Pathos

Open Science Impact Pathways

Deliverable 4.1

Methodological note on the CBA of open science practices

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Abbreviations

APC	Article Processing Charge
CBA	Cost Benefit Analysis
CSOs	Civil Society Organisations
CV	Contingent Valuation
EC	European Commission
EOSC	European Open Science Cloud
EU	European Union
FAIR	Findable, Accessible, Interoperable, Reusable
LRMC	Long run marginal cost
OA	Open Access
OD	Open Data
OM	Open materials
OS	Open Science
OSD	Open Source Code
PathOS	Open Science Impact Pathways (Horizon Europe Project)
RDI	Research, Development and Innovation
R&D	Research & Development
R&I	Research & Innovation
RCAAP	Repositórios Científicos de Acesso Aberto de Portugal
RDI	Research Development & Innovation
SME	Small and Medium-sized Enterprises (SMEs)
WTP	Willingness to pay

Foreword

This deliverable describes a preliminary version of the cost-benefit analysis (CBA) framework (*hereafter the OS CBA framework*) specifically developed for the assessment of Open Science practices. It draws from the research carried out by PathOS[1], whose objective is to identify and quantify the Key Impact Pathways of Open Science relating to the research system and its interrelations with economic and societal actors. With the OS CBA framework, PathOS wants to ensure consistency in measuring the impacts of Open Science by considering not only benefits but also costs and, moreover, comparing them with a scenario when OS is not available.

The OS CBA framework – presented in this deliverable – builds on principles firmly rooted in CBA tradition as well as on established CBA approaches recently developed for assessing investments related to science and research, including Research Infrastructures (RIs). It focuses on the specificities of the different projects which give concrete shape to OS practices by describing typical costs and benefits along with possible methods which can be mobilised for their quantification. Nevertheless, its application to the assessment of OS practices is still in its infancy.[2] Hence, the approach adopted is explorative and heuristic. The concepts described in this deliverable will benefit from further applications and testing in the specific framework of the PathOS project (on 2-3 selected case studies) and possibly beyond. Future versions will take into account, as best as possible, any comments or new findings. In particular, we expect to validate the type of costs and benefits of OS practices presented in this document, by enriching their description with practical examples gathered from case studies as well as interviews with selected stakeholders in the OS field. An updated release of this deliverable will be in June 2025 (M34, according to the PathOS timeline).

This deliverable is structured as follows. After presenting the rationale for using CBA and the main specificities of OS (Section 1), suggestions on key methodological assumptions (Section3), typical costs and benefits of OS practices along with possible methods which can be mobilised for their quantification (Section 3 and 4, respectively) are given. Then, conclusions are drawn (Section 5).

[1] See https://pathos-project.eu/ for further details.
[2] See, for instance, EC (2018), which presents one of the first attempts to estimate the cost of not having FAIR research data for the EU economy, based on a series of measurable indicators, or Koudouri et al. (2021), who conducted an appraisal of OpenAIRE.

1. Motivation and principles

1.1. Increasing need to assess the OS impacts

Open Science (OS) is reshaping the way research is carried out and knowledge is shared, accelerating scientific progress, fostering innovation, and promoting transparency and collaboration. Its role has been recognised in several policy settings (e.g. UNESCO Outlook 2023, OECD 2015, etc.), and since 2016, it has become a priority in the EU policy Agenda (EC Open Vision) being embedded in several programmes and initiatives (e.g. Horizon Europe, EOSC, etc). Despite the progress that has been made in the last two decades (see Paic, A. 2021), OS still faces obstacles that hinder its ability to achieve its full potential. Evidence of what the impacts of OS are – in particular, the impacts of OS on the economy - and how these can be maximised, which would accelerate the pace of its adoption, are lacking.

As emerged from the deliverable D1.2, "Scoping Review of Open Science Impact"[3] of PathOS, the existing literature peer-reviewed and grey (479 studies reviewed) is mostly concentrated around Open Access (primarily academic impact) and Citizen Science (primarily societal impact), while **evidence of economic impacts is rare** (only 13 papers were found mostly from the biomedical and health domains) and **rarely comparable between different studies let alone between open and closed science**.

Some papers discuss the perception of positive or negative impacts, the mechanisms behind OS impacts, enabling and inhibiting factors, and methods and indicators used in the literature. However, explicit quantitative and generalisable evidence is lacking (Fell, 2019). Some studies suggest that open access to findings and data can lead to savings in access, labour, and transaction costs. There are also examples of OS enabling new products, services, companies, research collaborations, and higher returns on R&D investments through improved accessibility and efficiency of research findings (Fell, 2019). Studies on the European Bioinformatics Institute Beagrie and Houghton (2016) and Nectar Virtual Laboratories Sweeny et al. (2017) have employed surveys and user questionnaires to assess the value and impact of the services provided within a basket of several other methods.[4] The evaluation of the non-profit organisation OpenAIRE, which promotes open-access infrastructure for European research, is the first study valuing OS benefits and conducting a cost analysis. The results indicated that stakeholders highly value interoperability, improved accessibility to scientific results, and adherence to Open Access mandates (Koudouri et al., 2021).

Despite these studies providing evidence of some OS impacts, the existing literature predominantly discusses positive or, to a lesser extent, negative effects, mechanisms, drivers,

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[3] https://zenodo.org/record/7883699

[4] For instance, the quantitative economic approaches employed by Beagrie and Houghton (2016) included: estimates of access and use value, contingent valuation using stated preference techniques, an activity-costing approach to estimating the efficiency impacts of EMBL-EBI data and services, and a macro-economic approach that seeks to explore the impacts of EMBL-EBI use on returns to investment in research. I

and barriers. In particular, **much of the previous research has mostly focused on the positive impacts of OS itself using a theoretical argumentation** rather than mapping costs and benefits and comparing them with a scenario where the same results would be obtained through non-OS means. This has potentially led to not sufficiently documented high expectations.

This gap highlights the need for a socio-economic assessment framework which allows the systematic and proper comparison of the socio-economic costs and benefits of OS. In this sense, Cost Benefit Analysis (CBA) is considered a promising candidate. CBA emerged from more than one hundred years of intellectual history (Dupuit, 1844 and 1853; Pigou, 1920; Little and Mirrlees, 1974) and has been widely adopted by international institutions and governments (EC 2014, EC 2021, EIB 2023, WHO 2006, Asian Development Bank 2013) as well as economists worldwide to evaluate the socio-economic impact of investment projects in traditional sectors (e.g. transport, environment, energy, health, education) and more recently in research, development and innovation (RDI) and space (Florio 2019; Bastianin and Florio 2018; Florio and Sirtori, 2016; Florio, Forte and Sirtori, 2015; Battistoni et al., 2016). A CBA framework for assessing the socio-economic impacts of RIs tailored to their specificities has been developed (Florio et al. 2016). As a follow-up of such developments, the 2016 ESFRI roadmap recognised the contribution of CBA in providing robust evidence on the assessment of the socio-economic impacts of RIs. Moreover, the H2020 Work Programme 2018-2020 explicitly indicated the CBA as a basis for the Preparatory Phase of the ESFRI project.

Building on these developments and additional related works (e.g. JASPERS 2013; Griniece et al. 2020; OECD 2008, 2010; ESA 2012, Morretta et al. 2023), we will provide - in what follows – some guidelines on how the CBA methodology can be used to map and assess impacts of OS projects.

1.2. The CBA perspective and its role in PathOS

CBA is an analytical tool for assessing the social desirability of an investment decision by investigating its costs and benefits in order to assess the net welfare change attributable to it (Giffoni and Vignetti 2019). In other words, it allows for assessing whether benefits from an investment decision (to whomever they accrue) exceed costs (from whomever they are incurred), thereby showing whether it represents a net change to the whole society (Florio 2019).

CBA boasts a rich history of *ex-ante* applications in informing the economic feasibility of investment decisions by quantitatively representing all societal costs and benefits. It has also been used after project implementation and closure, *ex-post CBA*, to measure the effects of the executed investment. In fact, CBA can be effectively conducted at any stage, including during the project's ongoing phase or *in medias res*. Although the application of CBA has evolved over time and undergone different phases of experimentation, consolidation, and diffusion in a variety of institutional settings and sectors, a number of key features and principles still remain grounded and offer a good framework for a solid and systematic approach to Open Science assessment. In particular, these features and principles are the following:

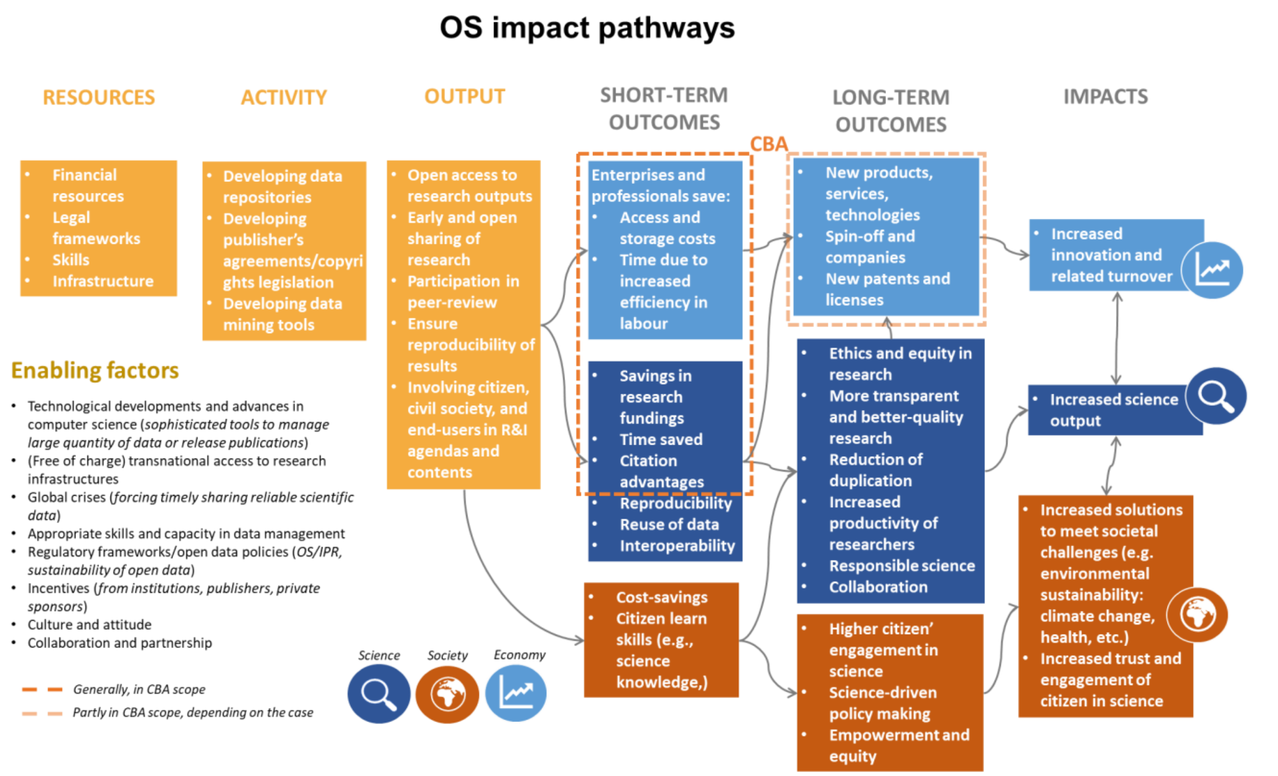
- **Long-term perspective**. A long-run timeframe is adopted (e.g. from 10 to 30 years) - depending on the sector of the project - to assess the social welfare[5] change attributable to it, implying the identification of a proper time horizon and the consideration of long-term sustainability; forecasting future costs and benefits over a long-time span (looking forward); adopting appropriate discount rates to calculate the present value of future costs and benefits.
- **Incremental approach**. Costs and benefits are considered incrementally, which requires a systematic comparison between the project option and a proper counterfactual ('with' and 'without the project' scenarios).[6]
- **All benefits and costs are expressed in monetary terms** (e.g. EUR) and are obtained by multiplying quantities by prices. This does not mean that only 'financial' effects are considered. On the contrary, accounting prices in the CBA are not necessarily those observed on the market. This is either because many goods are 'non-market' goods[7] or because observable prices do not truly reflect the social effect of the availability on an additional unit of a given good (i.e. market prices do not reveal the social opportunity cost of a given good). CBA recurs to empirical estimations of the shadow prices, which instead reveal the social opportunity costs. Methods commonly adopted to estimate shadow prices involve measuring the people's willingness-to-pay for a given good (from the consumer perspective) or the marginal production costs (from the production perspective). Finally, the net effect on society is computed by a quantitative performance indicator (the net present value, the internal rate of return, or a benefit/cost ratio).
- **Microeconomic perspective**. Indirect (i.e. on secondary markets) and wider effects (e.g. induced impacts or effects on national and supranational gross domestic product) are often excluded. The reason is threefold. Firstly, most indirect and/or wider effects are usually transformed, redistributed, and capitalised forms of direct effects; thus, there is the need to limit double counting issues. Secondly, there is little practice on how to translate wider effects into robust techniques for project appraisal. The choice is thus avoiding that the analysis would rely on assumptions whose reliability is difficult to check. Thirdly, CBA is based on the idea that GDP is a distorted measure of social welfare. For this reason, shadow prices, estimated according to a precise set of rules and methods, are adopted to value costs and benefits[8].

A comprehensive assessment of OS impacts would require distinguishing between short-term (direct) and long-term (indirect) outcomes, and impacts. Short-term outcomes correspond to benefits related to the OS project itself from the perspective of responsible organisations and its direct users, e.g., less time spent creating data due to the availability of FAIR data. They are in the sphere of control of the participating organisations, who implement and steer various activities. These effects may be upstream (e.g. on scientists involved in the set-up phase) and

[5] In this methodological note, the expression "social welfare" specifically refers to the normative microeconomic concept of social welfare, which reflects the aggregated individual utilities of each agent in the economy. See Florio (2014) for further details.
[6] See section 2.1 for further details on the counterfactual scenario.
[7] They are goods for which a market does not exist and therefore a price does not exist.
[8] It should be noted however that, although impacts on GDP are not explicitly part of the assessment, the CBA implicitly considers them through the estimation of shadow prices (e.g. shadow wages – the shadow price of labour - are used to estimate the benefit form the creation of new jobs and employment).

downstream (e.g. on the users). Long-term outcomes can be influenced by the OS project (e.g., OS project responsible organisations can interact with the users and stakeholder groups in question and can seek to influence their behaviour), although no direct causal link can be always established, but also by other factors. For example, the registration of a new patent by a company may be enabled by open access to cutting-edge research outputs but is the result of additional research activities carried out by the company itself . Impacts, covering lasting effects and structural changes manifesting in the economy and society, for instance, the decrease in deaths caused by strokes induced by the introduction of new e-health technology, are enabled by open science research but require many additional activities, investments and factors to actually materialise.

Figure 1: OS different layers impacts



Note: Preliminary, to be fine-tuned during the PathOS project. **Source:** Pathos Project

A CBA framework for OS – described in this deliverable – will serve as **a valuable tool for the appraisal of the short-term outcomes of projects that give shape to and operationalise OS practices**. The assessment of the impacts falls outside of the scope of the CBA, and it is left to other methods, which will be considered in the broader causal pathways framework provided by PathOS. Similarly, although long-term outcomes can be evaluated in the CBA framework, they cannot be attributed to the respective costs. For this reason, they may only be partially considered in the CBA assessment for certain specific cases. Indeed, PathOS closely aligns with the RI-PATHS framework, which was funded by the Horizon 2020 programme.[9] RI-PATHS framework develops a conceptual model that describes the socio-economic impacts of

[9] See https://ri-paths-tool.eu/en for further details.

research infrastructures and the financial investments associated with them. Indeed, PathOS borrows from the RI-PATHS framework the approach of tracing the causal chain of the OS impacts, namely *the impact pathways*, moving from the most immediate and direct effects to the more distant and broad ones, attempting to identify the mechanisms and conditions that allow the impacts to materialise. The expression *impact pathways* refers to the possible routes connecting resources and activities to outputs, outcomes, and impact.

Drawing upon the RI-PATHS model, **PathOS identifies three main impact pathways in the framework of OS practices: academic, societal, and economic**. These pathways include the non-linear sequences of steps that connect some inputs to immediate and measurable outputs and the socio-economic outcomes attributed to that input. Also, they extend to more indirect, broader impacts that may not be easily quantifiable.

While CBA aims to assess causal impacts through an incremental approach, allowing the identification of the net effect of a changed scenario, the analysis of the entire causal pathways offers a progressively broader perspective. Associating a causal effect while controlling for an extensive list of confounders and contextual factors becomes challenging, especially when attempting to do so in a rigorous, quantitative way. Indeed, CBA requires the quantification (expected, actual or both depending on the type of CBA) of the number of beneficiaries who directly benefit from OS services over a specified time horizon, allowing for monetising the accruing benefits. By using an incremental approach (see Section 2.1), CBA facilitates the assessment of the net causal change that occurs when carrying out OS projects compared to a benchmark scenario.

1.3. Key features of OS in a CBA framework

Open science has been defined as the efforts— taken by researchers, governments, research funding agencies or the scientific community itself— to make the primary output of publicly funded research more widely accessible in digital format to the scientific community, the business sector or society more generally (OECD 2015). In other words, it consists of adopting practices that allow for sharing knowledge and data as early as possible in the research process, in open collaboration with all relevant actors, including citizens. The first PathOS policy brief (Deliverable D5.5) identifies five different OS practices:

[1.] providing open access to research outputs (such as publications, data, software, models, algorithms, and workflows);
[2.] early and open sharing of research (for example, through preregistration, registered reports, pre-prints, and crowd-sourcing of solutions to a specific problem);
[3.] participation in open peer review;
[4.] measures to ensure the reproducibility of results;
[5.] involving citizens, civil society and end-users in the co-creation of R&I agendas and content, including citizen science.[10]

Overall, these OS practices refer to principles, approaches, attitudes that prioritise transparency, collaboration, and openness in scientific research. The adoption of a CBA

[10] In some cases, citizens science is not necessarily open.

framework for the assessment of OS **requires to move from the theoretical concept of OS practice to the concrete sphere of OS projects**. Indeed, the CBA cannot be used to evaluate an approach or an attitude rather the specific project which makes this attitude/approach possible. In this view, the OS project – on which the CBA may focus on - can be identified with a digital infrastructure project which is specifically financed/adopted to give shape to an OS practice. For instance, OS project suitable for CBA may include an open repository which preserves and provides open access to journal article reprints, pre-prints, and/or data. Also, it may take the form of an open data platform which offers access to specific data at no charge to users, or free software making easier the processing of data and information. Furthermore, it may concern a national policy that mandates open-access publishing as a prerequisite for receiving public funding**. A taxonomy of OS projects – on which the CBA focus on - will be developed in the framework of the PathOS project**.

While, in principle, the impacts of any change in the world can be evaluated using CBA, an OS project should possess some key characteristics to be considered suitable for evaluation with this assessment methodology. These features include:

- It delivers a specific type of service (e.g. access to raw data for an experiment/research, storage of data, processing and analysis of data, etc.).
- It targets specific objectives (e.g. innovation, solutions for societal challenges, etc.).
- It targets specific types of users as its effects clearly affect the well-being of specific categories of stakeholders (e.g. scientists, students, firms, citizens, and policymakers).
- Its boundaries are recognisable. In other words, all functional and technical components that are necessary to the achievement of its objectives and to the delivery of the intended service to the users can be identified.
- Resources employed to design/set-up and maintain the OS practice can be identified.
- Observed effects can be directly attributed to the OS project under assessment (e.g. they are an immediate consequence of it) and can be traced.
- Observed effects materialise over a specific time-horizon, which typically expands over a number of years.

Another important characteristic to consider in the evaluation of OS trough the CBA methodology is **the degree of openness** of the project under analysis. Firstly, the degree of openness relates not only to the fact that open access to some scientific information is provided but also to the possibility of understanding, validating, and exploiting such information. If, for instance, an OS project provides access to a database containing highly complex data, only researchers with a certain level of skills might be capable of exploiting such shared content, restricting the public and the potential impact of that database. On the other hand, if the same data are also provided in a simplified version and can be consulted by a broader public, the impact would likely be direct to different beneficiaries. The degree of openness might also refer to the access condition to the research outputs. For instance, in the case of open-source software, which means that users have open access to the source code and can implement modifications, create routines, etc., it is not taken for granted that users have free access to the software. Instead, open access to the software code can be made available under a subscription payment. Thus, the degree of openness of a research output is likely to affect the impact generation. **Understanding the degree of openness is particularly relevant when**

identifying the counterfactual scenario (see Section 2.1) to measure the net benefit brought about by the OS project.

1.4. Categories of potential beneficiaries

Assessing the impacts of a project requires identifying the agents that are potentially affected first.

In relation to Open Science, four groups of agents (potential beneficiaries or losers) have been identified so far, each contributing to the demand for OS practices in their unique way. This classification draws from OECD (2015) and will be improved on the basis of the findings collected through the PathOS project, especially after the OS CBA framework is tested on selected OS projects. These groups are:

- **Governments and Funders.** As the primary source of funding for Open Science, they aim to maximise the (socio-economic) returns from science, including a better connection between science and innovation and engagement with citizens (e.g., improving public trust in science and innovation process aligned with the needs of society). This alignment with societal needs comes with the careful allocation of resources and the needs for effective oversight to ensure that investments yield the desired socio-economic benefits.
- **Industry (enterprises and professionals)**. Industry stakeholders benefit from open access resources as access to new knowledge to develop new products and services. Indeed, there is a need for a stronger connection between science and innovation since companies' innovation processes are intrinsically related to their capability to access research. Reducing the barriers to accessing research results would allow them to benefit more from knowledge spillovers. However, when involved in research themselves, companies are often unwilling to engage in OS for reasons of appropriability.
- **Scientists, which are the producers of knowledge in this game**. They want level playing field (e.g., gender, careers, geographic divide) and remove barriers (such as paywalls) for access to information. Science should become more transparent to remain trustworthy. The challenge lies in balancing open access with maintaining quality and the integrity of the research, which can sometimes entail additional administrative and peer-review processes, potentially slowing down the publication speed. Additionally, OS entails the risk of potentially losing some competitive edge in the research production system due to field-specific barriers, and the reality that peer-recognised OS production is not always of the same quality as closed science.
- **Citizens,** want more engagement with science. This goes for the full science cycle – from conception of new ideas to design, data collection and analysis, and conclusions. Citizens want to trust science, they want to have access to scientific results (interest, be informed on sickness and diseases, environmental issues) and have a voice in determining priorities (e.g., NL Science Agenda).

2. Methodological Assumptions

2.1. Scope of analysis

When conducting any CBA, it is crucial to define the scope of the analysis, such as selecting the precise unit of analysis and the timing for which it is feasible and meaningful to carry out it.

As mentioned in section 1.3, the OS projects may consist of a repository, a platform for data sharing, a software, a policy, etc. which give shape to an OS practice (e.g. sharing of data, citizens involvement, etc.). In selecting the specific unit of analysis, **all functional and technical components of the OS project** - that are necessary to the achievement of its objectives and to the delivery of the intended service to the users - should be considered. However, tracing the boundaries of an OS project can be more challenging than one might expect. In this sense, the following considerations apply:

- **The OS project may consist of several components which are functionally linked to each other**, thus meaning that they all contribute to the delivery of a unique type of service. Appraising such a project requires considering all the components. For instance, an open database might be a component of a broader range of OS services shared by the same institution, e.g., a digital infrastructure. Along with the open database, the institution may also share open tools or software[11] to analyse the open data they supply. In this case, the different OS services are interconnected and contribute to the same service. For this reason, linking costs and benefits to a single output might be exceptionally challenging since the single OS output is part of the same intangible asset. Further, OS services often do not exist in isolation and their mere existence (or simply their added-value, quality, richness of content) relies on the existence of other resources (Drysdale et al. 2020).

- **The project may consist of several components, each of them delivering a specific type of service** (e.g., access to raw data for an experiment/research, storage of data, processing and analysis of data, etc.) **and targeting specific objectives** (e.g., innovation, solutions for societal challenges, etc.) **or type of users** (e.g., students, scientists in academia and industry, etc.). In doing so, the components are not functionally related to other components but each of them can be considered as a self-standing component. Appraising such a type of project requires to consider each component independently, but their aggregated impact can also be considered, if relevant.

Overall, selecting the **appropriate object of analysis means indicating which component(s) of a project the analysis refers to**. To provide a practical example, ELIXIR's activities rely on more than 400 open/FAIR bioinformatics resources. The CBA analysis may focus on one of these resources – such as a specific software, database, platform – which is intended to provide a

[11] They may be not completely open. For instance, the software can be free available, but its source is not open and cannot be modified.

specific service[12] or a combination of them if necessary. In the case that more than one resources – e.g., a combination of two/three databases or different software – contribute to the provision of a specific service – all these components may be considered in the analysis, since they are functionally related (e.g., without one of these components, the service cannot be delivered).

Once the boundaries of the OS project have been identified, **the timing for which it is meaningful carrying out the analysis should be defined**. As mentioned in Section 1.2, the CBA analysis adopts a long-term perspective: it considers costs and benefits along their lifecycle, thus generated by the project over its useful technical and economic life. This time horizon encompasses the period in which the project is designed, launched and remains operational. The first year of the time horizon is when the project starts to be developed, such as when resources are disbursed for the design of such project (e.g., design of protocols and procedures, conceptual study, feasibility studies, planning, etc.). The last year is when the project finishes to materialising its impact, or when it becomes obsolete and needs to be updated or expanded or redesigned. This time horizon can extend in the past, in this sense the analysis will be based on historical data (*ex post* CBA), in the future (*ex ante* CBA), in this case the analysis will be based on projections subject to some assumptions about future evolutions, or a mix of the two (*in media res* CBA). Even if in the field of science some of the benefits produced may last well beyond the operational phases, a long but finite time horizon is considered reasonable for assessing impacts. Such time horizon is project-specific and changes greatly in accordance with the scientific domain.

While defining the scope of the analysis, **it is also important to clarify which are the bodies responsible for financing the initiative, developing it, implementing it**, etc. The identification of the different stakeholders involved, and their roles is functional to the collection of data and information (e.g., on costs, number of users accessing the platform, number of users downloading data, etc.) needed for the performance of the analysis. For instance, the project may be the result of an international collaboration where different institutions have contributed to its financing, developing, delivering. In a distributed research infrastructure, it may also happen that responsibilities are shared between the hub and/or several nodes. If this is the case, it is worth to clarify what is the role of each institution/node involved. In these scenarios, additional challenges arise if considering that users may be, in part producers of OS, and they may have multiple affiliations with institutions which may not necessarily financially support the OS. For example, scientists globally utilise a repository by independently uploading material. In this context, the extent of collaboration can become so widespread and intricate that tracking is exceedingly challenging.

[12] For instance, one service from the lists available here https://elixir-europe.org/services

2.2. Counterfactual scenario

A key principle of the CBA is to assess costs and benefits of the proposed project according to an incremental approach such as by comparing them within a counterfactual scenario (without-the-project). This method serves to grasp the 'net' change, i.e., the change specifically attributed to the project analysed.

The choice of the counterfactual scenario requires a careful examination and implies defining what would happen in the absence of the OS project. Key questions must be addressed, such **as whether the impact would have materialised in a similar manner without the OS project or if the intensity of the impact would have been lower**. To adequately address these "what-if" questions, at least two counterfactual scenarios can be considered: **the zero-based scenario and the closed or do-nothing scenario.**

The zero-based scenario is applicable when an OS project provides access and availability to research products that would not have been available otherwise (i.e., a green field scenario). This scenario acknowledges that the OS project is responsible for the creation and sharing of materials that did not previously exist in the same form or were entirely unavailable. Examples include repositories collecting shared codes applicable across a range of programs. In the absence of such repositories, accessing those codes developed by unknown entities and researchers would be nearly impossible unless the codes are disseminated within organisations and research teams. Similarly, data repositories often collect shared datasets that were previously unavailable, even though their primary sources were accessible, e.g., a dataset crafted through data scraping techniques or one that aggregates a substantial volume of information. In this case, the incremental scenario corresponds to the OS project scenario itself.

In contrast, **the closed scenario is appropriate when a scientific product is already being shared, but access to it comes at a cost**. This typically involves scientific journals operating within closed environments, where individuals can access papers by paying either a yearly/monthly subscription fee or the price of individual articles. Another example is provided by software for which the use is subject to the payment of a licence. In this case, the counterfactual scenario should include the cost and benefits associated with the status quo, which should then be compared to the ones related to the OS project scenario to get the net effect.

A crucial step in selecting an appropriate counterfactual scenario involves conducting extensive discussions with researchers and specialists engaged in the OS design, as well as seeking impartial assessments from independent professionals. This is crucial because determining the counterfactual scenario, in some cases, requires robust assumptions. Importantly, the counterfactual scenario is often hypothetical and not directly observable. In such instances, it is practical to approximate and refer to the next best alternative. **Once the counterfactual scenario is determined, either the zero-based or the closed scenario, estimating all costs and benefits pertaining to that chosen scenario becomes essential.**

2.3. Difference between the financial and economic perspectives

The CBA is composed of financial and economic elements. Delineating between these components is crucial, as the financial performance of an investment project does not necessarily mirror its socio-economic impact. **Financial analysis pertains to the cost and revenue aspects of the project in the marketplace, while the economic analysis subsumes broader societal implications, measuring benefits as enhancements in social welfare and costs as corresponding reductions.**

Financial analysis is also relevant in the context of publicly funded projects that are not expected to generate revenues. Since it ascertains the costs and prospective source of funding over a designated reference period, it is useful to assess the capacity of the initiative to ensure the long-term sustainability of the OS project. Economic analysis is, however, the tool that points to social well-being. **Going beyond the confines of monetary transactions, it offers a view of a project or decision's repercussions on social welfare.** This wider lens necessitates the evaluation of projects from a welfare standpoint, emphasising social costs and benefits over mere financial costs and revenues. It is particularly meaningful for publicly funded projects that do not generate income but do actually provide social benefits, which, without this perspective, would not find a justification in financial terms. For instance, by definition, a free-licence scientific research tool for statistical analysis does not generate any revenue from the users, and conducting financial analysis to decide whether to develop or maintain the tool would likely lead to a decision not to proceed. However, economic analysis would reveal the social benefits spanning beyond the income-generation effect, e.g., the avoided costs (to users of the software) associated with proprietary software. Concretely, **the transition from a financial perspective to an economic perspective necessitates a redefinition of financial variables to embed the broader social impacts and indirect costs and benefits associated with a particular project.** These adjustments are important because what is observed in the market is a biased representation of social preferences due to several issues. These issues include taxes, country-specific restrictions on workforce and capital movements, unequal distribution of wealth and assets among people, different levels of understanding information within the society, and so on. For these and other reasons, the market prices do not always show the true worth of things to society (Florio, 2014). **In the specific context of this study, market distortions are particularly evident due to the predominantly public nature of the shared knowledge through OS practices.** This shared knowledge represents a non-market good, and its supply is typically governed by public policy decisions. Consequently, adopting an economic perspective allows for a comprehensive evaluation of the societal implications and the influence of public policy on the regulation of knowledge distribution and its impact on various stakeholders.

3. Social costs

Costs are defined as cash outflows directly incurred in the process of structuring, operating, maintaining, and upgrading the OS project. According to economic theory, every factor of production (such as capital, labour, and knowledge) carries an associated cost. Precisely, from an accounting perspective, each resource utilised in a project or enterprise is assigned a monetary value. This monetary market value is taken into consideration during financial analysis. The financial costs should then be corrected to arrive at the economic costs. In this way, each resource is linked to an opportunity cost that represents the value of the next best alternative forgone when a specific resource is chosen for a particular purpose. In simpler terms, this process involves making adjustments to account for the actual value of resources, goods, and services, considering what we give up by choosing one option over another. The missed option is the opportunity cost. As mentioned before, economic analysis implies looking at the real value of services or goods (i.e., the shadow prices), which indicates how scarce or valuable something is to society. When looking at a project's pros and cons, these true values allow for understanding the real good and bad impacts on everyone involved.

However, when measuring the economic costs, it is advisable to begin with the financial costs in any case. In the cost classification, one might build on the ESFRI (2019) guidelines, which distinguish financial costs between set-up and maintenance. Although these guidelines were developed for research infrastructures, described steps for identifying typical costs of RI can be useful in also identifying costs related to OS project. The following subsections outline potential types of costs associated with OS projects and are expected to be enriched and fine-tuned during the PathOS case studies.

Box 1 How to estimate shadow prices

Shadow prices can be estimated through various empirical approaches, as extensively reviewed by Boardman et al. (2006), Brent (2006), De Rus (2010), Florio (2014), Potts (2002), Potts (2012a), and Boadway, (2006). Among these methods, the most commonly used ones are the users' marginal willingness-to-pay (WTP), the long-run marginal social cost of production (LRMSC), and the simplified conversion factors method.

The concept of (marginal) WTP pertains to the maximum amount of money a consumer is willing to pay for an additional unit of a good or service. It serves as a primary tool for empirically valuing the direct benefits of a project, which are associated with the utilisation of the goods or services provided by the project, as well as for assessing externalities. In specific cases, WTP can also serve as a proxy for the opportunity cost of a project's inputs, such as land, wherein its usage within the project leads to adjustments in the net demand of other consumers for that particular good. The significance of using the WTP approach becomes particularly evident when estimating externalities for which no monetary compensation is exchanged.

The concept of the LRMSC of a good refers to the increase in the total cost to society, including private costs and external costs, required to raise the production of the good by one unit while keeping the production levels of all other goods constant. Typically, the LRMSC is utilised to assess the economic value of non-tradable inputs that experience an increase in production as a result of higher demand. However, when the WTP approach is not feasible or relevant, the LRMSC can be employed as an alternative to evaluating the output of certain projects.

A simplified operational approach to convert market prices into shadow prices involves applying suitable conversion factors to the main cost components considered in the financial analysis. These conversion factors can be derived from existing benchmarks established by national public authorities for CBA in other relevant fields. A conversion factor is defined as the ratio between shadow prices and market prices, serving as the multiplier by which market prices must be adjusted to obtain the corresponding shadow price. [13] Notably, particular emphasis should be placed on the opportunity cost of labour, which is assessed using the concept of the shadow wage. The shadow wage rate signifies the social opportunity cost of labour and may diverge from the observed wage due to labour-related distortions, such as unemployment, migration, taxes, and minimum wages, as well as factors present in the product markets. In accordance with the opportunity cost concept, the shadow wage should accurately reflect the social benefit of employing an individual in a specific region, country, and sector characterised by distinct labour market conditions, as opposed to other alternatives. By carefully considering the shadow wage and employing conversion factors, the simplified operational approach enables the estimation of OS costs in shadow prices, facilitating a more comprehensive and accurate economic evaluation. [14]

Source: Authors

3.1. Set-up costs

Set-up costs encompass various expenses associated with the initial set-up of the OS projects. These costs involve acquiring durable tangible and intangible assets, covering start-up phase expenditures, personnel costs, and potential replacement costs. In some cases, there might also be substantial upgrading expenses, which require significant changes in the technical approach, going beyond routine maintenance. Additionally, costs related to closing down or discontinuing access to a specific database or research tool may be incurred. These costs may be incurred in financial years different from the one in which they were initially invested.

[13] See Florio et al. 2016 for further details on the application of RDI projects and additional literature.

[14] The CBA literature offers different shadow wage formulas on the basis of the different hypothesis on labour and product market conditions. Recent theoretical contributions include Potts (2002); Londero (2003); de Rus (2010); and Potts (2012b). Recent empirical contributions include Honohan (1998); Saleh (2004); Picazo-Tadeo and Reig-Martinez (2005); and Del Bo et al. (2011). The latter presents a new, simple framework for the empirical computation of shadow wages at the regional level and empirical estimations for EU regions.

Box 2 Example of Set-up costs

Planning and design activities
Tangible and intangible assets acquisition
IT and other equipment purchase
Utilities consumed during the set-up phase (e.g., energy)
Start-up costs
Scientific, technical, and administrative personnel
Replacement costs
…
…

Source: Authors **Note**: preliminary, to be fine-tuned during the PathOS project

These data are used in the feasibility study when analysing the scenario from an ex-ante perspective or in the financial statement when examining the ex-post situation. However, the unique nature of the OS projects makes this accounting task less straightforward than one might expect. Indeed, apportioning the cost of a single OS service can be challenging due to the complex connections between the costs, the numerous actors involved in establishing the institution that provides the OS service, and the common scenario where an OS service is just one component supplied by the same institution.

The relevant data to consider are the cash or in-kind expenditures encountered in individual accounting periods (years). These expenditures are necessary to acquire various types of assets, or if in-kind contributions are involved, their equivalent market value should be taken into account, even if they are not reported as financial flows.[15]

3.2. Maintenance costs

Maintenance costs encompass all expenditures, both in-kind and outflows, that are essential for the operation and maintenance of a newly developed or upgraded OS projects. From an ex-ante perspective, cost forecasts can be derived from historical unit costs. Alternatively, from an ex-post perspective, financial statements and balance sheets can be utilised, with necessary adjustments made to adhere to the cash flow method. These operating costs can be categorised into two types: fixed and variable. Fixed costs remain constant regardless of the volume of services provided, given a specific capacity. On the other hand, variable costs fluctuate based on the volume of output. While average annual operating costs can be computed, it is crucial to recognise that operating costs may vary during the lifetime of the operating system, especially during the start-up and launch phases. A ramp-up phase, which can span several years before reaching full capacity, is typical in these early stages.

[15] A residual value of the fixed investments must be included within the investment costs account for the end-year. The residual value reflects the capacity of the remaining service potential of fixed assets whose economic life is not yet completely exhausted.

Box 3 Example of Maintenance costs

Scientific, technical, and administrative personnel
Training to users
Data curation and preparation
Utility consumption
Managing user access
Quality control
General management and administration
Promotional campaigns and other outreach expenditures
Decommissioning
....
...

Source: Authors **Note**: preliminary, to be fine-tuned during the PathOS project

Additional socio-economic costs associated with open science must be evaluated depending on the specificities of the OS projects under evaluation (e.g. open software, database, repository, etc.). These additional costs reflect the social challenges associated with the spreading and adoption of OS services and are not usually burden by the promoter rather by the users, typically researchers or professionals who work in the R&D departments of companies.

In Fell (2019), the author highlights a category of additional costs associated with the preparation phase of materials to be shared. When users choose to disseminate their scientific work through an open-access platform, the materials must undergo preparation and alignment with the platform's requirements, which would not be required otherwise. Alternatively, open-access platforms might necessitate specific preparation methods or skills unfamiliar to researchers, leading to an additional time investment to acquire and implement these new skills. In these examples, the social costs can be understood as the extra time invested by the researchers to perform these tasks, which is then quantified in monetary terms using the value of the researcher's wage.[16] In the first case, it can be associated with an additional operational social cost, while in the second case, with an investment social cost.

Additionally to these types of costs on the user's side, a range of other social costs might be associated with academic and industry researchers. Indeed, deciding to publish via open access might involve a cost: for instance, the opportunity cost of patenting. Indeed, an open access publication could result in the loss of potential earnings from a patent. Further, in academic field where OS adoption is still in its infancy, publishing in an open access journal might be considered less valuable among peers and could even slow the career path of academic researchers. These costs are likely to be field-specific and will be better explored in the case study phase.

16 The market wages are typically biased due to several factors related to labour product markets. However, when considering the researchers wage, it is often argued that they are a good approximation of the social cost of labour given the assumption (EC 2014). Alternatively, given the strong assumption, one can rely on secondary wage data collected in the private sector (e.g., Payscale, Glassdor, and so on). See Section 4 for further details.

An exhaustive list of additional socio-economic costs related to establishing an OS project does not exist, as OS practices are in constant flux, and the impacts of OS projects can vary depending on the specific context and counterfactual scenario chosen for analysis. Conducting a thorough and accurate assessment to identify potential costs that may arise from an OS project is essential.

4. Social Benefits

Benefits refer to the advantages that society gains from a particular OS project. Once the potential beneficiaries have been identified (see section 1.4), a list of typical benefits can be attached to each group. Depending on the project, some of them recur for different types of target groups. The benefits associated with OS project mostly regard **efficiency gains**, meaning getting the same output from research or innovation for less input, and, in some cases, **enablement**, which refers to all these activities born due to an open science environment, and which would have been less likely to materialise in the counterfactual scenario.

In what follows, we provide a preliminary description of these benefits along with possible methodologies which can be adopted for their quantification. This description will be finetuned and enriched during the PathOS project by taking into account feedback from the testing of the OS CBA framework to selected OS practices.

Table 2: Benefits associated with OS projects

BENEFIT	MARGINAL SOCIAL VALUE	ESTIMATION METHOD	BENEFICIARY TARGET GROUP(S)
Cost savings (see *Section 4.1*)			
Access cost savings	Avoided costs; Willingness-to-pay; LRMC	Avoided cost for accessing research outputs for free; Contingent Valuation; Cost of the internal research production; Benefit transfer.	Industry; Academics; Academic and Industry Researchers; Professionals; Citizens.
Storage cost savings	Avoided costs; LRMC	Avoided cost for not storing research outputs; Cost of producing an in-house storage system; Benefit transfer.	Industry; Academics; Academic and Industry Researchers; Professionals; Citizens.
Labour cost savings	Avoided costs, Willingness-to-pay for time saving	Choice Experiment/Contingent Evaluation; Avoided cost for Personnel; Benefit transfer	Industry; Academics; Academic and Industry Researchers; Professionals.

Transaction costs savings	Avoided costs	Avoided cost for Personnel; Benefit transfer	Industry; Academics; Academic and Industry Researchers; Professionals.
Enablement benefits (see *section 4.2*)			
Development of new/improved products, services, technologies, start-ups and spin-offs	Incremental shadow profits	Survey of business; Statistical inference from company data; Benefit transfer	Industry (enterprises including start-ups and spin-offs)
Patents	Marginal Social value of patents	Inventors' survey; Statistical inference from data on decision to renew patents or on economic terms of patent transactions; stock market valuation of market patent portfolio	Industry; Academics; Academic and Industry Researchers; Professionals.

Source: Authors **Note**: preliminary, to be fine-tuned during the PathOS project

4.1. Cost-saving

The concept of cost savings subsumes the improved production efficiency achieved by incorporating OS (Fell, 2019). This impact on cost savings refers to the ability to save both money and time due to OS, leading to reduced expenses and resource conservation in the scientific production process. For example, when using open software, open tools, and open data, enterprises can save time within their R&D departments and other areas. This saving also arises from reduced time spent on various activities, such as working hours, and by avoiding costs related to storage and access. By optimising the utilisation of OS services, organisations can streamline their operations and attain greater efficiency, making the cost savings benefit a reliable measure of the degree of social efficiency gain achieved through OS adoption.

The cost-saving benefit acts as a macro category, encompassing the overall benefits derived from OS. Within this macro category, four distinct benefits often complement each other, as they represent various sources and stages of savings that emerge when professionals, enterprises, and researchers become users of OS outputs.

Since the boundaries among different categories of benefits are often blurred, caution is needed when attributing various benefits to different stakeholders to avoid double counting. The following sections go into more detail and warnings on double counting and additional caveats related to the classification of these types of benefits.

4.1.1. Access cost-savings

The first type of cost savings captures the costs avoided when accessing essential knowledge or tools for knowledge generation within a closed environment, namely **access cost savings**. This benefit targets 1) public research funders and governments, 2) enterprises, and 3) private citizens interested in accessing research outputs.

Researchers, enterprises, professionals, and citizens can avoid the expenses typically associated with accessing proprietary or paid resources by utilising OS services. This includes expenses like subscription fees, licensing fees, or pay-per-use charges that would be incurred in a conventional closed system. Broadly, this benefit reflects the avoided cost of developing from scratch the same type of research output when not available under a fee payment, for instance, building a database within the users' organisation because it does not exist or producing it is less expensive compared to buying the access. **The avoided cost method** is one of the suitable ways of estimating the social value of this benefit (*Box 4*). The method relies on the principle that if there was no OS project, certain costs would be incurred to meet the needs or objectives the OS seeks to address. A first way of quantifying this avoided cost is by using the market price of a closed science similar service to compute the virtual price of the OS service. Specifically, the costs refer to the fees and subscriptions often paid to have access to scientific journals, databases, software, and other research outputs. No unique data source exists to extrapolate an absolute value of the saved cost since it varies depending on the beneficiaries' demand and the type of OS practice considered. As a general rule, market research should be carried out to look for the most similar service on the market. For instance, when assessing the social value of free software, one should look for similar software in the close market.

Box 4 Avoid cost method - access cost saving

The avoided cost equation might change depending on which type of OS output is being evaluated. However, a general formula can be summarised in the following way:

$$Access\ Cost\ Savings = \sum_{t=0}^{T}\sum_{i=1}^{N} p(q,t,N) * q_t$$

Where:

q_t might be the number of research outputs (journals, data, methods, tools) that might vary over time and might be counted depending on the type of the OS (e.g., a single article, an annual access, etc.);

$p(q,t,N)$ is the market price that can vary depending on the type of OS and over time. For instance, an enterprise might opt for paying the price of single articles having an annual budget instead of illimited access, which is usually chosen by research institutions. The same applies to data access, which prices might change depending on the type of data, the frequency, etc.;

t=0,…,T is the period over which the benefit should be computed;

i=1,…,N is the number of users involved that might vary over time and can affect the price, e.g., the access to software might depend on the number of users.

Source: Authors

However, market prices are not always available, perhaps because there is no similar service in the market. In this case, a valuable method for calculating the social value of the access cost is the Long-Run Marginal Cost (LRMC) method. Indeed, in economics, marginal cost refers to the amount of money required to produce one additional unit of a good or service. In this case, rather than valuing the money saved due to the open access, one values the saved production costs that would have been necessary to produce the equivalent research output in a scenario where the OS is unavailable.[17] For example, the appraisal of an open database should be done by evaluating all the costs related to the in-house data collection and database-building process. To not fall into the double counting, this appraisal should strictly count only the production costs to data collection and management to create the database (e.g., the labour cost equivalent to the time needed to collect the data) and should not include the costs associated with, e.g. the hardware to store the data, as those are related to the storage cost saving. In any case, this method might not always be preferred for the appraisal of any OS practice. For instance, Florio (2019) argues that measuring the value of open source software focusing on the producer side might underestimate the marginal social value of the good. This caveat is related to the potential income arising from any marketable use of the good, which is correlated to the cost savings of the users.

Another viable approach to assessing these benefits, which instead focuses on the users' side, is through the concept of willingness-to-pay (WTP), particularly when market prices are unavailable or do not accurately represent the true economic value of the savings (*Box 5)*. In the context of CBA, WTP serves as a reliable indicator of the benefits or avoided costs. Essentially, WTP refers to the monetary amount individuals are willing to pay to enjoy a particular benefit or avoid a certain cost (Boadway, 2006). To determine WTP, the so-called stated preference techniques are employed, which allow for eliciting people's preferences in hypothetical scenarios. Among these techniques, contingent valuation (CV), which is a survey-based economic technique typically adopted for the valuation of resources, goods or services that are not exchanged in a market, is considered the most suitable method when estimating values for a change or set of changes that are seen as an indivisible whole (Johnston, 2017). CV enables the appraisal of the total economic value of a public good by conducting surveys in hypothetical markets, where individuals are asked about their preference for the economic value they would assign to the specified public good. For instance, the social value of an open database can be assessed using a CV by asking users how much they would be willing to pay in a hypothetical scenario where the open database would become available under the payment of a subscription.[18]

[17] When considering open access papers there is a caveat associated to this method. Utilising the LRMC to produce papers that would otherwise be available only under a fee may introduce an issue related to the incentives raised by having open access papers. Indeed, one might be inclined to read more papers if they are freely available, as opposed to producing only what is strictly necessary.

[18] An example of this application is Beagrie and Houghton (2021).

Box 5 Contingent Evaluation – WTP of the user to access OS output

The CV assesses the willingness to pay of the user to access the OS output. The guidelines by Johnston (2017) should be followed for the implementation of this method. Once obtained the willingness-to-pay for a unit of time (e.g., yearly) across the survey respondents, the value of the access cost savings equals:

$$Access\ Cost\ Savings: \overline{WTP} * N * T$$

Where:

$\overline{WTP}$ is the average willingness to pay;

N is the estimated number of users;

T is the span of time chosen for the evaluation of the benefit.

Source: Authors

4.1.2. Storage cost-savings

The second type of savings quantifies the cost avoided by eliminating the store of digital resources towards storage payments, namely the **storage cost saving**. This benefit targets 1) public research funders and governments, 2) enterprises, and 3) private citizens interested in accessing research outputs. By leveraging OS, the need for private storage can be obviated, as free access enables easy referencing at any time, with open repositories serving as substitutes for conventional private data storage.

As for the previous category, the avoided cost method is one suitable way of assessing these types of savings. In this case of data storage savings, the avoided cost method focuses on identifying and quantifying the costs that are avoided or reduced due to the availability of the OS services that allow for substituting private data storage with open repositories or eliminating the need to store research outputs.

The avoided cost might be calculated by quantifying the storage space needed/utilised and the market price of a data storage service associated with the storage space to compute the virtual price for the assessment of the benefit associated with OS service. The approach to take would be to conduct market research that allows for comparing the paid alternatives in terms of features with the OS to choose the price of the most similar product. However, when a similar storage service is not in the market, the benefit can be evaluated by adopting LRMC. In this context, the LRMC of storage can be approximated by the unit costs incurred by OS users to increase the production of a data storage system by one unit. This specifically may include costs such as hardware, software development, personnel, and so on.

4.1.3. Labour cost-savings

Another benefit associated with OS is **cost savings in labour**. This benefit reflects the gain in opportunity costs that arise by exploiting open knowledge and tools for 1) public research funders and governments, 2) enterprises, and 3) professionals. In other words, this benefit materialises by saving the working time of the users of the OS services. For instance, using shared codes and protocols diminishes the need to code from scratch, but instead, one can at least build on some piece of existing code, thus saving working time. Sharing data mining techniques allows for automated information collection, reducing the manual effort required to collect the same data by means of manual data entry. The existence of open/FAIR data allows researchers and professionals to save time in finding the data needed since they are, by definition, more findable. OS projects also contribute to time savings when designing research projects and writing papers, especially because easier circulation of the research outputs reduces the duplications of research outputs (e.g., codes, papers, data).

The labour cost-saving benefit thus represents the value generated through decreased working hours and can be seen as an effective measure to assess the efficiency gains in production facilitated by OS. **A way of monetising it from the user perspective is the appraisal of the time saved measured by the social cost of labour, i.e., shadow wages.** The social cost of labour is typically distinct from observed salaries and identifies the opportunity cost of labour. Indeed, actual wages can be biased due to distortions in labour and product markets, such as, among others, the presence of minimum wages, high unemployment rates, the existence of informal or illegal sectors, etc. However, for skilled and highly skilled workers who have previously been engaged in similar activities, the shadow wage can often be assumed to be equal or close to the market wage (EC 2014). When salaries are unavailable or assuming unbiased wages are considered too strong, average wages obtained from private companies that collect individual salary data for consultancy purposes can be adopted as well.[19] Another viable option might be public surveys providing micro-data on wages. Utilising national average wage data is also feasible, although it does involve a high level of approximation.

Hence, given this assumption, the social value can be expressed by the salary equivalent to the time saved by the user, and the benefit can, therefore, be assessed using the avoided cost method (*Box 6*). For example, if a researcher saves an entire workday, the labour cost saving would reflect the researcher's daily salary.

Box 6 Avoided cost method - labour-cost savings

The beneficiaries should provide the salary per employee, together with the estimation of the time (number of hours) saved. When it is not possible, an attempt to recover the salary associated with the researcher or other employee, depending on some characteristics, might be done by exploiting; for instance, private local companies operating in the human resource sector might provide salary data that can be exploited as benchmarks. When it is impossible to estimate the salary per employee, the country-based average cost of labour can be retrieved from the national statistical institutes. Indeed, such institutes usually estimate the hourly cost of labour per employee since it is usually adopted to compute productivity measures. When using average values, one could decide to adjust the cost of labour by taking into consideration the existing estimation of the intersectoral wage differential to reduce measurement errors. Regarding cross-country assessments, labour cost data can be retrieved from OECD productivity indicators.

In practice, the benefit is obtained by the following:

[19] For instance, for the US (and some other geographical areas) labour market, PayScale might be a useful tool.

$$Labour\ Cost\ Savings = \sum_{t=0}^{T}\sum_{i=1}^{N} h_{it} * w_{it}$$

Where:

h_{it} is the individual time saved;

w_{it} is the individual hourly cost of labour;

$t = 0, \ldots, T$ is the span of time over which the benefit should be computed;

$i = 1, \ldots, N$ is the number of professionals involved in the time saving.

Source: Authors

Another way of assessing the benefit is estimating the **WTP for time-saving** among the OS users. As mentioned in Section 4.1.1, it is a survey-based economic technique typically adopted for the valuation of resources, goods or services that are not exchanged in a market. In this case, the elicitation method typically adopted is called choice modelling and allows for understanding how people choose different options or alternatives (Johnston 2017) for the same good, e.g., different attributes of the OS that might lead to different scenarios of saved time.[20]

4.1.4. Transaction cost-savings

The last category of cost-savings relates to avoiding transaction costs incurred through time spent navigating copyright agreements, conducting ad-hoc negotiations for access to specific data or protocols, and other research outputs. Open data, protocols, software, and other related resources have the potential to decrease the time required for accessing data through agreements and procedures since they imply shared and harmonised protocols and agreements for openness and access. In contrast, closed environments typically entail more *ad-hoc,* time-consuming processes to obtain information, such as navigating complex databases or adhering to intricate procedures. The social value of this benefit should be evaluated in the same way as the labour cost savings (see Section 4.1.3). Despite being related to both labour and access cost savings, given the weight of the transaction costs when research collaborations involve hundreds of facilities, it is worth keeping them separate from either labour or access cost savings.[21]

4.1.5. Caveats in assessing OS efficiency benefits

Although the listed benefits appear distinct in theory, **closer examination reveals a high risk of overlap when they are empirically measured because they are strictly interrelated, and the boundaries among them are blurred.** When assessing the diverse benefits of OS, a

[20] This technique has been applied, among others, by Koudouri et al. (2021) in the evaluation of the OpenAIRE open access platform.

[21] See for instance the example in Lee (2015).

careful and precise appraisal method is crucial to avoid overlap and double counting due to the intertwined nature of these benefits:

- **When investigating the access cost savings via CV,** responses may not align with the intended focus of access cost savings, often including broader perceived benefits and values. For example, the evaluation of EMBL-EBI's data resources by Beagrie and Houghton (2021) revealed a respondent associating the value with the preservation of an entire science ecosystem, implying a perception of value beyond mere service access. The risk of overlapping benefits also includes transaction cost savings. To minimise the double counting, the analyst necessitates precise question framing and clear delineation between the overlapping benefits.

- **In evaluating storage cost savings**, clear demarcation with access cost savings is crucial to avoid inadvertent inclusion of the former in the appraisal of the latter, especially when employing CV or LRMC. Clear specifications are essential when assessing these benefits separately, ensuring accurate representations of each value.

- **For labour cost savings appraisals,** the double counting is minimised by clarifying the time under evaluation. The assessed time should exclude spans dedicated to storage processes and rapid access to research outputs and should specifically only include time saved conducting active research tasks. For instance, time savings derived from using open, standardised methods that eliminate researchers' need for independent development should be considered.

- **In assessing transaction costs**, attention is needed to prevent their inclusion in the appraisal of access and labour cost savings due to the intertwined nature of these values. Clearly outlining the appraisal's objective minimises the risk of double counting, especially during survey-based evaluations.

Another caveat that is worth mentioning might be related to the characteristics of the users, who, especially when working in a research field where funding is relatively scarce, might underestimate the social value of the service under evaluation.[22] Again, it is important to be aware of potential biases and minimise them during the survey design process.

4.2. Enablement Benefits

The category of enablement benefits constitutes a second dimension of advantages stemming from OS projects. Along the causal pathway timeline, enablement benefits are observed to occur subsequent to efficiency gains, e.g., the saved time allows for being more productive in research.

These benefits originate from the knowledge spillovers that result from the wide dissemination of research outputs. Since scientific journals serve as a primary medium for the scientific

[22] See, for instance, Beagrie and Houghton (2013) that assess the social value of the Archaeology Data Service.

community and industry to stay informed about cutting-edge research, the academic norms governing journal access and pricing assume significant importance (Cohen et al. 2002). OS practices likely expand among the scientific community the possibility for knowledge production, through open access and open data, which empower individuals to access and reuse publicly funded research results and data openly. Likewise, enterprises by accessing OS outputs and using OS services are likely to foster their innovation. Additionally, early and easy accessibility to knowledge is likely to enhance the likelihood of patent registrations.

However, attributing the enablement gains solely to OS is more challenging than one might expect. Indeed, other contributing factors or inputs likely play significant roles in the causal relationship between OS and the realisation of new products and services. As previously mentioned, the enablement often results from savings in time and money, allowing researchers and enterprises to focus on research tasks that would have been deferred if OS services had not provided access to knowledge. This consideration necessitates acknowledging the uncertainty in pinpointing the exact role of OS in new technology developments.

At this stage of the work, enablement benefits are listed and described, but the determination of how and whether they will be incorporated into CBA will be resolved and validated through subsequent case studies.

4.2.1. New products, services, technologies, start-ups, and spin-offs

OS projects play a pivotal role in generating knowledge spillovers that directly contribute to the advancement of novel products, services, or technologies. This benefit is particularly advantageous for 1) enterprises and 2) public research funders and governments.

The rapid dissemination of knowledge facilitated by an OS environment has a notable advantage. Open publications, codes, data, software, research discoveries, and data can be swiftly and widely shared. This culture of openness fosters a climate of innovation within enterprises as valuable information becomes easily accessible. OS projects, providing easier access to diverse sources of knowledge and ideas, stimulate innovation across research communities, various industries and among professionals. The transparency and openness allowed by the OS projects allow to more efficient collaboration and knowledge exchange among researchers and businesses. This streamlined process can lead to reduced research and development costs, enabling researchers and enterprises to explore new ideas and experiments without the constraints of expensive access fees or restrictive licensing agreements. As a result, OS offer opportunities for a better and more transparent science and for businesses to pursue innovative avenues that might have been financially prohibitive in a closed system. Enterprises then gain the potential to develop novel and cutting-edge products, services, and technologies that may not have emerged in a less collaborative and accessible environment.

In section 3, we have previously discussed the additional social costs associated with OS projects when enterprises and professionals lack the capacity to exploit shared research outputs effectively. However, in cases where the lack of capabilities is substantial and anticipated, OS projects can play a catalytic role in the **creation of start-ups and spin-offs**. These enterprises are specifically established to address the knowledge gap. This phenomenon occurs, for instance, when intricate and comprehensive open data, despite their inherent value, present challenges in direct market utilisation due to the specialised expertise required for their manipulation, interpretation and analysis. As a result, novel companies may emerge to bridge this knowledge gap by undertaking the task of preparing and processing such complex data. These new enterprises serve as intermediaries, leveraging their expertise to extract meaningful insights from the vast pool of open data. By doing so, they facilitate the practical application of this valuable information and make it accessible to a broader range of industries and professionals. Several examples of new company formations are highlighted in Garcia et al. (2018), a qualitative study illustrating the surge of European SMEs that base their businesses on the availability of open data from public bioinformatics databases provided by the EML-EBI and other ELIXIR Nodes. Some companies specialise in customising data to meet client needs, while others integrate open data with additional relevant information from various sources. Further, other companies assist clients in identifying the appropriate datasets and software.

This type of benefit is typically quantified by measuring the **incremental shadow profits** resulting from their sale (*Box 7*).[23] The term *incremental* signifies that the profits derived from selling new or improved products should be compared to a hypothetical scenario where the OS did not exist, or the knowledge would have been available under payment. The term *shadow* highlights the consideration of market distortions, such as higher shadow profits due to factors like the location of infrastructure in an area with high unemployment or low innovation levels. As for new products, services, and technologies, the economic value of this benefit is quantified as the **shadow profit generated by the newly formed businesses** over their expected lifetime, compared to a scenario without the implementation of OS projects.[24] However, as previously disclosed, the complete attribution of this social value to OS outputs appears to be challenging. The comparison of these benefits with the costs of launching and maintaining an OS project would be fair only if it were the only one triggering the materialisation of the benefits, which does not seem to be always the case. For these reasons, further research is needed on to what extent these benefits can be included in the analysis and compared to costs.

Box 7 Incremental shadow profits - new products, services, technologies, start-ups, and spin-offs

The assessment of this benefit firstly implies the quantification of the demand for each innovation over the period under evaluation. In the case of the creation of start-ups, the quantification regards the newly created companies. Then, the estimation of the expected profits can be carried out.[25] Once estimated the expected profits associated with each enablement, the social value $\mathbb{E}(Z)$ is equal to:

$$\mathbb{E}(Z) = \sum_{i=1}^{N} \sum_{t=0}^{\mathrm{T}} \mathbb{E}(\Pi_{it})$$

[23] See Florio et al. (2016) for further details.
[24] Ibid.
[25] Ibid.

Where:

i=1,…,N is the number of the enablement (products, services, technologies, and start-ups)

t=0,…,T is the span of time over which the benefit should be computed and can be expressed in any unit of time.

$\mathbb{E}(\Pi_{it})$ is the expected shadow profit associated with any enablement

Source: Authors

4.2.2. Patents and licence deals

Another dimension of enablement gain is related to patents and other forms of intellectual property rights. This benefit is particularly advantageous for enterprises.

As emphasised by Bryan and Ozcan (2021), the lack of freely accessible publications acts as a barrier to innovation, particularly for underfunded institutions and enterprises (Frank, 2013). For small enterprises, in particular, access to scientific publications plays a crucial role in gaining knowledge about cutting-edge research, enabling the recombination of ideas and insights. Using OS services can contribute to an increase in patent registrations for innovative products, services, and technologies by enterprises. When a patent is registered, it generates private returns for the inventor and the potential for knowledge spillover to society.

When evaluating this benefit, it is important that the expected shadow profit generated by the new product is not double counted. Indeed, **the marginal social value of the patents** (*Box 8*) is normally associated with a private value (for the enterprise) and with an externality (for the society).

Box 8 Marginal social value estimation of patent and licence deals

The estimation of the patent value can be summarised as follows.[26] The first step involves forecasting the incremental number of patents expected to be generated due to OS project. Next, the average rate of usage of granted patents is forecasted based on a promoter's history or data on citations of patents issued in the same scientific field or similar infrastructures. The average number of references (backward citations) to existing patents is also projected.[27] Further, the estimation of the marginal private value of patents is carried out while ensuring that double counting is avoided, considering the change in expected profits resulting from the sale of innovations. Lastly, the quantification of the externality of patents in monetary terms and patent citations is carried out. Once obtained all the elements, the value equals:

$$\mathbb{E}(P) = \sum_{i=1}^{N} \sum_{t=0}^{T} \mathbb{E}(MSV_{(pvit,exit)})$$

where:

i=1,…,N is the number of the patents

[26] The details on the estimation of patent value in the context of RDI can be found in Florio et al. (2016).
[27] In Bryan and Ozcan (2021) it has been shown that in-text patent citations might be a more accurate way of counting the number of references compared to front page citation.

t=0,...,T is the span of time over which the benefit should be computed and can be expressed in any unit of time

$\mathbb{E}(MSV_{(pvit,exit)})$ is the marginal social value (MSV) that includes both the private value (pv_{it}) and the externality (ex_{it})

Source: Authors

5. Remarks and Conclusion

This methodological note is the starting point of the developing a CBA framework specifically tailored to the assessment of OS projects that give shape and actualise OS practices. The ambition of the proposed framework is to classify a broad list of social costs and benefits associated with OS projects along with the provision of guidelines on how to empirically measure them.

The proposed approach can be summarised as follows. The social costs refer to cash outflows directly incurred in the process of structuring, operating, maintaining, and upgrading the OS project. They can be classified into two macro-categories: set-up and maintenance costs of the OS serviced provided. The note then introduces an analysis of additional costs that must be considered (e.g., the potential need to acquire new skills to utilise OS services). On the other hand, the social benefits linked to OS project can be grouped into two main categories: efficiency gains or cost-savings (e.g., access, storage, and labour cost savings) and enablement benefits (e.g., the emergence of new products, services, start-ups, or spin-offs, and patents and license deals). Along with the ambition of classifying costs and benefits, the note sheds light on several caveats and issues that are embedded in the assessment of OS. The risk of double counting and issues related to the possibility of entirely attributing specific benefits to the OS are discussed.

This green framework will be tested on selected OS practices in the following stages of the PathOS project. The testing phase will allow for fine-tuning the general framework and case-specific details and issues mentioned in the text.

Moreover, it is important to note that this approach is not designed to be used in isolation in the appraisal of all the potential impacts of OS. Instead, it integrates with the broader framework of PathOS, an impact pathway assessment framework for open science. The CBA serves as a crucial initial step within this larger framework and specifically to measure the direct impacts of Open Science.

By sketching this general framework for OS evaluation, this methodological note aims to address a crucial gap in the literature and offers a systematic approach to assess the social implications of OS projects. It opens possibilities for further research and empirical investigations in this area.

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