The Indispensable Role of Software Ecosystem Services

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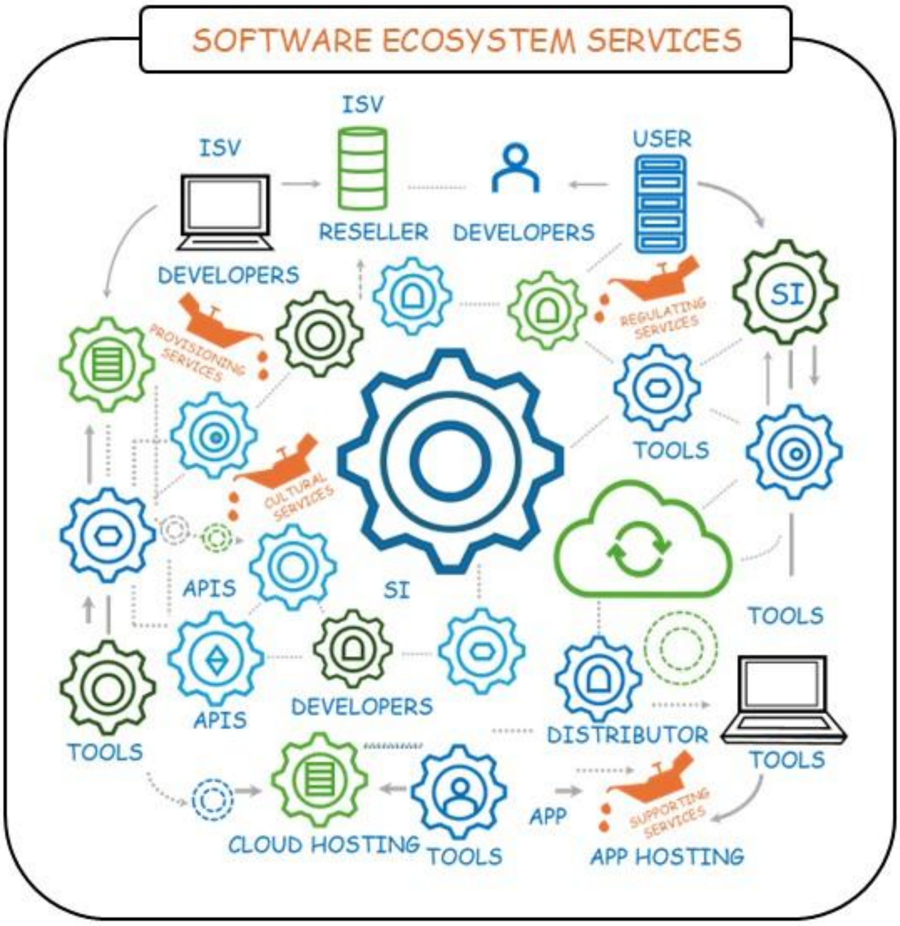

Software Ecosystem Services (SES) are defined as the essential conditions and processes enabling innovation and value creation within software ecosystems. SES are categorized into four primary types: Provisioning, Regulating, Cultural, and Supporting Services. The study identifies potential risks to sustainability due to dominant players and highlights the importance of balancing services for a resilient ecosystem. These insights set a foundation for sustainable software ecosystem strategies.

The indispensable role of software ecosystem services

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Abstract

Software ecosystem services (SES) are essential for the sustainability and functionality of software ecosystems, but they lack comprehensive categorization, hindering further study. This study explores the concept of software ecosystem services through a systematic literature review and brief survey. Drawing analogies from natural ecosystems, we define software ecosystem services as the conditions and processes through which software ecosystems create, provide, and sustain innovation and value creation via software. Software ecosystem services are categorized into four primary types: provisioning, regulating, cultural, and supporting services.

Our findings highlight the crucial role of services that do not directly add customer value but are essential for the software ecosystem's functionality, such as authentication and authorization services, collaboration and communication platforms, and app stores. By highlighting these vital yet often overlooked services, the research identifies potential sustainability threats for software ecosystems, such as the dominance of a few major players, which mirrors the risks of monocultures in natural ecosystems. This study lays the groundwork for further research aimed at ensuring the long-term sustainability and resilience of software ecosystems.

Keywords: Software Ecosystems, Software Ecosystem Services, Sustainability, Systematic Literature Review

1. Introduction

A natural ecosystem is a biological community of interacting organisms and their physical environment. This includes both living organisms and non-living components interacting as a system (Chapin et al., 1996). Software ecosystems are groups of software producing organizations collaboratively serving a market for software and services, generally with an underlying platform or technology (Jansen et al., 2009).

Since James Moore used the analogue between natural and business ecosystems (Moore, 1993), this similarity has been applied consistently in academic research. Software engineering (SE) has for example exploited many phenomena in nature to improve the efficiency of algorithms, tools, models, and processes (Dhungana et al., 2010).

The concept of natural ecosystem services has been defined to enable the identification and quantification of their impact, ensuring clarity, delineating scope, and facilitating effective communication. Constanza et al. 2014 estimate a decrease in value of natural ecosystem services from $145 trillion/yr. in 2007 to $125 trillion/yr. in 2011 (Costanza et al., 2014). Natural ecosystem services are defined as the conditions and processes through which natural ecosystems and the species that make them up sustain and fulfill human life (Daily, 1997). Sustainability is characterized as critical to survival

(Kremen, 2005) and it is integral to ecosystem management, playing a key role in ensuring the continued functioning and provisioning of ecosystem services (Braat & de Groot, 2012a).

One of the fascinating things about software ecosystems is that there are software and platforms engineered that do not directly contribute value for the customer, such as app stores, software repositories, and payment services. These services are instrumental for the software ecosystem to function, and yet they do not support customers in performing their key processes more effectively or efficiently. A more thorough understanding of these services using the analogy to natural ecosystems is required to support software ecosystem researchers in framing and analyzing the construction of software ecosystems.

It can be argued that sustainability is under threat within the context of software ecosystems from a political (Fukuyama et al., 2021) or legal perspective (Jacobides et al., 2020). Big tech companies are seen as monopolistic; for example, the legal challenges against Apple in both the US and Europe are based on the alleged dominance of their App Store, which is seen as stifling innovation and competition.

Analogies facilitate understanding and learning by linking complex information to familiar concepts, making them valuable tools for comprehending difficult scientific concepts Duit, 1991). From a software ecosystem perspective, it continues to be valuable to use analogies with natural ecosystems and leverage research from this domain to identify and qualify new concepts. For this reason, we will examine whether the concept of SES exists in the current software ecosystem literature in a manner similar to how they are defined in the natural ecosystem knowledge base.

The main research question for this study is:

1. “How can software ecosystem services be defined”?

This work is structured as follows: in section 2, we propose the framework that we will use for this research using the analogy with natural ecosystems and the ecosystem services. This will include, using the same analogy, the explanation for the importance of defining SES. Section 3 details the systematic literature review that we executed, including selection of database selection, search keywords and an overview of the process. In Section 4, we share in detail the findings from our SLR and draw initial conclusions. In section 5 we present the approach of the brief survey that we executed to complement the SLR, the mapping of available software ecosystems services identified in secondary data and highlight the initial finding of the imbalance in the provision of SES by a few dominant players. Section 6 offers a critical reflection on the achievements and limitations of our research. We outline potential threats to the sustainability of software ecosystems and suggest areas for future research. Finally, Section 7 concludes the study, summarizing the key contributions and emphasizing the importance of defining and categorizing SES to facilitate comprehensive analysis and strategic planning within software ecosystems.

2. Theoretical Foundations

Research in the area of natural ecosystems has expanded rapidly (Costanza et al., 2014), while human well-being and progress toward sustainable development are vitally dependent on improving the management of Earth’s ecosystems to ensure their conservation and sustainable use. But while demands for ecosystem services such as food and clean water are growing, human actions are at the same time diminishing the capability of many ecosystems to meet these demands. (Leemans & De Groot, 2003)

For operational purposes, ecosystem services are classified along functional lines:

1. Provision Services
    - Products obtained from ecosystems, such as food, fresh water, biochemicals and genetic resources.
2. Governing Services
    - Benefits obtained from the regulation of ecosystem processes, such climate regulation, water purification and pollination.
3. Cultural Services
    - Nonmaterial benefits obtained from ecosystems such as spiritual and cultural, aesthetic, cultural heritage.
4. Supporting Services
    - Services necessary for the production of all other ecosystem services such as soil formation, nutrient cycling, or primary production.

The amount of research on natural ecosystem services accelerated as it became evident that the sustainability of natural ecosystems was under increasing pressure. There was a realization that a prerequisite for both analysis and action is agreement on a fundamental conceptual framework (Leemans & De Groot, 2003).

The urgency felt within the domain of natural ecosystems should also be recognized within software ecosystems. For instance, clearing a forest to increase food production can have highly detrimental impacts on a larger scale: significant loss of forest cover in upstream areas may reduce dry-season water availability downstream (Leemans & De Groot, 2003). Similarly, owning, managing, and developing an app store may benefit the parent company, developers, and customers, but it may simultaneously restrict upstream innovation by, for example, accepting only one payment solution. This monoculture may prove detrimental to the sustainability of the software ecosystem.

We will employ the analogy between natural ecosystem services and SES to facilitate understanding and enhance learning when defining SES.

In order to be able to answers the main research question we will need to answer the following supporting research questions:

1. What is included in the current software ecosystem knowledge base using the analogy with ecosystem services in natural ecosystems?
   We will search for the literal term “software ecosystem services” to identify current literature and look for closely related synonyms in an effort to capture existing knowledge.
2. Is drawing an analogy with the four subcategories of ecosystem services (provisioning, regulating, cultural, and supporting) useful in an effort to define software ecosystem services?
   Services are inherently intangible, which makes them difficult to quantify and describe. We will evaluate the solutions chosen for addressing this challenge in natural ecosystem services and categorize them into four groups.
3. Which organizations are offering SES and can a threat to sustainability be identified?
   We will map services offered by participants of the software ecosystem into the four categories and assess if this substantiates the definition of the categories. This will also put us in a position to identify the potential dominance of participants.

2.1. Proposed software ecosystem services categories

In order to utilize the four categories from natural ecosystems, we need to adapt the definitions to make them applicable to software ecosystems.

These are the definitions we assess in this research:

- **Provisioning Services**: Primary services that provide essential resources and functionalities.
- **Regulating Services**: Services ensuring compliance, security, and proper functioning of the ecosystem.
- **Cultural Services**: Services that enhance user interaction, community engagement, and collaborative efforts.
- **Supporting Services**: Supplementary services that enhance the efficiency and effectiveness of primary services.

There is one important adjustment that we make in comparison to the definitions used in natural ecosystem services: provisioning natural ecosystem services do include goods (like food) and services (such as waste assimilation) (Costanza et al., 2014), we exclude goods (like a CRM application) but include services (like DevOps tools) because is beyond the scope of this research to include all goods produced by a software ecosystem.

3. Method

The methodology used in the research is a systematic literature review according to guidelines from Kitchenham (Kitchenham et al., 2009). The search strategy was defined through an iterative process, resulting in the decision to break up the single search string into multiple search strings to effectively capture the relevant literature. This search was performed in the Scopus database in May 2024, ensuring comprehensive coverage of peer-reviewed studies in English. The keywords used reflect the four categories of ecosystem services and were designed to capture all relevant research on software ecosystem services (SES)."

3.1. Inclusion and exclusion criteria

The following inclusion criteria for selecting studies:

1. Studies must be peer-reviewed, ensuring scientific rigor and quality.
2. Studies written in English and available in full text.
3. Studies that explicitly mention software ecosystem services or closely related terms, such as software ecosystem offerings or functionalities.
4. Studies that discuss ecosystems in the context of software platforms, platforms, or related services.

The following exclusion criteria were applied:

1. Studies unrelated to software ecosystems, such as those focused on artificial intelligence, cybersecurity, or unrelated software fields.
2. Studies that were not available in full text or those written in languages other than English.
3. Conference papers or industry reports without peer-reviewed quality standards.

3.2. Search keyword

The objective of this SLR is to identify and summarize the current state of knowledge within the software ecosystem knowledge base, covering SES by drawing an analogy to the definition used ecosystem services knowledge base.

The focus of the search is the software ecosystem domain, so the keyword “software ecosystem” is used to filter out results beyond that scope. To broaden the results without losing focus, the keyword “software platform” was added. Secondly, to find literature covering services, the following keywords were included: “services,” “offerings,” “functionalities,” and “capabilities.”

These keywords proved too broad, so, following Kitchenham's (Kitchenham et al., 2009)recommendation to use multiple search strings, we adopted the functional categorization used for ecosystem services. This resulted in four sub-search strings focused on “provisioning services,” “regulating services,” “supporting services,” or “cultural services.”

For this category “provisioning services,” we used the following keywords: “provisioning,” “supplying,” “providing,” and “delivering.” This resulted in this search string for this category:

- ("software ecosystem" OR "software platform") AND ("services" OR "offerings" OR "functionalities" OR "capabilities") AND ("provisioning" OR "Supplying" OR "Providing" OR "Delivering")

For the category “regulating services,” these keywords were used for this category: “regulating,” “controlling,” “managing,” and “stabilizing.” This resulted in this search string for this category:

- ("software ecosystem" OR "software platform") AND ("services" OR "offerings" OR "functionalities" OR "capabilities") AND ("cultural" OR "community" OR "societal" OR "human")

For the category “cultural services,” these keywords were used for this category: “cultural,” “community,” “societal,” and “human.” This resulted in this search string for this category:

- ("software ecosystem" OR "software platform") AND ("services" OR "offerings" OR "functionalities" OR "capabilities") AND ("cultural" OR "community" OR "societal" OR "human")

For the category “supporting services,” these keywords were used for this category: “supporting,” “foundational,” “underlying,” and “sustaining.” This resulted in this search string for this category:

- ("software ecosystem" OR "software platform") AND ("services" OR "offerings" OR "functionalities" OR "capabilities") AND ("supporting" OR "Foundational" OR "Underlying" OR "Sustaining")

3.1. Bibliographic database selection

Initially, Google Scholar, Web of Science, and Scopus were used as databases for the literature review. However, after careful consideration, it was decided to include only the literature from Scopus.

When searching using Google Scholar, it proved challenging to identify relevant literature due to the lack of filtering functionality. For all four types of searches, the same “approximately 17,000 results” were returned. When the filter “allintitle” was used, the findings ranged between 70 and 90 results, with a high percentage of irrelevant studies. Moreover, all four different search strings returned the same study from a commercial research institute (Fraunhofer IESE) as the most relevant research which highlights the absence of transparency in the selection that Google Scholar makes.

Web of Science (WoS) initially provided better results, but after applying the WoS categories as a filter, only limited results emerged. As shown in table 1, none of the 14 resulting studies contained the term “ecosystem services”.

Web of Science Search results			
	Title & Abstract	Abstract only	Filtered on Business, Management, Business Finance & Communication
Provisional Services	0	117	4
Regulating Services	0	33	2
Cultural Services	0	94	3
Supporting Services	0	69	5

Table 1 Search results in the Web of Science database

As depicted in the PRISMA diagram (Figure 1), when searching within the study title, abstract, and keywords using the search strings outlined in Section 1, we initially found a total of 1,387 studies. To filter out studies covering topics like artificial intelligence, data science, cybersecurity, and software engineering, we applied the “business, management, and accounting” subject area filter. This filter focuses on studies related to organizational behavior, strategic management, entrepreneurship, finance, accounting, marketing, human resource management, operations management, corporate governance, and business ethics. This filtered out 1.311 studies.

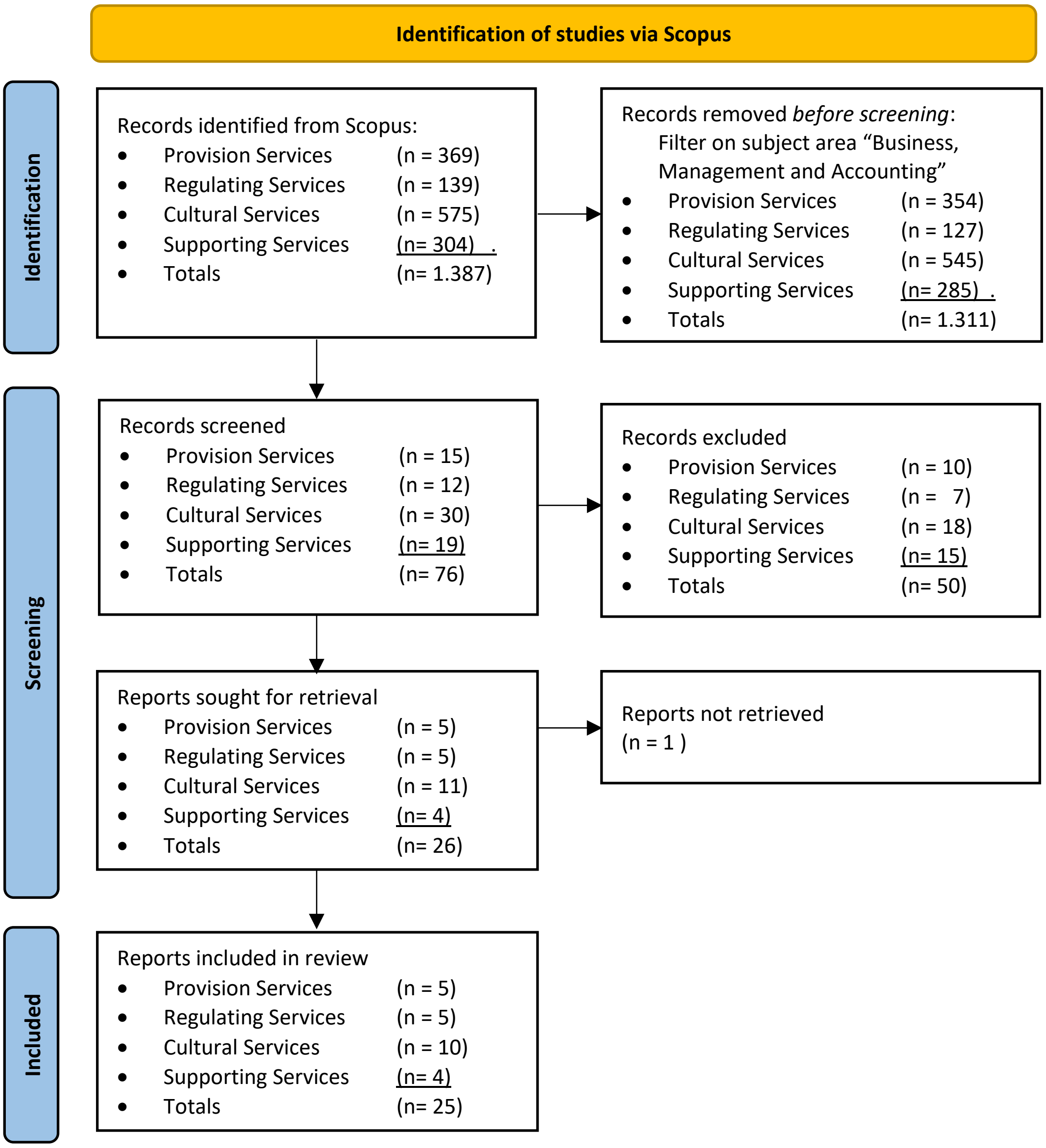

Figure 1 **Overview literature selection according to Page et all** (Page et al., 2021)

In the next step, we reviewed 76 studies by assessing the titles and keywords and reading the abstracts. This had to be done manually, as the use of consistent inclusion or exclusion criteria was not possible at this stage of the literature selection process due to the wide variety of topics covered by the studies. For several studies, such as the one titled “Dynamic Context Awareness of Universal Middleware Based on IoT SNMP Service Platform,” exclusion was obvious. However, the study “API Management Maturity of Low-Code Development Platforms” required deeper analysis and was included, as it covers research on the design and maintenance of application programming interfaces, which are crucial for organizations that want to create value-driven enterprise networks (Overeem et al., 2021).

After this review step, the list of studies to be read contained 26 studies. One study (Shi et al., 2021) could not be retrieved. Twenty-five studies were read, analyzed, and summarized in section 4.

Figure 1 Overview literature selection according to Page et all (Page et al., 2021)

3.2. Threats to Validity

Several potential threats to the validity of this systematic literature review were identified and addressed:

Selection Bias: Choosing Scopus as the primary database may introduce bias by excluding studies from other databases. To mitigate this, we conducted additional searches using the Web of Science database and Google Scholar, though these yielded no substantial additional results.

Measurement Bias: Systematic differences in assessing study outcomes could lead to inaccuracies. To mitigate this, all selected papers were reviewed independently by at least three researchers, who assessed their relevance and alignment with the research criteria. Discrepancies were discussed and resolved collectively to ensure consistent inclusion standards across studies.

Search String Limitations: Although comprehensive search terms were used, relevant studies with different terminology may have been missed. To mitigate this, broad search terms were employed, and studies using similar, though not identical, terminology were reviewed.

4. Review Findings

The review of the current literature aimed at identifying research that defines or describe services available in software ecosystems, fitting within one or more of the following categories: providing, regulating, cultural, or supporting. To ensure comprehensive coverage, the search terms were consistently broadened with three additional synonyms, preventing the omission of relevant literature described using different terms.

An initial finding reveals that the terms “ecosystem services,” “ecosystem offerings,” “ecosystem functionalities,” or “ecosystem capabilities” are rarely employed, even in the absence of the qualifier “software.” Only one study employs the term “ecosystem services” within the context of defining a digital ecosystem (Koch et al., 2022). The review also indicates that the existing literature offers limited value in the effort to define SES. As will be demonstrated in this section, it is even debatable whether the consistent use of search terms ensures the correct categorization of various studies in the literature review, or if they would be more appropriately placed in different categories.

In the remainder of this section, guided by our first supporting research question, “What is included in the current software ecosystem knowledge base using the analogy with ecosystem services in natural ecosystems?,” an overview of descriptions used in the literature will be provided. A detailed analysis of the concept of “boundary resources” as discussed by Petrik and Herzwurm (2019) is included. This concept requires further exploration to ensure a clear differentiation between the definitions of boundary resources and SES.

4.1. Provisioning Software Ecosystem Services

The concept of provisioning services, defined as “the primary services that provide essential resources and functionalities,” is described in five studies. None of these studies use the term “software ecosystem services.

The provisioning of services ensure trust can add value to a software ecosystem while trust plays a crucial role in a software ecosystem as it influences the interactions and relationships among stakeholders such as software engineers, software providers, organizations, and end-users. Software providers play a crucial role in ensuring the trustworthiness of software packages and projects by collecting data on trust and making it available to end-users according to Hou et al. (Hou et al., 2021).

Platform providers play a crucial role in fostering innovation within a software service ecosystem by managing the platform, promoting, and regulating third-party software, and strategically positioning software services. They facilitate innovation by providing core services and bridging service clusters. Additionally, they guide the development and interaction of software services, contributing to the ecosystem's overall success and sustainability (Kim & Altmann, 2022).

App store deployment signifies a shift in the vendor's strategy towards becoming a platform supplier, fostering a platform strategy that incentivizes complementary innovations and decreases the scope of the product offering (Magnusson & Nilsson, 2013).

Platform providers are crucial in the low-code development ecosystem, enabling citizen developers to create diverse software products without extensive engineering knowledge. They ensure well-designed APIs are available for organizations to extend software products, fostering collaboration and value creation in enterprise networks (Overeem et al., 2021).

4.1.1. Boundary Resources

In their study, "IIoT Ecosystem Development through Boundary Resources," Petrik and Herzwurm define boundary resources as "capabilities that facilitate the use of core functionality of a platform in application and service design (Petrik & Herzwurm, 2019). They describe these resources as including application programming interfaces (APIs) and software development kits (SDKs). However, their definition has the potential to be seen as overlapping, so we loosely employed the backward snowballing technique, as described by Wohlin et al. (Wohlin et al., 2020) to evaluate if this was the case.

We identified the 31 studies that were referenced, excluded seven that could not be retrieved, screened 24, and read 15.

The conclusion of this review is that the definition of boundary resources is much narrower while they are designed to support arm's-length relationships between platform providers and app developers, highlighting the collaborative role of distributed actors in optimizing these resources (De Reuver et al., 2018).

Platform owners actively provide various resources, including information portals, documentation, helpdesks, and alignment workshops, to bridge knowledge gaps within platform ecosystems (Foerderer et al., 2019).

These boundary resources, such as APIs, SDKs, incentives, intellectual property rights, and agreements, facilitate the use of core platform functionalities in application and service design (Ghazawneh & Henfridsson, 2013).

PaaS (Platform as a Service) providers, particularly in cloud platforms, manage relationships with complementors by offering boundary resources (Giessmann & Legner, 2016).

Boundary resources enable the co-creation process in service ecosystems and address issues related to value co-creation (Hein et al., 2019). The host manages these resources within open digital platforms, promoting resource sharing and third-party contributions (Karhu et al., 2018).

According to Mohagheghzadeh and Svahn (Mohagheghzadeh & Svahn, 2016), boundary resources are "software tools and regulations that serve as the interface for the arm's-length relationship between the platform owner and the application developer," referencing Ghazawneh and Henfridsson (Ghazawneh &

Henfridsson, 2013). These resources help platforms facilitate interactions with external actors, maintaining control while enabling value-driven lock-ins and fostering developer interactions within the ecosystem (Ofe & Sandberg, 2019).

Boundary resources on software platforms are intended to facilitate value co-creation, provided by platform owners to partners, not necessarily identified as developers (Schreieck et al., 2019).

Typically, these resources include APIs or SDKs, along with rules to regulate contributor behaviors and mitigate threats to the platform (Skog et al., 2018).

4.2. Regulating Software Ecosystem Services

The search for regulating SES that ensure compliance, security, and proper functioning yielded four studies that provide insight into the value of these services, although they do not use the term "software ecosystem services.

TITAN is a software platform that manages the life cycle of Big Data science workflows, including design, annotation, development, testing, deployment, and execution. It uses an ontological framework to consistently handle processes, models, and domain knowledge throughout workflow management (Benítez-Hidalgo et al., 2021).

Release management involves activities such as coordination of release cycles, dependency management, communication, and stabilization to ensure a well-integrated and polished product for end-users (Foundjem, 2019).

Through the positive feedback loop generated by network externalities, digital firms aim to exploit and capture the value created by increasing user adoption to benefit from network efficiencies and improve their competitive position in the market (Hoffmann, 2021).

Service management in cloud computing ensures effective provisioning, monitoring, and delivery of services to meet Cloud Service Users" expectations. Instance Management and Service Management are interconnected components that work together to achieve this goal (Saravanakumar & Arun, 2012)

4.3. Cultural Software Ecosystem Services

The term "software ecosystem services" is not used in the 11 studies that describe services that enhance user interaction, community engagement, and collaborative efforts.

Akoumianakis highlights in his exploration of practice-oriented toolkits for virtual communities of practice, the need for technological tools that enable virtual teams or communities of practice to achieve true cooperation and collaboration (Akoumianakis, 2009).

The importance of collaboration among various actors and the need for an IT-based platform to develop an Open Data software ecosystem is highlighted by Gama and all. This platform should enable interactions between data providers, consumers, aggregators, sponsors, and other participants. It plays a crucial role in developing Open Data-based products and services, integrating different actors, fostering innovation, and delivering practical benefits like civic apps(Gama & Lóscio, 2014).

The role of software vendors has evolved significantly. They now operate within software ecosystems, collaborating with service and software component suppliers, value-added resellers, and proactive customers. By managing relationships and navigating technical and social challenges, vendors can create new business models, build enduring partnerships, and adapt to the evolving software landscape, enhancing their success (Jansen et al., 2011).

To foster a healthy open-source Ruby ecosystem, Kabbedijk et al. recommends encouraging current developers to collaborate more, rather than just supporting new developers or gems. It highlights the importance of a core group of about 10% of developers and gems that dominate the ecosystem. Promoting cooperation among existing developers can enhance the Ruby community's health and sustainability (Kabbedijk & Jansen, 2011).

The availability of a social component highlights the significance of having a leading entity, whether governmental, organizational, or academic, that coordinates and facilitates collaboration among various stakeholders to drive the success and growth of a regional software ecosystem (Larrucea et al., 2016).

The co-creation of communities is crucial in product development cycles. Mäkinen et al emphasize their importance in allowing companies to interact with customers, gather user input, engage in co-creation during development, and foster creative collaboration. Co-creation communities transform company-user interactions and enhance product development processes (Mäkinen et al., 2014).

Malhotra et al. mentions that HRM practices leveraging CCEs" knowledge are essential for adapting to change and fostering innovation within the organization (Malhotra et al., 2020).

Co-creation is examined by Mizushima and Ikawa in the Eclipse open-source software ecosystem, highlighting the need to maintain developer motivation, promote innovation, and link activities to company profit. It aims to clarify the company-led co-creation structure by constructing a process model that supports sustainable development through value sharing, value acquisition, and both quantitative and qualitative development. The document also explores how the Eclipse ecosystem's mechanisms drive co-creation and business competition, detailing the roles of individuals and companies and how competition and co-creation coexist within the ecosystem (Mizushima & Ikawa, 2011).

End-users play a crucial role in adaptation mechanisms by providing valuable feedback that can be used for runtime adaptation. The document suggests that through explicit user feedback, users can participate actively in the adaptation loop. This feedback can include interactions with chatbots to provide natural language feedback, helping in user categorization and the execution of enactment action plans. By offering their preferences, needs, and feedback, end-users contribute to enhancing their own user experience in mobile applications (Motger et al., 2021).

The level of digital participation empowers individuals to be involved in activities that matter to them, fostering diverse participatory processes such as crowdsourcing, participatory budgeting, peer-to-peer sharing, and online consultations. By making participation seamless and inclusive, digital technologies have revolutionized how people engage in societal activities, promoting transparency, accountability, and democratic functioning (Piperagkas et al., 2020).

The social component of software ecosystem development is crucial for understanding the dynamics within the ecosystem, as mentioned in "Ruby Software Ecosystem Dynamics". It emphasizes that profit is no longer solely generated from individual products but from the collective interaction and collaboration among all companies within a software ecosystem. The relationships, interactions, and cooperation between actors in the ecosystem play a significant role in driving success and maximizing profit within the ecosystem. Understanding and effectively managing these social dynamics are essential for software vendors to thrive in the evolving landscape of software ecosystems (Viljainen & Kauppinen, 2011)

4.4. Supporting Software Ecosystem Services

"Software ecosystem services" is used in the study of Koch et al. one of the four studies that describe services that provide supplementary support to enhance the efficiency and effectiveness of primary services.

Koch defines an "ecosystem service" as a service asset that is exchanged between providers and consumers within a digital ecosystem. The ecosystem service enables the transfer of service assets, such as their provision and consumption, by brokering these assets between providers and consumers in the ecosystem service. The role responsible for this brokering activity is referred to as the service asset broker within the context of an ecosystem service. (Koch et al., 2022). This definition is appropriate within the context of defining "digital ecosystems"; however, it is too limited to be effectively utilized in defining SES.

Interaction between developers and users is crucial for complementary innovation in digital ecosystems. This involves co-creation, where developers and users exchange resources and information on a common platform. Developers provide what users need by integrating various resources, while users offer feedback and input. This mutual exchange drives complementary innovation, fostering the emergence and evolution of robust digital ecosystems (Zhang et al., 2024).

Fang et al. argue that hackathons act as forums for social learning, knowledge exchange, and social coordination, aligning the collective expectations of attendees and facilitating the diffusion of platform technologies. Specifically, hackathons enable developers to identify and join emerging trends, fostering platform adoption and ecosystem growth. Therefore, in the context of platform ecosystems, hackathons serve as supporting services by providing a conducive environment for developers to learn about, experiment with, and adopt platform technologies (Fang et al., 2021).

Interaction between developers and users are regarded as a vital driver of complementary innovation. This collaboration facilitates the emergence and evolution of digital innovation ecosystems by integrating resources and offering what the other party needs. This interaction is crucial in promoting value co-creation within these ecosystems (Zhang et al., 2024)

4.5. Initial findings

The existing literature on software ecosystems includes several studies that define services that do not directly contribute value to the customer, such as app stores, software repositories, and payment services. These services are instrumental for the functioning of the software ecosystem. However, the literature lacks a consistent approach to collectively describe or define these services, and the term “software ecosystem services” is rarely used. It can be concluded, in response to our first supporting research question, that while the current literature indicates the existence of SES, it does not define them comprehensively.

5. Mapping of available services

5.1. Identifying and assessing software ecosystem services.

In this section, we will examine the second supporting question “What ecosystem services are available, and who provides these services?” and the third one “Which organizations are offering SES and can a threat to sustainability be identified?“ Through this analysis, we aim to determine whether SES can be identified and assess the value of the proposed categories, enabling us to answer our main research question: “What is the definition of a software ecosystem service”?

To complement the findings of our SLR we executed a comprehensive assessment of available services through a brief survey. This approach enabled us to systematically analyze and interpret secondary data, thereby bridging the gap in current academic literature and offering a nuanced understanding of the operational landscape.

The list of available SES is not intended to be complete or final, as this is not feasible. Similar to natural ecosystem services, it is a “living list.” For example, G2 Crowd, a company that provides reviews of business software and services (a software ecosystem service), currently lists around 45,000 software solutions and services in 900 categories, continuously updates and adds new categories to reflect emerging technologies and market trends (G2 Crowd, 2024). A complete list is also not required for the purpose of our research.

Leveraging models used in the research in natural ecosystem services, we will use “The Economics of Ecosystems and Biodiversity” (TEEB) framework (Braat & de Groot, 2012b), which is structured around three key steps aimed at better understanding and assessing ecosystem services and their value. We will focus solely on step 1, “Identify and Assess.” Steps 2, “Estimate Values,” and 3, “Capture Values,” can be explored in future research. This future work could prove insightful, as SES can be quantified (unlike the challenges in quantifying natural ecosystem resources), potentially aiding in assessing the dominance of software ecosystem participants and their impact on sustainability.

After examining providers of reviews of software solutions and services such as G2 Crowd, Capterra, and Clutch, as well as web-based platforms offering version control and collaboration tools like GitHub and GitLab, and AI language models including Google Gemini, Bing Copilot, and ChatGPT, it was decided that the latter provided the most effective results.

The following prompt was consistently used in ChatGPT:

- For provisioning services: “What are examples of software ecosystem services provided in software ecosystems that are <u>primary services that provide essential resources and functionalities</u> within a software ecosystem and which organizations provides these?”
- For regulating services: “What are examples of software ecosystem services provided in software ecosystems that are <u>providing compliance, security, and proper functioning</u> within a software ecosystem and which organizations provides these?”
- For cultural services: “What are examples of software ecosystem services provided in software ecosystems that enhance <u>user interaction, community engagement, and collaborative efforts</u> within a software ecosystem and which organizations provides these?”
- For supporting services: “What are examples of software ecosystem services provided in software ecosystems that provide supplementary support to enhance the efficiency and effectiveness of primary services within a software ecosystem and which organizations provides these?”

The results of the brief survey, after collecting the data, evaluating the resources, undoubling, and cleaning of the results, can be found in table 2. The full list of findings can be found in the addendum.

A certain limitation in quality must be acknowledged in brief survey; however, the findings significantly contribute to the assessment of available services, thereby aiding in the definition of SES. When categorizing these services into the four proposed categories, they align well with the definitions provided, which enhances the understanding of their functions.

Gaining the right insights into the actual offerings necessitates, in most cases, assessing the providers of these services and conducting a detailed analysis of their offerings. An additional benefit of this approach is that it offers a comprehensive overview of the role and influence of various participants within the current global software ecosystem.

The results of the brief survey, utilizing secondary data, identified 33 SES provided by 85 organizations or companies. Of these, 79 organizations offer services in a single software ecosystem service type, while seven provide services in two or more types. One software ecosystem service is offered by 69 companies, ten companies offer two services, and two companies offer three services. Additionally, four companies provide four or more services. As presented in table 3, the number of services provided in combination with the number of categories these services are offered in provides an interesting perspective.

Provisioning Service

The primary services that provide essential resources and functionalities.

- App stores and marketplaces
- Backup and disaster recovery services
- DevOps Automation and Optimization
- DevOps tools
- Cloud APIs, Infrastructure, Hosting
- Content delivery networks (CDNs)
- Continuous Integration/Continuous Deployment (CI/CD) platforms
- Data APIs
- Package Management Systems
- Repository Hosting Services

Regulating Services:

Compliance, security, and proper functioning.

- Analytics and data management
- Analytics and monitoring services
- Application Performance Management (APM)
- Auditing and logging services
- Authentication and authorization services
- Identity and access management
- Penetration testing and vulnerability scanning services
- Security and compliance services

Cultural Services

Enhance user interaction, community engagement, and collaborative efforts.

- Collaboration and communication platforms
- Communication and collaboration
- Developer Communities
- Marketing and advertising
- Support and community services

Supporting Services

Supplementary support to enhance the efficiency and effectiveness of primary services.

- Analytics and data services
- Business Intelligence and Analytics
- Consulting and training services
- Consulting services
- Development tools
- Development tools and services
- Industry Analysis and Market Research
- Payment and billing
- Project management tools
- Support and customer service

Table 2 Results of the brief survey

	# SES provided	# of SES categories active
Google	10	4
Microsoft	8	4
GitHub	5	4
Amazon Web Services (AWS)	4	3
LinkedIn	1	1

Table 3 Top 5 providers found in brief survey.

This demonstrates that nearly 25% of SES are provided by less than 5% of the companies offering these services. Table 4 provides an overview of this situation. This imbalance would be exacerbated if GitHub and LinkedIn were included under Microsoft, factors such as presence across multiple categories were considered and values like revenue weighting would be taken into account.

Provisioning Services	App stores and marketplaces	Amazon Web Services Marketplace, Apple App Store, Google Play Store, Microsoft Store
	Backup and disaster recovery services	Veritas, Acronis, Amazon Web Services (AWS), Carbonite, Datto, Google Cloud, Microsoft Azure, Veeam, Zerto
	DevOps Automation and Optimization	Ansible, Chef, Puppet
	DevOps tools	CircleCI, Jenkins, Travis CI
	Cloud APIs, Infrastructure, Hosting	Amazon Web Services (AWS), Google Cloud Platform (GCP), Microsoft Azure
	Content delivery networks (CDNs)	Akamai, Cloudflare
	CI/CD platforms	CircleCI, Jenkins, Travis CI
	Data APIs	Firebase Realtime Database, GraphQL, REST APIs
	Package Management Systems	maven, npm, pip
	Repository Hosting Services	Bitbucket, GitHub, GitLab
Regulating Services	Analytics and data management	Amplitude, Google Analytics, Mixpanel
	Analytics and monitoring services	Google Analytics, Mixpanel, New Relic
	Application Performance Management (APM)	AppDynamics, Dynatrace, New Relic
	Auditing and logging services	Elasticsearch, IBM Security, Loggly, LogRhythm, RSA, Splunk, Sumo Logic
	Authentication and authorization services	Amazon Web Services (AWS), Auth0, Duo Security, Google Cloud Identity, Microsoft Azure, Okta, Ping Identity, RSA
	Identity and access management	Okta, OneLogin
	Penetration testing & vulnerability scanning services	Cobalt, IOActive, Nettitude, Rapid7, SecureLayer13, Trustwave, Veracode
	Security and compliance services	Deloitte, Ernst & Young, Kaspersky, McAfee, PwC, RSA, Symantec, GitHub, Stack Overflow
Cultural Services	Collaboration and communication platforms	Microsoft Teams, Slack, Zoom
	Developer Communities	GitHub, Reddit, Stack Overflow
	Marketing and advertising	Facebook, Google Analytics, LinkedIn
	Support and community services	GitHub, Stack Overflow
Supporting Services	Analytics and data services	Crashlytics, Google Analytics
	Business Intelligence and Analytics	Google Analytics, PowerBI, Tableau
	Development tools	Android Studio, Microsoft Visual Studio, Xcode
	Development tools and services	GitHub, JetBrains (IntelliJ IDEA), Microsoft Visual Studio
	Industry Analysis and Market Research	Forrester, Gartner, IDC
	Payment and billing	PayPal, Square, Stripe, Square, Stripe
	Support and customer service	Desk.com, Freshdesk, Zendesk
	Project management tools	Asana, Jira, Trello
	Consulting and training services	Codeacademy, Pluralsight, Udemy
	Consulting services	Accenture, Deloitte, PwC

Table 4 Overview of SES by SES category and providers

These initial indications require far more future research which is outside the scope of this study. They do though, show that defining software ecosystems services has an important purpose. The identification and categorization will enable software ecosystem researchers in framing and analyzing the construction of software ecosystems. Including the assessment if the sustainability is under thread through the domination of one or more software ecosystem actors. This dominance can lead to diminishing the capability of the software ecosystem to innovate and meet markets demands. Similar to the challenges in natural ecosystems as documented in the literature.

6. Discussion

6.1. Contributions

In this research we have defined and categorized SES through a systematic literature review and brief survey. By drawing analogies to natural ecosystems, we have provided a structured framework that enhances understanding of SES. The four proposed categories—provisioning, regulating, cultural, and supporting services—offer a comprehensive lens through which to analyze the functions and impacts of these services within software ecosystems. This categorization facilitates a nuanced approach to research and development, enabling better strategic planning and management within software ecosystems. Our findings highlight the crucial role of services that do not directly add customer value but are essential for the ecosystem’s functionality, such as app stores, software repositories, and payment services. This research underscores the importance of defining these services to ensure a holistic analysis of their impact and influence on the software ecosystem’s sustainability and innovation.

6.2. Limitations

Despite these achievements, our research encountered several limitations. The primary limitation is the scarcity of literature explicitly using the term "software ecosystem services." This scarcity made it challenging to gather comprehensive data, necessitating broader searches and the inclusion of closely related synonyms. Additionally, the lack of consistency, overlap and contradictions in the use of terminology across studies posed difficulties in categorizing various services accurately. Another limitation is the reliance on brief survey for identifying available SES. While this method provided valuable insights, it also introduced a certain degree of subjectivity and potential bias due to the quality and scope of secondary data sources. Furthermore, the dynamic nature of software ecosystems means that the list of identified services is neither exhaustive nor static, requiring continuous updates to remain relevant.

6.4. Areas for Future Research

Future research should focus on several key areas to build on our findings. Firstly, empirical studies are needed to validate the proposed framework and refine the definitions and categories of SES. These studies should aim to quantify the impact of these services on the ecosystem’s sustainability and innovation potentially applying step two and three of the TEEB framework (Braat & de Groot, 2012b). Our research identifies several potential threats to the sustainability of software ecosystems, which should be substantiated by, for example, adding weighting to the SES based on revenue. This approach could be similar to the work of Costanza et al. in the quantification of natural ecosystem services. (Costanza et al., 2014)

Additional research into the impact of specific SES may also provide important insights. For example, the perception that the Apple App Store stifles innovation in the US and Europe could be further examined through research focused on a specific set of SES.

Finally, software ecosystem researchers could focus on identifying essential SES that are critical for maintaining healthy software ecosystems. This could aid in analyzing the construction of software ecosystems and potentially identifying key services that should be introduced. For example, a provisioning service such as an App Store or a cultural service like a developer community could be essential components.

7. Conclusion

The main research question posed in this study is: "How can software ecosystem services be defined?" Based on the findings of the systematic literature review and brief survey, Software Ecosystem Services, analogous to natural ecosystem services, can be defined as “the conditions and processes through which software ecosystems create, provide, and sustain innovation and value creation via software.” This definition is consistent with the definition by Daily et al. (Daily, 1997). used in the natural ecosystems knowledge base, is supported by Kim et al. (Kim & Altmann, 2022) who states that platform provider play a crucial role in fostering innovation, the role of service management described by Saravanakumar et al in meeting Cloud Service Users expectations (Saravanakumar & Arun, 2012) or the interactions between developers and users as a vital driver of complementary innovation as researched by Zhang et al. (Zhang et al., 2024).

Categorizing the services into four main types has proven to be useful for comprehension:

- **Provisioning Services**: Primary services that provide essential resources and functionalities, such as platforms and infrastructure that support software development and deployment.
- **Regulating Services**: Services ensuring compliance, security, and proper functioning of the ecosystem, including governance frameworks, security protocols, and regulatory compliance mechanisms.
- **Cultural Services**: Services that enhance user interaction, community engagement, and collaborative efforts, such as forums, developer communities, and collaborative platforms.
- **Supporting Services**: Supplementary services that enhance the efficiency and effectiveness of primary services, including developer tools, support systems, and educational resources.

These categories provide a structured framework for understanding and analyzing the various roles and impacts of services within software ecosystems, facilitating a more comprehensive and nuanced approach to research and development of software ecosystems.

The findings underscore the importance of defining SES to facilitate a comprehensive analysis of their impact and influence. This approach enables the framing and analysis of the construction of software ecosystems. Initial outcomes indicate a significant imbalance caused by the substantial number of SES provided by an extremely limited number of actors in the global software ecosystem. This dominance poses potential threats to the sustainability and innovation of software ecosystems, akin to the risks presented by monocultures in natural ecosystems. Addressing this imbalance requires further empirical research to validate these findings and explore mechanisms to promote a more balanced distribution of service provision.

In conclusion, this study contributes to the academic discourse by proposing a structured framework for defining and categorizing SES. Future research should build on these initial findings to develop strategies that promote a balanced and resilient software ecosystem, mitigating the risks associated with the dominance of a few key players. This work lays the groundwork for further theoretical and empirical exploration, aiming to ensure the long-term sustainability and resilience of software ecosystems.

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