy instruments such as the Open Data Directive.

8.4 | Future lines of work

A maturity toolkit would allow governments to conduct self-assessments and guide them in implementing the proposed API framework. In this study, a pilot project and online tool (Mark Boyd et al., 2020b) were undertaken to help governments identify their progress towards implementing the full API framework. Further testing and refinement will occur after the publication of the framework (Mark Boyd et al., 2020a) so that governments can reorient themselves towards a more cohesive approach, while still gaining value from their current API-related activities. We plan to work on the refinement of the basic online tool to help governments score their maturity and identify and prioritise future actions.

Short-term activities as part of the study will focus on the following aspects: engaging public- and private-sector stakeholders (e.g. by creating specific working groups and mixed public/private workshops), focusing on cybersecurity and privacy aspects, analysing API legal and organisational aspects and providing a set of technical recommendations on API discoverability and access.

As the technological and architectural landscape is evolving very quickly, investigating new digital government platform solutions might also be considered in the short-term activities as part of the study. For example, the Estonian X-Road platform (one of the cases studied within the study) is evolving towards a new-generation government platform architecture that considers 'proactive services' and includes an intelligent virtual assistant, microservices, event-driven messaging environments and 'chaos engineering' to build messages 'rooms' called 'X-Rooms' (Vaher, 2020).

Medium-term and sustainable activities and possible follow-up studies should also consider providing support to raise awareness through training initiatives on APIs, such as those prompted and organised by the Interoperability Academy and the European Support Centre for Data Sharing and proposed by or with the support of the European Commission.

Moreover, the role of APIs in digital ecosystems should be better analysed and considered. APIs are a technological solution that apply to and have an impact on a number of domain areas and technologies. A number of horizontal domain areas (e.g. geospatial data, earth observation and statistics) and vertical areas (e.g. agriculture, transportation, health and emergency management) are currently using API-based solutions. A general effort to open and use APIs to improve the connection of these digital ecosystems and to allow the private sector to have access to digital government is required, and the impact of this effort should be investigated. This study anticipates some relevant impacts, but the effect of APIs in these areas is still unknown and, probably, underestimated.

8.5 | Closing remarks

We thank readers for dedicating time to reading this document. All in all, we hope that this study can concretely support governments in their journey towards the adoption of API strategies and in their digital transformation. The evidence collected from our study should help improve understanding of the current API landscape and the importance of APIs in triggering the enablement of digital ecosystems in some priority domains of the public sector.

We hope that our findings orient government API strategies towards cohesive, efficient and effective API-based digital platforms, as suggested with the proposed API framework. Our final goal is to better support the policy targets of governments and the priorities of the European Commission, in particular the priority *A Europe Fit for the Digital Age*.

We know that there are still many unresolved issued presented in the study and the report and so we would gladly receive any feedback that will help us to improve our future work on the digital transformation of governments and technological solutions such as APIs.

Notes

(1) This is just an example; the structure of a request of an API can be much more complex.
(2) This might depend on the size of the dataset for which the bulk download is needed for performance reasons.
(3) The i2010 e-government action plan 2006–2010, the e-government action plan 2011–2015 and the e-government action plan 2016–2020.
(4) See also the last architectural study on SDG, which specifies the 'Application services/interface with the most salient application components and interoperable enablers, which shall be considered in order to facilitate technical interoperability when developing an Interoperable European Solution' (Section 4.4.2 of Everis (2018)).
(5) Current CEF building blocks include big data infrastructure, a context broker, e-archiving, e-delivery, e-identification, e-invoicing, e-signature, e-translation, the OOP and blockchain.
(6) The programme will build on the DSIs achieved under the current CEF programme and will support the further evolution and wider implementation of policy elements such as the EIF.
(7) For a definition of the ProgrammableWeb.com API directory data model, see https://www.programmableweb.com/news/programmablewebs-new-api-directory-data-model-explained/analysis/2016/07/08.
(8) See also Santoro et al. (2019).
(9) It should be noted that, independently from the catalogue APIs that give access to the metadata, many of the entries of the catalogues may not be good enough to be accessible and used by a data consumer (Berners-Lee, 2012).
(10) At the time the EUSurvey was launched, the new Open Data Directive (European Union, 2019a) had not yet been published, so some respondents asked for a revision of the Public Sector Information Directive to also introduce APIs for open data and public-sector information. Indeed, the latest version of the directive explicitly requires APIs for 'high-value' and dynamic datasets, thus dealing with this suggestion.
(11) See Article 5(c): 'Principles relating to processing of personal data'.
(12) Please note that, in the rest of this section, the term 'data model' is used to refer to both the data format and content encoding.
(13) 'A resource is a conceptual mapping to a set of entities, not the entity that corresponds to the mapping at any particular point in time' (Fielding, 2000). The components (e.g. clients and servers) perform actions on resources by using representations of them. A representation captures the current or intended state of a resource and can be expressed in any message format supported by any two interacting components (e.g. XML and JSON).
(14) Communication protocols are formal descriptions of digital message formats and rules. They are required to exchange messages in or between computing systems and are required in telecommunications.
(15) It is important to note that, because this would require an entire study itself, we will not present domain-specific standards or technical specifications. In addition, we aimed to be as neutral as possible (i.e. by not expressing preferences for a certain technical specification or standard) in the selection of and definitions used in relation to the topics presented.
(16) The list of documents is available online as open data (Mark Boyd and Vaccari, 2020).
(17) The list is numbered from 1 to 12, but this does not imply a rigid sequence of actions; it is simply internal (to this report) enumeration.
(18) Such as the *Core Public Services Vocabulary* (European Commission, 2019c).
(19) See, for example, the private company API landscape at Medjaoui (2020).
(20) See, for example, the set of best-practice principles for designing and delivering government services published by the Digital Transformation Agency of the Australian government.
(21) Previous research has been conducted by IBM in a project called 'API harmony' (Wittern et al., 2016).
(22) See, for example, the practice of the city of Tampere, Finland (Government of the city of Tampere, 2018).
(23) Service-level objectives are defined as follows: 'Targets for a given attribute of a cloud service that can be expressed quantitatively or qualitatively. Therefore, they seek collaborative communication models in which service levels are negotiated with department users and act as target goals to guide implementation. Service level indicators can then be used to report regularly on implementation results' (European Commission, 2014b).
(24) A collection of facts, rules and relationships about a specific domain of interest represented in symbolic form.
(25) The report by Williams (2018) contains an exhaustive description and analysis of the cases.

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List of abbreviations

AI	artificial intelligence
AmDex	Amsterdam Data Exchange
API	application programming interface
APIs4DGov	application programming interfaces for digital government
CBS	(Dutch) Centraal Bureau voor de Statistiek
CEF	Connecting Europe Facility
DAWA	Danmarks Adressers Web API
DG CNECT	Directorate-General for Communications Networks, Content and Technology
DG DIGIT	Directorate-General for Informatics
DIAS	Copernicus Data and Information Access Services
DINSIC	Direction interministérielle du numérique et du système d'information et de communication de l'État
DINUM	Direction interministérielle du numérique
DSI	digital service infrastructure
DSM	digital single market
ECMWF	European Centre for Medium-Range Weather Forecasts
EDP	European Data Portal
EFTA	European Free Trade Association
EIF	European interoperability framework
ELISE	European Location Interoperability Solutions for e-Government
EMT	Empresa Madrileña de Transporte
ETSI	European Telecommunications Standards Institute
EU ODP	European Union Open Data Portal
FHIR	fast healthcare interoperability standard
FIWARE	Future Internet Ware
GDPR	General Data Protection Regulation
GPS	global positioning system
HAL	Hypertext Application Language
HATEOAS	hypermedia as the engine of application state
HTTP	Hypertext Transfer Protocol
IANA	Internet Assigned Numbers Authority
ICT	information and communications technology
INSPIRE	Infrastructure for Spatial Information in Europe
IoT	internet of things
ISA/ISA^2	interoperability solutions for public administrations, businesses and citizens
ISO	International Organization for Standardization
IT	information technology

JLA	JoinUp Licensing Assistant
JRC	Joint Research Centre
JSON	JavaScript object notation
KLIP	Cable and Pipe Information Portal
MEC	multiaccess edge computing
NGSI	next-generation service interface
OAS	OpenAPI Specification
OASC	Open and Agile Smart Cities
OECD	Organisation for Economic Co-operation and Development
OGC	Open Geospatial Consortium
OOP	once-only principle
OSF	Open State Foundation
PSD	first Payment Services Directive
PSD2	Second Payment Services Directive
RAML	RESTful API Modeling Language
RDF	Resource Description Framework
REST	representational state transfer
RPC	remote procedure call
SAML	Security Assertion Markup Language
SDG	single digital gateway
SDN	software-defined networking
SEMIC	Semantic Interoperability Community
SLA	service-level agreement
SMEs	small and medium-sized enterprises
SOAP	Simple Object Access Protocol
SPARQL	SPARQL Protocol and RDF Query Language
SPDX	Software Package Data Exchange
SWOT	strengths, weaknesses, opportunities and threats
SWS	semantic web services
TfL	Transport for London
TOOP	The Once-Only Principle Project
UNEP	United Nations Environment Programme
W3C	World Wide Web Consortium
WoT	web of things
XACML	Extensible Access Control Markup Language
XML	Extensible Markup Language
YAML	YAML Ain't Markup Language

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ANNEXES

- GLOSSARY
- APPLIED METHODOLOGY
- APIs4DGov OUTPUTS QUICK REFERENCES
- POLICY INSTRUMENTS QUICK REFERENCES

Annex 1 | Glossary

This section presents the definitions of the terms collected so far as part of the APIs4DGov study. Apart from the few expressions proposed by this study, an effort has been made to reference the authoritative/official resource for the definition of each term, including the definitions taken from standardisation bodies, the CEF documentation (European Commission, 2019p) and the glossary published in a preliminary report of this study (Williams, 2018).

Application programming interface (API)	An API is defined as follows: 'The calls, subroutines, or software interrupts that comprise a documented interface so that an application program can use the services and functions of another application, operating system, network operating system, driver, or other lower-level software program' (Shnier, 1996).
API-first model approach	An API-first model is an approach in which the organisation reviews its goals and asks if an API is the best way to achieve each goal (Medjaoui, 2014; McKendrick, 2019; Mehdi et al., 2018).
API gateway	HTTP enables the use of intermediaries to satisfy requests through a chain of connections. There are three common forms of HTTP intermediary: proxy, gateway and tunnel (Fielding and Reschke, 2014). An API gateway is a software component that was initially popular within the microservices world, but is now also a key part of an HTTP-oriented serverless architecture. An API gateway's basic job is to be a web server that receives HTTP requests, routes the requests to a handler based on the route/path of the HTTP request, takes the response back from the handler and finally returns the response to the original client. An API gateway will typically do more than just this routing, also providing functionality for authentication and authorisation, request/response mapping, user throttling and more. Depending on the gateway features, API gateways are configured, rather than coded, which is useful for speeding up development, but care should be taken not to over use some features that might be more easily tested and maintained in code (Chaplin and Roberts, 2017).
API versioning	API versioning is one of the steps of an API life cycle (Jacobson et al., 2011). There is no common agreement on the definition of API versioning. If, from one side, an API is the embodiment of a technical contract between a publisher and a developer and this contract should stay intact, then, on the other side, there is sometimes the need to begin with a completely new version. So, even though we have found that API versioning is 'The ability to change without rendering older versions of the same API inoperable' (Deloitte, 2018) or that 'Non-backward-compatible changes break the API (i.e. a new one has to be released, and consumers must migrate from the old to the new one)' (Mehdi et al., 2018), we could accept the fact that, in the life of an API, starting over with a new version that might not be fully backward compatible with an older version or that might make the older version deprecated is unavoidable. Therefore, retiring an API is often an unacknowledged part of the API life cycle (Mark Boyd, 2016b) and versioning is part of the API design life cycle.
Architecture	Architecture refers to the fundamental concepts or properties of a system in its environment, embodied in its elements and relationships, and in the principles of its design and evolution (ISO et al., 2011).
Authentication	Authentication is the ability to prove that a user or application is genuinely who that person or what that application claims to be (IBM, 2014a; ENISA, 2019; NIST, 2019).
Authorisation	Authorisation protects critical resources in a system by limiting access to only authorised users and their applications (IBM, 2014b).

Collaboration (on public services)	Collaboration on public services indicates that a government is pursuing collaboration with third parties to deliver added value in public service design and/or public service delivery. Collaboration involves using shared resources, taps into the power of mass collaboration on societal issues and can lead to the development of innovative, distributed and collective intelligent solutions. Collaboration is also related to the concept of service-oriented principles of reuse, composition and the modularity of a service. With the addition of new services, new (public) value is proposed to users. This value relates only to creating private value for new businesses, but also to creating public value (i.e. added value for society) (European Commission, 2019q).
Container	An alternative to using a platform as a service (PaaS) on top of a virtual machine is to use containers (e.g. the popular hub Docker). Containers provide a way of more clearly separating an application's system requirements from the nitty gritty of the operating system itself (Chaplin and Roberts, 2017).
Digital government	Digital government refers to the use of digital technologies, as an integrated part of governments' modernisation strategies, to create public value. It relies on a digital government ecosystem, comprising government actors, non-governmental organisations, businesses, citizens' associations and individuals, which supports the production of and access to data, services and content through interactions with government (OECD, 2014).
Digital platform	Although the definition of a digital platform would require an analysis of its characteristics from different points of view (Van Gansen et al., 2018), in the context of this study, a 'digital platform' is a digital 'product that serves or enables other products or services' (Gartner, 2020b). It provides reusable, common business services to accelerate the development of the next generation of government services that are simple and intuitive and make it easy for people and businesses to deal with government (Australian Government, 2019b).
Digital technologies	Digital technologies or ICT include the internet, mobile technologies and devices, as well as data analytics, used to improve the generation, collection, exchange, aggregation, combination, analysis, access, searchability and presentation of digital content, including for the development of services and apps (OECD, 2014).
Documentation/ definition (in API)	Documentation (or a definition) is a technical content deliverable, containing instructions about how to effectively use and integrate with an API (Swagger.io, 2019b).
E-government	This refers to the use by governments of ICT, particularly the internet, as a tool to achieve better government (OECD, 2014).
External API	An external API is designed to be accessible outside agency boundaries, ranging from government inter-agency interactions to the wider population of web and mobile developers. This means it may be used both by developers inside the organisation and by any developers outside that organisation who wish to use it for other purposes (definition based on Williams (2018)).
Information technology (IT)	IT refers to the use of technology for the storage, communication or processing of information. This technology typically includes computers and telecommunications, applications and other software. The information may include business data, voice recordings, images and video. IT is often used to support business processes through IT services (Axelos, 2011).
Infrastructure	Infrastructure refers to the framework or features of a system or organisation (Wordreference.com, 2020).
Internal API	This type of API is generally used to facilitate the sharing of data and services between systems within an agency, avoiding the need for complex point-to-point integration. They are not visible to any system outside the agency that created the API and are generally in the domain of the agency's IT department (definition based on Williams (2018)).
Interoperability	This refers to the capability to communicate, execute programs or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units (IEEE, 1991).

IT infrastructure	IT infrastructure refers to all of the hardware, software, networks, facilities, etc., that are required to develop, test, deliver, monitor, control and support IT services. The term IT infrastructure includes all of the IT elements, but not the associated people, processes and documentation (Axelos, 2011).
IT service	An IT services is a service provided to one or more customers by an IT service provider. An IT service uses IT and supports the customer's business processes. An IT service combines people, processes and technology and should be defined in an SLA (Axelos, 2011).
Legal interoperability	Each public administration contributing to the provision of a European public service works within its own national legal framework. Legal interoperability is about ensuring that organisations operating under different legal frameworks, policies and strategies are able to work together (European Commission, 2017a).
Microservice	A microservice is a basic element that results from the architectural decomposition of an application's components into loosely coupled patterns consisting of self-contained services that communicate with each other using a standard communications protocol and a set of well-defined APIs, independent of any vendor, product or technology (Karmel et al., 2016).
Northbound interface	A northbound interface of a component is an interface that allows the component to communicate with a higher level component, using the latter component's southbound interface. The northbound interface conceptualises the lower level details (e.g. data or functions) used by, or in, the component, allowing the component to interface with higher level layers. When used in a software-defined networking (SDN) community, for example, this involves APIs referring to programmatic interfaces that live on the northern side of the controller interface and not the south-side protocol driver interfaces (Open Networking Foundation, 2013; Metzler, 2015).
Open asset	This refers to government data, software, specifications and frameworks that are open, so that anyone can freely access, use, modify and redistribute their content with no or limited restrictions such as commercial use or financial charges (definition proposed by this study).
Open government	Open government can be defined as the opening up of government processes, proceedings, documents and data for public scrutiny and involvement, and is now considered a fundamental element of a democratic society (OECD, 2017). The open government initiative was started in 2009 by Barak Obama (The White House, 2009); after that, numerous governments adopted open data initiatives. It is founded on the belief that greater transparency and public participation can not only lead to better policies and services, but also promote public-sector integrity, which is essential for regaining the trust of citizens in the neutrality and reliability of public administrations.
Open services	These are digital public services that can be reused by other public administrations or eventually by third parties to provide value added services via a mechanism of service composition. Open services necessitate proper design of digital public services. The design principles of service-oriented architecture can prove useful: modular, decomposed services; interoperability through an API; and loose coupling (European Commission, 2016c).
Organisation	In general, here, the term 'organisation' refers to a public administration unit or any entity acting on its behalf, or to an EU institution or body (European Commission, 2016c).
Organisational interoperability	This refers to the way in which public administrations align their business processes, responsibilities and expectations to achieve commonly agreed and mutually beneficial goals. In practice, organisational interoperability means documenting and integrating or aligning business processes and the relevant information exchanged. Organisational interoperability also aims to meet the requirements of the user community by making services available, easily identifiable, accessible and user focused (European Commission, 2017a).
Participation (in policymaking)	Participation in policymaking happens when governments open up governmental decision-making to citizens, businesses and public administrations to ensure an open process for participation with the aim of enhancing public value (European Commission, 2019q).
Platform	See 'Digital platform'.
Private API	See 'Internal API'.

Public API	See 'External API'.
Public value	Public value refers to various benefits for society, which may vary according to the perspective or the actors, including the following benefits: (i) goods or services that satisfy the needs and expectations of citizens and clients; (ii) production choices that meet citizens' expectations of justice, fairness, efficiency and effectiveness; (iii) properly ordered and productive public institutions that reflect citizens' desires and preferences; (iv) fairness and efficiency of distribution; (v) legitimate use of resources to accomplish public purposes; and (vi) innovation and adaptability to changing preferences and demands (OECD, 2014).
Remote procedure call (RPC) API	An RPC API is a set of procedures (methods) that the client application can invoke and is executed by the server to fulfil a task. RPC APIs stem from the replacement of in-memory object messaging with cross-network object messaging in object-oriented applications (Feng et al., 2009).
Representational state transfer (REST)	REST is a software architectural style that defines a set of constraints that restrict the roles/features of architectural elements and the relationships allowed among those elements within any architecture that conforms to REST (Fielding, 2000).
Resource (in the REST architectural style)	In the REST architectural style, resource representation is central. Any information that can be named can be a resource: a document or image, a temporal service (e.g. 'today's weather in Los Angeles'), a collection of other resources, etc. (Fielding, 2000). A resource involves conceptual mapping to a set of entities, rather than referring to the entity that corresponds to the mapping at any particular point in time (Fielding, 2000).
RESTful API	RESTful APIs are based on the REST architectural style (Fielding, 2000).
Semantic interoperability	Semantic interoperability ensures that the precise format and meaning of the data and information exchanged are preserved and understood throughout exchanges between parties, in other words it ensures that 'what is sent is what is understood'. In the EIF, semantic interoperability covers both semantic and syntactic aspects (European Commission, 2017a). — The semantic aspect refers to the meaning of data elements and the relationship between them. It includes developing vocabularies and schemata to describe data exchanges, and ensures that data elements are understood in the same way by all communicating parties. — The syntactic aspect refers to describing the exact format of the information to be exchanged in terms of grammar and format.
Service-oriented architecture	Service-oriented architecture refers to an application pattern in which applications offer services to other applications by means of interfaces (European Commission, 2019q).
Smart city	There is no definitive definition of a smart city because of the breadth of technologies that can be incorporated into a city for it to be considered a smart city. From the definition given by Mark Deakin and Husam Al Waer in their research publication (Deakin and Waer, 2011), the factors that contribute to a city being classified as smart are: — the application of a wide variety of digital and electronic technologies in the city and its communities; — the application of ICT to enhance life and working environments in the region; — the embedding of such ICT within government systems; — the territorialisation of practices that bring people and ICT together to foster innovation and enhance the knowledge that they offer. For a more formal definition of the term, see also Ramaprasad et al. (2017).
Social value	This report uses the OECD definition of 'public value' as that for 'social value': 'Public value refers to various benefits for society that may vary according to the perspective or the actors, including the following: 1) goods or services that satisfy the desires of citizens and clients; 2) production choices that meet citizen expectations of justice, fairness, efficiency and effectiveness; 3) properly ordered and productive public institutions that reflect citizens' desires and preferences; 4) fairness and efficiency of distribution; 5) legitimate use of resource to accomplish public purposes; and 6) innovation and adaptability to changing preferences and demands.' (OECD, 2014).

Software-defined networking (SDN)	SDN is a paradigm whereby a central software program, called a controller, dictates the overall network behaviour (Kim and Feamster, 2013).
Software development kit	Typically, this is a set of software development tools that allows the creation of applications for a certain software package, software framework, hardware platform or computer system (Shamsee et al., 2015).
Software ecosystem	A software ecosystem is a set of businesses functioning as a unit and interacting with a shared market for software and services, together with the relationships among them. These relationships are frequently underpinned by a common technological platform and operate through the exchange of information, resources and artefacts (Messerschmitt and Szyperski, 2003).
Southbound interface	In SDN, the southbound interface refers to the interface and protocol between programmable switches (SDN-capable switches) and the software controller (Kim and Feamster, 2013).
Spatial object	A spatial object is a geographical feature, namely an abstract representation of a real-world phenomenon related to a specific location or geographical area (European Commission, 2019r).
Standard	A standard is a document that specifies a technological area with a well-defined scope, usually by a formal standardisation body and process (OGC, 2019b).
Technical specification	A technical specification is a document written by a consortium, vendor or user that specifies a technological area with a well-defined scope, primarily for use by developers as a guide to implementation. A specification is not necessarily a formal standard (OGC, 2019b).
Three-tier architecture	A three-tier architecture is a client–server architecture in which the functional process logic, data access, computer data storage and user interface are developed and maintained as independent modules on separate platforms. Three-tier architecture is a software design pattern and a well-established software architecture (Techopedia, 2018).
Time to first hello world	This is a metric that measures how successful documentation and API design is at enabling consumers to test a new integration with the API (Wiegers, 2018).
Transparency	Transparency refers to disclosing relevant documents and other information on government decision-making and government activity to the general public in a way that is relevant, accessible, timely and accurate (European Commission, 2019q).
Value chain	The value chain itself describes the full range of activities that are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), to delivery to final consumers and final disposal after use (definition proposed by this study).
Web API	Web APIs are APIs that are offered and consumed through the web. They deliver requests to the service provider and then deliver the response back to the requestor (i.e. they are an interface for web applications or applications that need to connect to each other via the internet to communicate) (Definition.net, 2019).
Web application	The term 'web application' refers to a web page or collection of web pages delivered over HTTP that use server-side or client-side processing (e.g. JavaScript) to provide an 'application-like' experience within a web browser. Web applications are distinct from simple web content in that they include locally executable elements of interactivity and persistent state (W3C, 2010).
Web service	Different definitions of web services exist. The W3C defines a web service as 'a software system designed to support interoperable machine-to-machine interaction over a network. It has an interface described in a machine-processable format (specifically WSDL [Web Service Description Language]). Other systems interact with the Web service in a manner prescribed by its description using SOAP messages, typically conveyed using HTTP with an XML serialisation in conjunction with other Web-related standards' (W3C, 2004). This definition links the concept of a web service to a set of specific technologies (SOAP and Web Service Description Language). Others provide more generic definitions. For example, in IBM (2014b), the authors state that a 'Web Service is a generic term for an interoperable machine-to-machine software function that is hosted at a network addressable location' and Papazoglou and Georgakopoulos (2003) define a web service as 'a specific kind of service that is identified by a URI [uniform resource identifier], whose service description and transport utilise open internet standards'. These definitions extend the W3C definition by essentially defining a

	web service as a service that is offered over the web. The Advancing Open Standards for the Information Society (OASIS) reference model for service-oriented architecture defines a service as 'a mechanism to enable access to one or more capabilities, where the access is provided using a prescribed interface and is exercised consistent with constraints and policies as specified by the service description' (OASIS, 2006).
Web service interface (provided by a web service)	Web service interfaces are designed to offer access to high-level functionalities for end users (either humans or machines) (definition proposed by this study).
Whole-of-government approach	This refers to the joint activities performed by diverse ministries, public administrations and public agencies to provide a common solution to particular problems or issues. The approach and content of these initiatives can be formal or informal and the areas covered can be related to policy development, public project management or public services (Australian Government, 2004).

Annex 2 | Applied methodology

We have based our research on the recommendations of the *ICT Impact Assessment Guidelines*, developed within the ISA² programme (European Commission, 2017f), and have extended these recommendations through the analysis of additional data sources. Figure 28 summarises the combination of a number of research methods that have been used to investigate the different aspects of the study. This approach was found to be fundamental to meeting the objectives of the study and to analysing new possibilities offered by APIs from different disciplinary perspectives and stakeholders' views. It was found that the use of this approach facilitates the cross-fertilisation, complementarity and validation of the results from different methods and allows for corroboration between quantitative and qualitative data.

We have based our analysis on different activities targeted at the following European government stakeholders:

— the e-government action plan steering board, which is composed of Member States' representatives who are responsible for their national e-government strategies (European Commission, 2016m);

— the chief information officer network, namely a network of DG DIGIT peers in the EU Member States' public administrations;

— the Digital Champions of the European Union, namely ambassadors for the DSM, appointed by their Member States to help every European become digital (European Commission, 2014c);

— the OASC network (OASC, 2019).

The activities include:

— a quantitative data analysis based on data collected from different resources, including the documents in the JoinUp platform (European Commission, 2019s), a set of APIs from data catalogues and API registries (including the ProgrammableWeb directory of APIs) and a set of API cases collected from previous studies on e-government and digital government at the EU level;

— a survey specifically focused on public-sector API strategies, based on a semi-structured questionnaire – the survey has run from September 2018 to the end of the study (European Commission, 2018k);

— a survey assessing the validation of the API framework and the recommendations we propose in this study (European Commission, 2019t) – the survey has run from September 2019 to the end of the study;

FIGURE 28: Applied methodology.
Source: Customised from ICT Impact Assessment Guidelines, *ISA² Programme (European Commission, 2017f).*

— a workshop, organised at the JRC premises in October 2018, the goal of which was to understand the main aspects of the public-sector API strategies in the EU – the outputs of the workshops (i.e. presentations and talks) are available at European Commission (2018a);

— three workshops, which were organised during 2019 in collaboration with the APIdays series of conferences, namely in Helsinki, Barcelona and Paris (APIdays global, 2019);

— a hackathon, organised as part of the INSPIRE 2018 conference, from which we extracted useful insights, especially regarding API trends in the geospatial domain (European Commission, 2018l);

— a number of stakeholders' cross-fertilisation meetings, with colleagues from DG DIGIT and DG CNECT.

A number of resources from the web have been taken into consideration to retrieve information on government APIs. The following are just some of these, and these specific references could be used in the future to search for and update specific information about APIs:

— the JoinUp platform, a collaborative platform created by the European Commission to help e-government professionals share their experience with each other (European Commission, 2019s);

— the EDP (European Commission, 2019f), a unique source of government open data that harvests the metadata of public-sector information available on public data portals across European countries – the EDP publishes these data in a single catalogue, together with information regarding the provision of data and the benefits of reusing them;

— the EU ODP, which provides access to an expanding range of data from the EU institutions and other EU bodies (European Commission, 2020f);

— the ProgrammableWeb directory, the world-leading source of news and information about APIs (ProgrammableWeb.com, 2019c);

— the final report of the study *Towards faster implementation and uptake of open government*, which aimed to provide input to the European Commission to support the new dynamically evolving e-government action plan 2016–2020 (European Commission, 2016g).

In the next sections, we present the activities related to our multiple-case study analysis, the survey and the workshop on API strategies.

Multiple-case study

From the API cases identified in the study, we selected seven diverse cases on the use of APIs in the EU public sector (Williams, 2018) to cover a variety of different circumstances and dimensions, with the purpose of deriving insight from a broad base of the API community. The selection was based on meeting the following set of criteria:

— different levels of API strategy adoption (operational or strategic),

— different sizes of public organisations (local, national and supranational),

— a coverage of Member States in the north and south of the EU,

— a range of sectors and public services (transportation, utilities, smart-city-related public services, gazetteers, permits and more).

The cases selected, illustrated in Figure 29, were as follows: (i) an interview with parties focused on the high-level vision or strategy behind API use (the Italian Digital Transformation Team), (ii) interviews with parties focused on using APIs as components of wider architectural platforms/ecosystems (Estonia's X-Road and FIWARE) and (iii) interviews with people involved in specific API implementation (Madrid Mobility Labs, the Amsterdam city data API, DAWA and the Flanders KLIP web API).

A brief description of the cases ([25]) follows.

— **X-Road** is an API-driven data exchange ecosystem platform that was initially developed between 1998 and 2001. It represents a government API framework developed by the Estonian government and licensed under the MIT licence. It is also used as a backbone

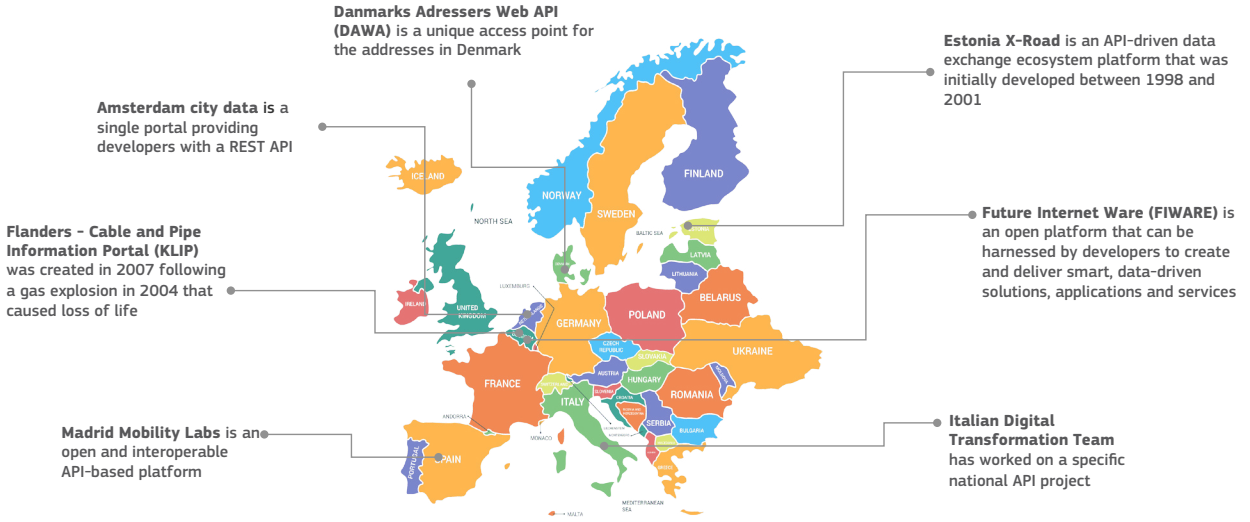

FIGURE 29: Case studies.
Source: JRC, own elaboration.

of the Finnish national data exchange layer. Originally built for SOAP/XML web services, it now extends to REST APIs (e-Estonia, 2019).

— **FIWARE NGSI v2** is an open platform that can be harnessed by developers to create and deliver smart, data-driven solutions, applications and services. It is a public–private partnership funded by the EU, corporate members and venture capitalists to develop the following: (i) a scalable open-source platform to access and manage heterogeneous related data through standardised unrestricted APIs, (ii) a standard for exchanging context information, namely the FIWARE NGSI (ETSI, 2019; FIWARE Foundation, 2014) and (iii) generic enablers and solutions to provide smart services with the FIWARE context broker as the main component (FIWARE Foundation, 2017).

— **Italian Digital Transformation Team (API strategy).** The Digital Transformation Team, which was created to build the 'operating system' of the country, has developed a specific API strategy. The strategy's goal is to create a series of fundamental components on top of which simpler and more efficient services could be built for citizens, government and businesses (Team Digitale, 2019).

— **Amsterdam city data.** A single portal has been developed to provide developers with access to Amsterdam's open data and some non-public classified data with controlled access for city employees. These city data went live in 2016 for civil servants and in mid-2017 for developers. The architecture is loosely coupled, using APIs to deliver data to the frontend portal (Soetendal, 2019).

— **DAWA** displays data and functionality regarding Denmark's addresses, access addresses, road names and zip codes. DAWA is used to establish address functionality in IT systems. The target audience for this site is developers who want to integrate address functionality into their IT systems. DAWA is part of the Amazon Web Services suite (Danish Agency for Data Supply and Efficiency, 2019).

— **KLIP** was developed by the government of Flanders in 2007 following a gas explosion in 2004 that caused loss of life. It is an API-driven platform in which all public and private utilities must share and request detailed digital maps showing the location of underground cables and pipes prior to carrying out engineering works (Informatie Vlaanderen, 2019).

— **Madrid Mobility Labs** is an ecosystem of APIs and a portal that brings information to citizens through multiple channels and applications for transportation-related APIs, such as on buses, parking, public bicycles, traffic, city hall sensors, third-party sensors and data (EMT-Madrid, 2019).

The structured interview for each case was designed to gather information about the following aspects (European Commission, 2019u):

— general information on the case study;

— non-technical aspects such as the strategy and vision of the implementing organisation and the purpose, usage, enablers, cost and benefits of the API;

— technical aspects such as the API specification or standard, authentication and authorisation, management and support;

— the need of the European Commission to provide/advocate regulations, guidelines or standards to enhance interoperability.

Survey

Our survey is aimed at gathering information about the state-of-the-play of government API strategies across Europe and abroad. The survey had three axes: the first explored information about API strategies at different levels of governments (international, national, regional and local), the second explored present API implementation projects and the third explored the demand for European actions regarding APIs.

The survey contained 130 questions related to the three axes' topics. Specifically, the first axis – API strategies – focused on gathering information about the goals, drivers, enablers, barriers and risks of current API strategic thinking. It also enquired about budgetary aspects and business models being adopted. It also explored the impacts of API adoption from four perspectives, namely economic, social, organisational and technical. The second axis – API implementation projects – focused on gathering information about API implementation projects, about the availability of guidelines and best-practise documentation, about the sectors in which API solutions are being adopted, about access policies and methods that are being utilised and about the monitoring methods and metrics used. The third axis – API European vision – focused on understanding strategic gaps that may be addressed through actions at the European level.

Thirty-five representatives from the European government stakeholders targeted submitted their responses. Different government levels were represented; specifically, 22 responses stemmed from national institutions, eight were from local institutions and five were from an international institution. The sample size, although limited, facilitated the identification of certain patterns, to focus the work on the different phases of the project.

Figure 30 depicts the maturity-level spectra of the samples. From the responses obtained, it can be seen that 12 organisations already have an enacted API strategy and three have even already made amendments to it. Sixteen organisations have ongoing API strategy design processes and five organisations do not have an API strategy or plan to have a specific API strategy in the near future.

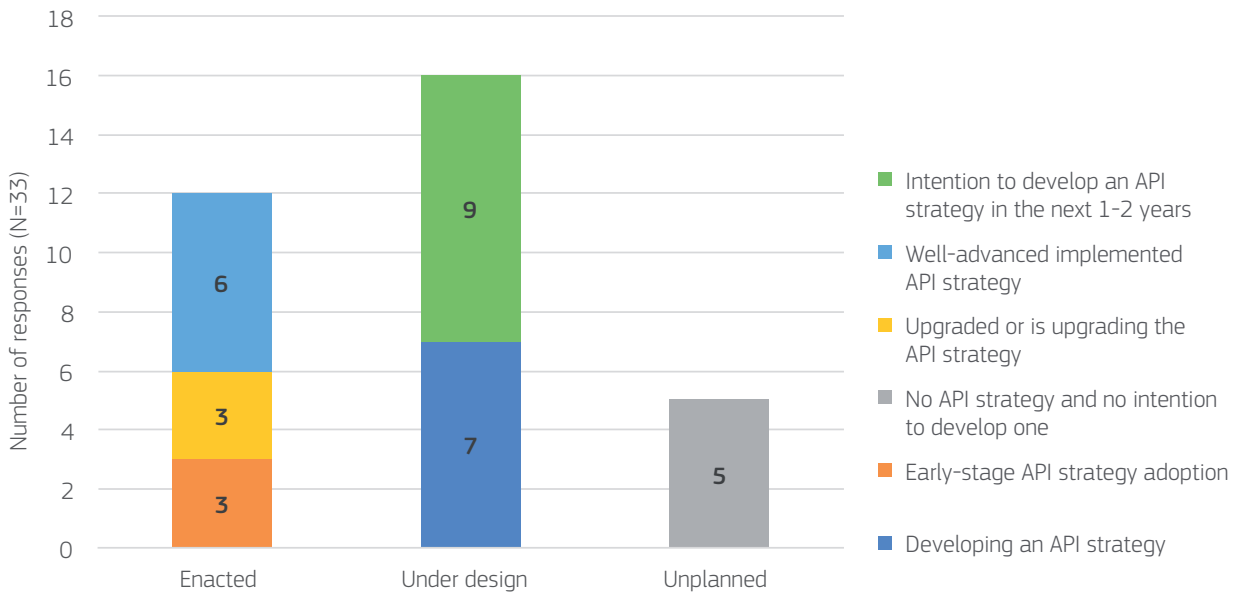

FIGURE 30: API strategies maturity level (survey).
Source: JRC, own elaboration.

Workshop

The project held a stakeholder workshop (17–18 October 2018 in Ispra, Italy) (European Commission, 2018f) to share the initial findings and gather more input related to government strategies for APIs across Europe and beyond. The workshop included keynote speeches from world-renowned experts from industry and academia, as well as contributions from API practitioners and representatives from different government levels (local, national and international) across Europe. The workshop's highlights are summarised below. Alongside introductions from the JRC and DG CNECT about the scope and purpose of the study and this workshop, four keynote speakers outlined some main considerations for workshop participants.

— **David Berlind** (Chief Editor of Programmable Web) set the scene with a keynote speech defining API concepts. He reflected on how inherent features of API solutions, such as reusability and substitution, potentially endow organisations with internal efficiency gains. He also highlighted the flexibility and ease of scalability that APIs offer for externalising resources for inter-organisational solutions. During a second intervention, he explained how the whole API classification exercise of setting up a ProgrammableWeb API catalogue has helped to understand key aspects of APIs.

— **Kin Lane**, the 'API evangelist', provided an in-depth look into the critical aspects that one should keep in mind when establishing sustainable organisational API systems. He also presented the lessons learnt from the implementation of an API strategy in the United States under Barack Obama's administration, for which he was a Presidential Innovation Fellow.

— **Medhi Medjaoui**, lead API economist at the API Academy and co-founder of the APIdays series of conferences, focused on APIs in the economic arena. He presented an analysis of the transition from the current API economy to a programmable economy, including both macro- and microeconomic perspectives. He stated that holistic API strategies in organisations should cover private, partner and public realms, given the main forms of interaction that APIs can support.

— **Mark Boyd**, writer and analyst of the API sector, opened the session related to APIs in the city realm. He presented relevant aspects of current city API deployments across the EU, specific API application cases and foresights about the key enablers for the sustainable growth of API city-based ecosystems.

As well as these keynote speeches, specific sessions were dedicated to representatives from governments across Europe. They presented their API strategies and experiences, providing valuable information about organisational arrangements, technical infrastructure approaches, the barriers and risks faced (and mitigation measures), community-building initiatives and the links between APIs and government platforms.

Annex 3 | Quick references to the study outputs

This document is the final report and main deliverable of the APIs4DGov study. It is complemented by a series of outputs of the study which could support the next actions in adopting APIs in governments. Some of these outputs are openly published as JRC technical reports and focus on specific topics of the study that could be relevant for readers. As highlighted by the study, governments should adopt APIs in a coordinated way. This report gives some ideas on a possible framework but, to give governments a more concrete tool, a further more detailed technical report has been published within the study (Mark Boyd et al., 2020a).

The specific government API case studies analysed in this work are also documented in detail in a separate report (Williams, 2018). These case studies present some of the ways that governments have implemented APIs in various areas and at different government levels. These case studies have also been used to support the ISA^2 ELISE action (European Commission, 2016j).

A webinar, developed within the study, could also be beneficial for those readers who would like to know more about governance models, ecosystems and benefits of APIs for public-sector organisations. The webinar, performed within the ISA^2 ELISE action, has also been published (European Commission, 2019v).

To establish a common level of technical background knowledge and an even landscape on web APIs, a document on web API general-purpose standards, terms and European Commission initiatives has been published as a technical report (Santoro et al., 2019).

For those readers who would like to know more about the background material of this study, a complete record of the workshop on EU API strategies has been published (European Commission, 2018f). In addition, all of the datasets that support the study have been published as part of the JRC data catalogue (European Commission, 2020h). These datasets could be used to support similar studies or to further adopt APIs in government.

The survey on government API strategies, which was used to develop our analysis on many aspects of the study, including costs and benefits and key enablers, drivers, barriers and risks, is also publicly accessible (European Commission, 2018k).

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