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Abstract	A governance model for FLUIDOS---a decentralized ecosystem with multi-stakeholders---is discussed. The discussion is centred around how to ensure a balanced benefit for all stakeholders while being economically and environmentally sustainable. Our methodology includes an online survey and a co-design workshop to define the core principles of FLUIDOS's data governance model. We also highlight the environmental optimization principles that FLUIDOS should consider, and the challenges associated with such optimization. Finally, the principles and governance model will be finalized in version 2 after interaction with external and internal stakeholders.
Keywords	Data governance, distributed systems, cloud computing, environmental models, business models

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EXECUTIVE SUMMARY

This document discusses the need for a governance model for decentralized and multi-stakeholder ecosystems like FLUIDOS. This model should ensure a balanced benefit for all stakeholders while being economically and environmentally sustainable. Our methodology to investigate such models includes an online survey and a co-design workshop with project partners to define core principles for FLUIDOS data governance model. We also highlight the environmental optimization principles that FLUIDOS should consider to reduce energy consumption and greenhouse-gas emissions through a carbon-aware computing model and better utilization rate of available devices. The challenges involved in conducting a complete life-cycle assessment for FLUIDOS elements are also discussed. The principles and governance will be finalized in version 2 of this deliverable after interaction with external and internal stakeholders.

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ABBREVIATIONS

CAPEX	Capital Expenditures
CED	Cumulative Energy Demand
EOL	End Of Lifte
FEU	Fossil Energy Use
FLUIDOS	Flexible, scaLable and secUre decentralIzeD Operationg
FU	Functional Unit
ICT	Information and Communication Technology
IDSA	International Data Spaces Association
IP	Internet Protocol
IT	Information Technology
GHG	Greenhouse Gas
GWP	Global Warming Potential
LCA	Life-Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
ML	Machine Learning
NRCED	Non-renewable Cumulative Energy Demand
OPEX	Operational Expenditures
PFEU	Primary Fossil Energy Use
SaaS	Software as a Service
SEU	Secondary Energy USE
TCP	Transmission Control Protocol
UNFCCC	United Nations Framework Convention on Climate Change

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1 INTRODUCTION

A complex ecosystem, potentially involving multiple actors, such as the one envisioned by FLUIDOS requires rules and policies to work properly. This document, leveraging an exploratory approach with partners, investigates governing principles for an ecosystem based on a FLUIDOS-like decentralized and multi-stakeholder infrastructure. These governing principles are commonly called "Governance Model", and in the case of FLUIDOS entail also specific values of FLUIDOS vision, such as the "sustainability of IT resources" implicitly underpinned by the concept of "resource re-usage" that lies at the base of the Peer-to-Peer model proposed by FLUIDOS.

1.1 SCOPE

As a first step, in the definition of a Governance Model, this document, rather than setting in stone the governance, provides elements of discussion for its definition, which will be finally formalized in version 2 of this deliverable, following interaction with external and internal stakeholders.

An ecosystem composed of multi-faceted stakeholders having different goals can work only if common goals, needs, and rules are identified, that aim to provide balanced benefits to all the stakeholders: obviously, a community survives and stays together only if it has a common scope (which may also evolve over time, of course) that act as catalyst of the joint efforts of the community.

In the case of FLUIDOS, the overall idea is that there is an opportunity for (new and existing) infrastructure owners (that are not necessarily providers) to share their resources (especially at the "edge", i.e. more localised than traditional cloud providers) for the benefit of potential service providers that today don't have access to such resources unless they procure the required infrastructure (via a CAPEX model, differently from the OPEX model offered by public clouds).

This opportunity for infrastructure owners is also a chance to foster a more sustainable usage of IT resources, given that in many cases owners of private IT infrastructure are not fully exploiting them, thus leading to a not very environmentally friendly ratio between energy consumption and computational throughput.

Clearly, for a community around these two opportunities to work out, it needs to be economically sustainable for the actors to stay engaged and motivated, and find ways to ensure that the economical sustainability goal (which may even be pursued as the main objective by certain stakeholders) is not decrementing the impact on environmental sustainability.

This document, as a starting point, explores different options for environmentally sustainable models for decentralized computing and business models for fluid computing, while defining the core principles for FLUIDOS Governance.

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1.2 METHODOLOGY

Defining governance, business models, and sustainable models for multi-stakeholder infrastructure, like the one envisioned by FLUIDOS, requires collecting insights from the different actors that take part in it. As a first exercise to draft FLUIDOS principles and vision, we engaged the different organisations that are part of the project to gather their view on these topics. While we are very aware that project partners may represent just a limited set of the multifaceted stakeholders that in the future may be part of FLUIDOS-like ecosystem, it is important to start from a first concept, so as to have an early vision to be shared with external stakeholders for comment, revision, and refinement. With this goal in mind, we leveraged an online survey and a co-design workshop to collect insights. In the following paragraphs, we briefly report on outcomes of the two exercises.

1.2.1 Survey on Governance, Business Models and Sustainability Models

The survey contained three sections focusing on three key orthogonal aspects:

1. **Governance models for Infrastructure and Data**
   The first section, aimed at understanding who the key stakeholders are and what are the core principles to be considered, highlighted that actors that should govern FLUIDOS are mainly Infrastructure providers and Brokers. The less important are Developers and non-IT resource providers. Additionally other actors such as regulators and trust anchors have been suggested.

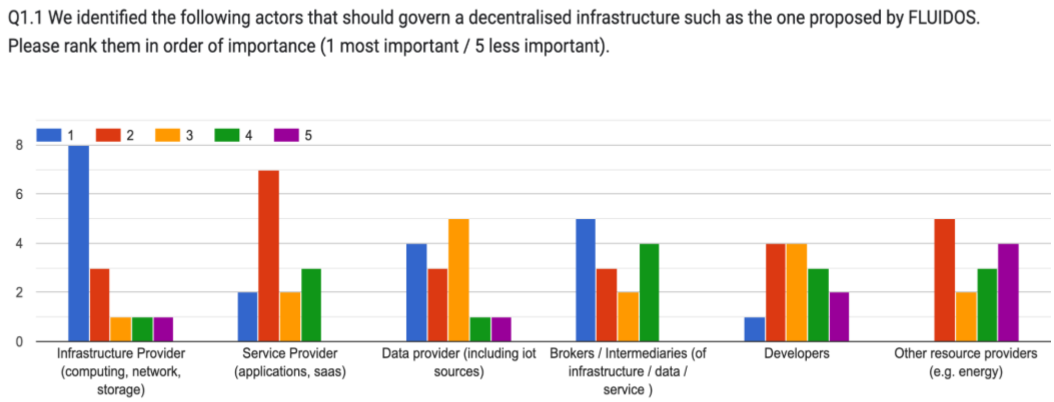

FIGURE 1: ACTORS THAT SHOULD GOVERN A DECENTRALISED INFRASTRUCTURE SUCH AS FLUIDOS.

In terms of principles, the survey highlighted that the most important principles are Security, Simplicity of Usage, Accountability and Confidentiality/Privacy . The less important are Openness, Sustainability and Transparency (Figure 2) .

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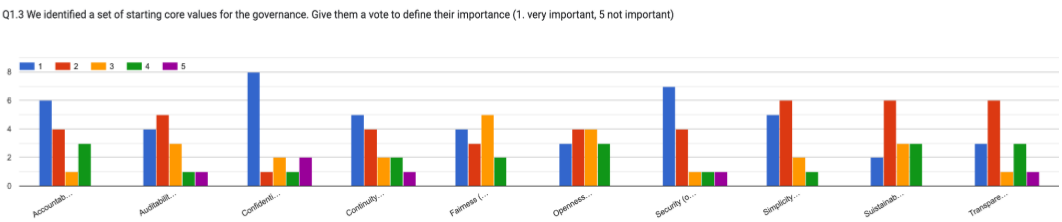

FIGURE 2 : CORE VALUES FOR GOVERNANCE

2. Environment-friendly models for decentralized computing

In terms of environmental sustainability related matters, the questionnaire highlighted that the full life cycle (including production cost of the hardware) is the favourite option to compute the environmental impact of a FLUIDOS decentralized deployment.

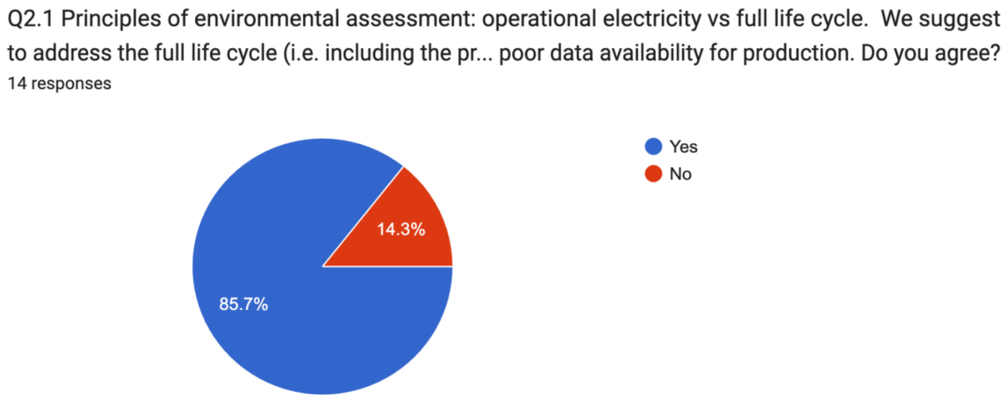

FIGURE 3 : PRINCIPLES OF ENVIRONMENTAL ASSESSMENT: OPERATIONAL ELECTRICITY VS FULL LIFE CYCLE.

As regards the prioritisation between reducing carbon footprint and energy consumption, the wide majority prioritised reducing carbon footprint.

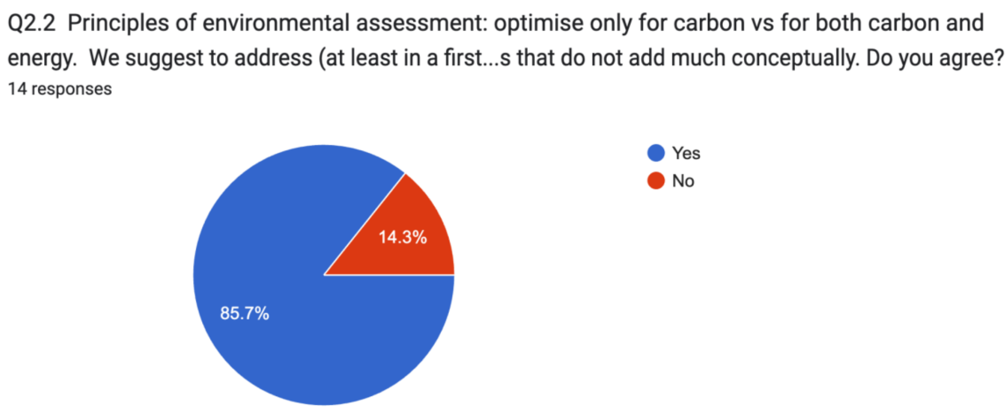

FIGURE 4 : PRINCIPLES OF ENVIRONMENTAL ASSESSMENT: OPTIMISE ONLY FOR CARBON VS FOR BOTH CARBON AND ENERGY

On the other hand, it seems that both global optimisation (i.e., of the overall FLUIDOS infrastructure) and local optimisation (i.e., of a single application) are considered important principles, with a slight preference for local optimisation.

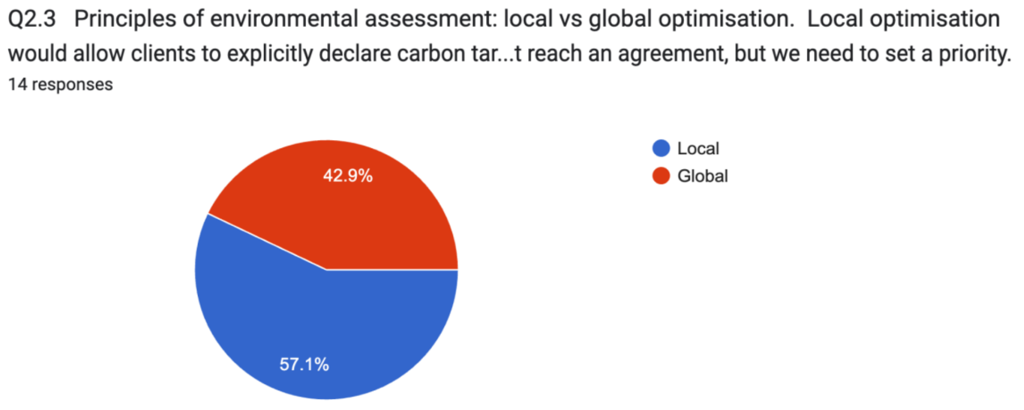

FIGURE 5: PRINCIPLES OF ENVIRONMENTAL ASSESSMENT: LOCAL VS GLOBAL OPTIMIZATION

3. Business models for fluid computing

This section "Business models for fluid computing" explored different aspects related to the definition of a business model for decentralised / fluid computing.
The survey highlighted that partners consider Cloud Providers and SaaS providers the most likely actors that will contribute resources to the creation of decentralized infrastructure like the one envisioned by FLUIDOS. The less likely actors are Natural Persons.

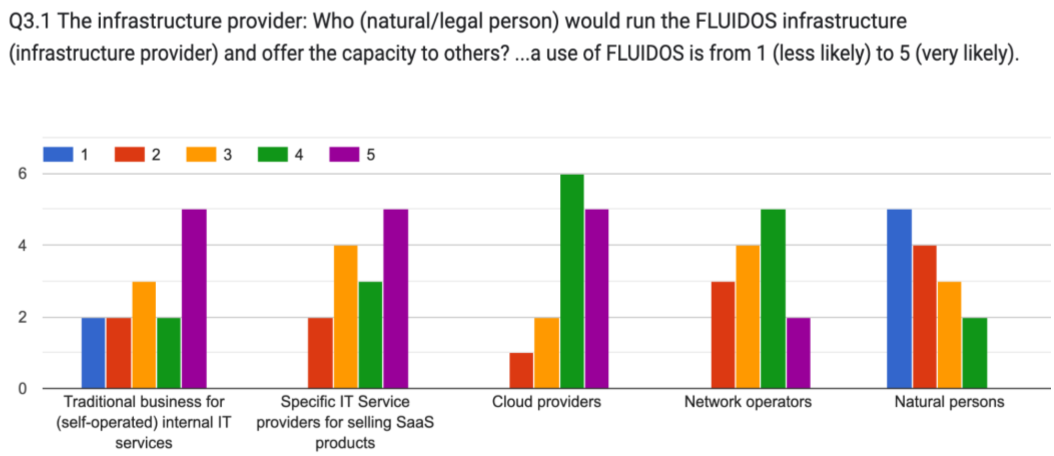

FIGURE 6: INFRASTRUCTURE PROVIDER: WHO WOULD RUN FLUIDOS

In terms of users, the main actors according to the consortia are likely to be SaaS providers, followed by Cloud Providers. The less likely users are considered again Natural Persons.

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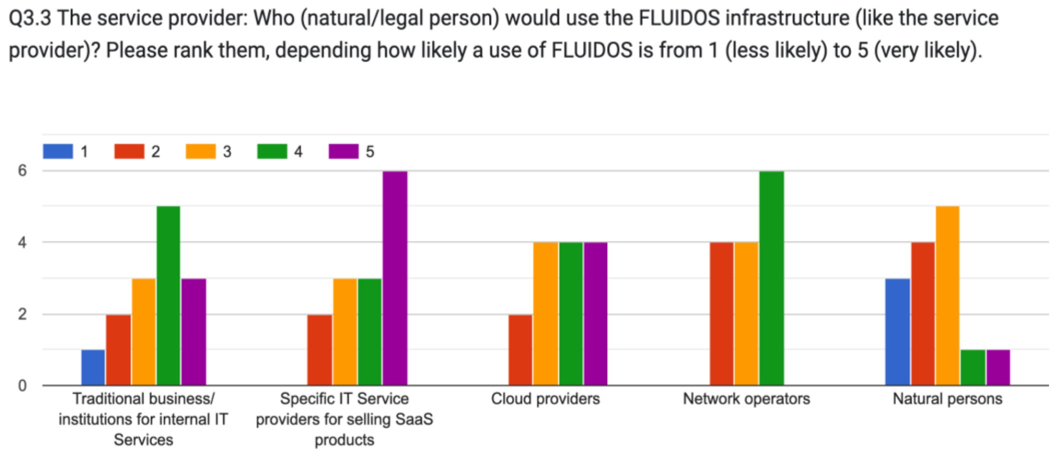

FIGURE 7: THE SERVICE PROVIDER: WHO WOULD USE FLUIDOS

In terms of income model, the consortia consider pay-per-use and subscriptions the most likely models to be adopted.

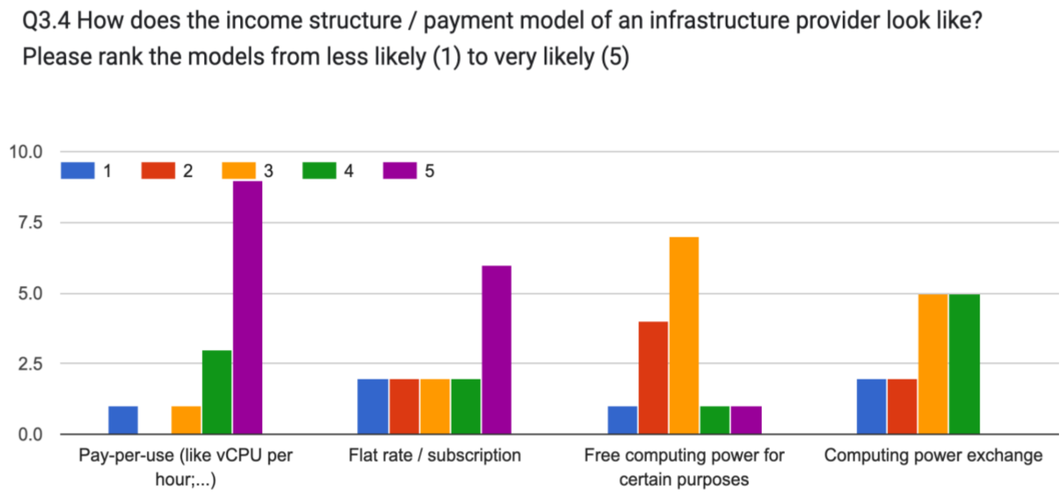

FIGURE 8: PAYMENT MODELS

1.2.2 Workshop on business models

Following the survey, a workshop was held to enrich our investigation further. The workshop on FLUIDOS resulted in several key points that were documented on a Miro board (Section 4.3). The main question in the workshop was about the mission and values of FLUIDOS with sustainability principles in mind. The vision for FLUIDOS was described with three overarching points: (i) the detachment of physical infrastructure and applications, (ii) security and privacy, and (iii) transparency in cloud infrastructure. Potential customers for FLUIDOS were identified and they include those with

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distributed ML training needs, IoT customers, robotic fleets, smart buildings, smart cities, and more. Sustainability is important for these customers for various reasons, such as avoiding unsustainable business practices and making better use of existing resources. The stakeholders for FLUIDOS include energy providers, developers, aggregators, and more. The value proposition and revenue model were also discussed, with ideas such as profitability through reduced infrastructure management costs and a free model. The results are meant to be used for further discussions on the business model for FLUIDOS. A detailed discussion on the workshop is available in Section 4.3.

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2 INFRASTRUCTURE AND DATA GOVERNANCE

Governance Model, in its wider meaning, refers to the set of principles, rules, processes and tools that are used to enable the proper functioning of an organisation by ensuring that decision-making is effective and assigns accountability to the actors involved in the governance (Stoker, 1998).
While, indeed, governance generally refers to "organizations" such as companies, it has been also well adopted in the context of open-source projects, data management, and infrastructure management. In the context of FLUIDOS, the focus relevant for us (at least in this document) at this stage of the project is the reason why a decentralised infrastructure, such as the one envisioned by FLUIDOS, should work to promote the goals of its stakeholders. In this section, we discuss key stakeholders identified as part of FLUIDOS governance and discuss a list of potential principles we think should be considered to define policies, and hence tools that put into practise FLUIDOS governance. It is not the scope of this document yet to translate principles into "policies" and "tools", being this quite related – in the case of FLUIDOS – with the architecture design covered in other activities of the projects. Principles elicited here should be regarded as part of the non-functional requirements that FLUIDOS should consider.

Before digging into stakeholders and principles taken in consideration for FLUIDOS governance, we briefly discuss some relevant governance models.

2.1 RELEVANT EXAMPLES OF GOVERNANCE

2.1.1 Open-source projects governance

While FLUIDOS is likely to be released as open source, it hasn't been made public yet, given that it will be a standalone initiative, rather than a set of projects and contributions to existing initiatives such as the Cloud Native Computing Foundation[1]. As mentioned earlier, at this stage the project focus is not yet on the governance of the outcomes of the project (e.g., their "open-source governance model": this will be part of the topics covered by Exploitation and Innovation Management activities) but rather the vision of the governance model for FLUIDOS as a decentralised infrastructure (and eventually the data hosted on it). Despite that, Open-Source governance models are very interesting to FLUIDOS because they generally relate to a set of different and sparsely geo-located organisations collaborating over the internet to make the project work. At an abstract level FLUIDOS envisions the same thing: several different and sparsely geo-located organisations that contribute to create an infrastructure. Two main open-source governance models have been effectively discussed in (Raymond, 1997): the bazaar, i.e. projects that encourage contributions from a variety of organisations; and the cathedral, i.e. projects that restrain contributions to a small core of actors.

[1] https://www.cncf.io/

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Multi-stakeholder Governance Model: The Gaia-X project aims at creating an open, transparent, and secure digital ecosystem for data and service sharing. The project envisions a federated and secure data infrastructure based on the principle of decentralization. The governance model of Gaia-X is based on the principles of openness, inclusiveness, and consensus-building, and it is designed to enable all stakeholders to have a say in the development and implementation of the initiative. The goal of this model is to ensure that Gaia-X reflects the diverse needs and perspectives of the European cloud community and that it operates in the best interests of all its stakeholders. The organizational structure of Gaia-X is built on three pillars: the Gaia-X Association, the national Gaia-X Hubs, and the Gaia-X Community. Gaia-X Hubs are the central contact points for companies, stakeholders, initiatives, associations, and public sector bodies in each country contributing to the Gaia-X project. The project goal is to create a dynamic, grassroots ecosystem that will help to identify relevant user requirements and to conceptualize use cases, and to bundle national initiatives.

The International Data Spaces Association (IDSA) is a non-profit organization that aims to promote the development of secure, trustworthy, and interoperable data-sharing infrastructures. The governance model of IDSA is based on the principles of multi-stakeholder collaboration and self-organization. Further, it adopts a "Data Sovereignty-by-Design" principle, which emphasizes the importance of data ownership, control, and security for businesses and individuals. The IDSA provides a framework for secure data sharing based on standardized interfaces and protocols, allowing companies to share data in a controlled and secure manner. The organization brings together members from various industries, including manufacturing, automotive, logistics, and healthcare, to develop and implement the IDS architecture. The IDSA is also involved in the development of international standards for data sharing, including ISO/IEC 27000 and 2700X series. The ultimate goal of the IDSA is to create a global network of data spaces that allow organizations to share data securely and efficiently, thereby promoting innovation and economic growth.

2.2 PRINCIPLES FOR GOVERNANCE

Data governance refers to the management of data assets, including policies, procedures, standards, and controls that ensure the accuracy, completeness, consistency, and reliability of data. Effective data governance ensures that organizations can use data efficiently, make informed decisions, and comply with regulations (Khatri & Brown, 2010; Kassen, 2022; Mahanti & Mahanti, 2021).

Here are key principles for effective data governance:

- **Accountability**: Establish clear ownership and responsibility for data management activities, including data quality, data security, and data privacy.
- **Transparency**: Ensure that data management policies, procedures, and practices are clear and understandable to all stakeholders, including data owners, data custodians, and data users.
- **Compliance**: Ensure that data management activities comply with applicable laws, regulations, and industry standards.

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- **Accessibility**: Ensure that data is easily accessible to authorized users when and where they need it, while maintaining appropriate controls to protect the confidentiality, integrity, and availability of data.
- **Data Quality**: Ensure that data is accurate, complete, consistent, and timely to support business needs and decision-making.
- **Data Lifecycle Management**: Develop processes for managing data throughout its lifecycle, including creation, storage, use, retention, and disposal.
- **Collaboration**: Encourage collaboration and communication among stakeholders involved in data management, including business users, IT professionals, legal and compliance teams, and data governance leaders.

- **Continuous Improvement**: Regularly review and improve data management practices to ensure that they are effective, efficient, and aligned with business objectives.

By following these principles, organizations can establish a solid foundation for effective data governance, which can help them make better decisions, reduce risk, and drive business value.

2.3 STAKEHOLDERS

FLUIDOS potential stakeholders include users and providers of applications/services that need a continuum and/or guaranteed performance at the edge; institutional or private players interested in environmental, economic, and social sustainability; small cloud service and infrastructure providers; and producers of low-carbon electricity. During the aforementioned workshop the attendees identified the following stakeholders:

- Aggregators
- Network and cloud providers
- Energy suppliers (low carbon)
- Developers
- ICT device manufacturers
- Various sustainability agencies (Governmental and NGO)
- Users + Providers of XaaS at the edge Enterprises

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3 ENVIRONMENTALLY SUSTAINABLE MODELS FOR DECENTRALISED COMPUTING

This section discusses the general principles of the environmental optimisation deployed in FLUIDOS, and the principles of the environmental impact assessment that are required as prerequisite. Decentralized computing refers to the distribution of computing resources across a network of computers rather than relying on a single centralized system. This approach can offer numerous benefits, such as increased scalability, improved fault tolerance, and enhanced privacy. However, decentralized computing can also consume significant amounts of energy and have negative environmental impacts. Therefore, it is important to develop environmentally sustainable models for decentralized computing. .The novel paradigm deployed in FLUIDOS is expected to bring about energy savings and greenhouse-gas (GHG) reductions through two main mechanisms:

1. A carbon-aware computing model capable of shifting loads in space and time to take advantage of low-carbon electricity, but also,

2. The avoidance of device production through a better utilisation rate of available devices.

To account for both these factors, and in particular the second one, an LCA will be conducted for the determination of GHG-emissions focusing on the production phase and the use-phase of devices employed in FLUIDOS.
In the following two main subsections, we address the main principles of environmental optimisation and assessment (together with the related decisions and trade-offs among them), and the main challenges that are to be expected and that partners should be aware of across all work packages (as the decisions taken there might reflect positively or negatively on the environmental optimisation).
Criteria for the optimisation function: i) energy efficiency of computation, ii) carbon intensity of electricity (variable in space and time), iii) production phase allocation (perhaps also EOL).

3.1 PRINCIPLES OF ENVIRONMENTAL ASSESSMENT

Over the last two decades or so, two relatively independent traditions have developed for the environmental assessment of ICT: Assessments published in computing or electrical engineering literature typically focus on the operational electricity of the ICT equipment. Meanwhile, the well-established life-cycle assessment (LCA) methodology has been deployed within environmental sciences to study the environmental impact of ICT as well. While the former studies often had access to better primary data and could take advantage of the domain knowledge of the authors, LCA clearly yields the more comprehensive and thus semantically more accurate modelling method.

3.1.1 Life-Cycle Assessment (LCA) Method

The LCA method considers both the emissions and the resources used along all product life stages. The life stages of a product are fivefold: i) raw material extraction, ii) raw material manufacturing, iii)

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product manufacturing, iv) use stage, and v) end of life. This complete scope of the life cycle is referred to as Cradle-to-Grave. For the cloud services of FLUIDOS, a partial LCA will be conducted, taking into account the two dominating product phases for IT devices, i.e. production and use phase.

In accordance with the ISO norm 14044 (ISO 14044, 2006), performing an LCA consists of the following four phases: i) goal and scope of the LCA, which defines the product system, system boundary, functional unit, reference flow and motivation to ensure transparency, ii) Life Cycle Inventory (LCI) which includes data collection and relates this data to input and output flows, iii) Life Cycle Impact Assessment (LCIA), in which the resource consumption and emissions of the quantified flows are normalised to environmental impact categories, and iv) an evaluation of the findings.

The environmental impact during the use phase of computation devices stems mainly from the energy consumption needed for computation tasks. A computation task will be normalised in the functional unit (FU) (see discussion in Section 3.2.1 below) with varying inputs and outputs depending on the specific device and source of energy. As for the manufacturing phase, a wide variety of devices participate in FLUIDOS, and emissions from their production will vary depending on the specific device and the production facilities (Wäger, Hischier, & Widmer, 2015) . With this extended scope that covers the two most relevant life cycle phases instead of just the use phase, the most important flows of the complete life cycle are quantified, thereby allowing a more differentiated decision process going forward.

In LCA terminology (ISO 14040, 2006) , a reference flow is defined as the quantity of each resource, product and emission needed to fulfil the function of the FU. This includes the energy demand and the flows of the production phase. The reference flows of the use phase may be difficult and complex to determine in practice, but are conceptually straightforward, i.e., the respective quantities per FU. However, to determine the reference flows of the production phase, a percentage of each resource, product and emission needs to be allocated to each computation task.

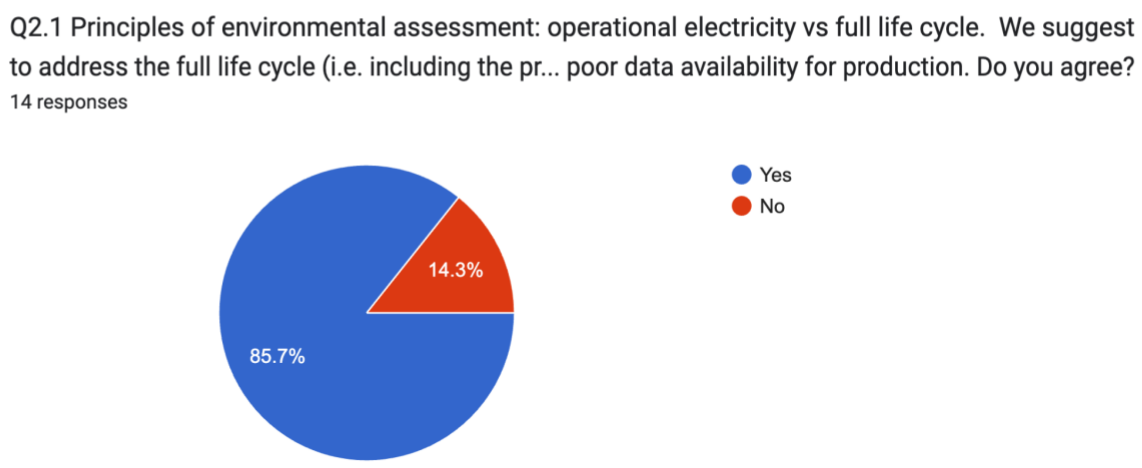

FIGURE 9: OPERATIONAL ELECTRICITY VS FULL LIFE CYCLE

This LCA of fluid computing is the academically correct method for assessing environmental impacts and emissions, yielding a solid database for the optimisation algorithm. This decision in favour of an

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LCA, which was initially laid down in the proposal for FLUIDOS, was confirmed during the internal survey on governance, business and environmental sustainability models and the subsequent workshop. The preparation and methodology, as well as the structure of the internal survey and the subsequent workshop are described in Section 1 above. During this survey, 85.7% (12/14) of participants agreed on the option of addressing the full life cycle in addition to the operational electricity needed during the computation tasks. However, it was also argued that in contrast to operational consumption, flows in a complete life cycle assessment are difficult to assess, due to poor data availability. Furthermore, it was addressed that production cost of hardware should be distributed along the hardware lifecycle. These challenges will be addressed in the following paragraphs, as well as in project work directly dealing with cost-effective and energy-aware infrastructure.

3.1.2 Impact Categories

Once the LCI has been completed, the quantified flows are assigned to an impact category. This LCA will focus on the impact category Global Warming Potential over 100 years (GWP-100), which quantifies the impact on climate change. The GWP has initially been standardised under the Kyoto Protocol 1979. An updated dataset was established by the UNFCCC in 2013. The GWP covers miscellaneous climate active substances while allowing greater clarity by combining them into a single value. According to this convention, the assigned flows are converted to the unit CO2 equivalents. In this impact category, CO2 has the relative value 1 and all other flows are converted according to their individual effects on global warming. For example, 1 kg of CH4 is converted to 26 kg CO2 equivalents, as the global warming caused by 1 kg of methane over 100 years corresponds to the warming caused by 26 kg of CO2.

In addition to the GWP, the energy consumption will be calculated. For this task, a wide range of indicators is available. Table 1 below presents an overview. Each of these yields a different result, due to shifted focus areas. The indicator utilised in the LCA of FLUIDOS should cover all energy extracted from nature, including renewable energy. Hence, this is best achieved by the indicator cumulative energy demand (CED).

TABLE 1: ENVIRONMENTAL IMPACT INDICATORS OVERVIEW

Statistical indicator	primary energy consumption	“Primary energy is energy embodied in sources which involve human induced extraction or capture, that may include separation from contiguous material, cleaning or grading, to make the energy available for trade, use or transformation.” (Øvergaard, 2008)
	secondary energy consumption	“Secondary energy is energy embodied in commodities that comes from human induced energy transformation.” (Øvergaard, 2008)

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LCA indicator	The cumulative energy demand (CED)	Primary energy use, both renewable and nonrenewable, for energy and material purposes is considered. This includes all energy extracted from the environment (Arvidsson & Svanström, 2016)
	nonrenewable cumulative energy demand (NRCED)	Non-renewable primary energy extracted from nature is considered. This indicator is typically used in the ReCiPe method as a midpoint impact assessment (Arvidsson & Svanström, 2016)
	secondary energy use (SEU)	This indicator considers all secondary energy use during the product life cycle (Arvidsson & Svanström, 2016)
	fossil energy use (FEU)	This indicator does not consider renewable energy. Whether nonrenewable energy types besides fossil energy, such as nuclear power, are included is not specified. It is not defined whether primary or secondary energy is considered. This may vary between studies (Arvidsson & Svanström, 2016) .
	primary fossil energy use (PFEU)	The PFEU has the same framework as the FEU, but is set to consider primary energy use (Arvidsson & Svanström, 2016)

The GWP will be prioritised during the initial creation of the FLUIDOS database, as it is the more relevant metric from a sustainability perspective. It will also make for a more manageable optimisation in the beginning, allowing for a possible iterative extension later on.

This prioritisation was confirmed during the internal survey with project partners, in which 85.7% (12/14) of participants agreed to address carbon only in the first project phase, during which the conceptual foundation of FLUIDOS will be laid. However, it has been stated that when including energy, conflicts will ultimately arise and need to be solved, leading to a trade-off between the two given options being the best overall solution. It has also been argued that energy is just as important as carbon during the environmental sustainability assessment. This outcome aligns with the proposed strategy for the following work packages.

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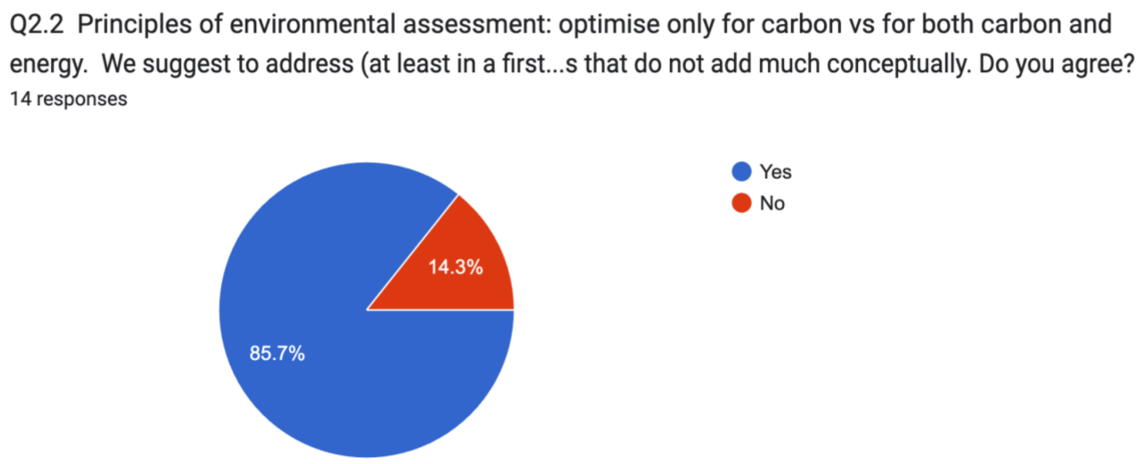

FIGURE 10: OPTIMISE ONLY FOR CARBON VS FOR BOTH CARBON AND ENERGY.

3.1.3 Global vs. Local Optimisation

Quite a challenging design decision (and one with far-reaching implications) is whether FLUIDOS should deploy a local or a global carbon and energy optimisation. In a local scheme, FLUIDOS clients would state their sustainability preferences together with other requirements, such as latency or price, and the FLUIDOS optimisation algorithm would find the optimal balance between them for each client request individually. In a global optimisation, by contrast, clients would only state all their other requirements, and each FLUIDOS node would distribute the tasks in such a way that all these other client constraints are respected, while overall carbon is minimised (and possibly energy, at a later stage).

Both approaches have advantages and drawbacks. A local optimisation gives users a more fine-granular control for stating their preferences, including sustainability-related ones. The optimisation according to each client's preferences (and the corresponding task distribution) is still performed by the FLUIDOS infrastructure (whether by a broker, aggregator, catalogue, etc, this remains to be seen according to the system design decisions), but individually for each request - the optimisation could thus be more manageable. A global optimisation, on the other hand, might inherently lead to more overall carbon (and/or energy) savings, although this ultimately would depend on the preferences stated by clients in the local optimisation paradigm.

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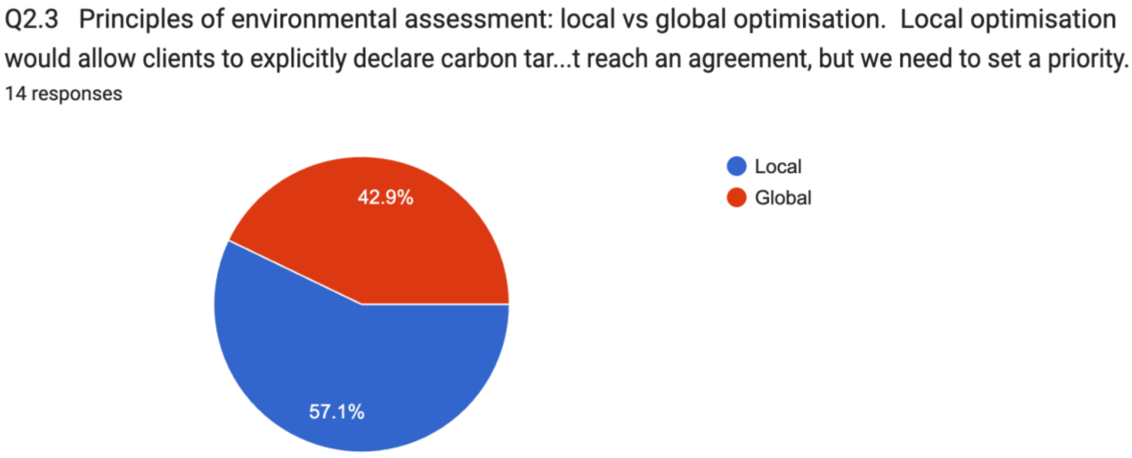

FIGURE 11: LOCAL VS GLOBAL OPTIMIZATION

The valid arguments on both sides also reflected in the answers to our poll: unlike the previous questions, opinions are quite divided on whether to optimise locally or globally, with 57% (8/14 answers) arguing for a local optimisation and 43% (6/14) for a global one. Some of the arguments brought in favour of the local paradigm were more pragmatic:

- “Local should simplify the way to optimise.”
- “As starting phase, as global optimization seems more difficult.”
- “Local optimisations may have faster outcome or give a first hint before enlarging the scope.”
- “Let's start with a simpler problem first.”,

while others were rather conceptual in nature:

- “When picking a provider my goals should be taken into account. Global goals may conflict with my goals.”
- “In decentralised systems local behaviour drives emergent and global behaviour.”
- “Local optimisation is coherent with a "decentralised and collaborative" approach.”

While some partners believe the local optimisation would be the simpler paradigm, others on the contrary argue that the global paradigm would be more straightforward to implement:

- “The global optimisation problem seems to be more straightforward to design and implement.”
- “Easier implementation.”

Another pragmatic argument in favour of t global optimisation is the following:

- “To further differentiate from the competition, regardless of the lack of quality data.”

There are, however, also important conceptual arguments in favour of the global paradigm:

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- "Carbon/environment is a global issue, global solutions/perspective is better."
- "I think that this should mainly be the responsibility of providers (and not users), and given the privileged position they have in the architecture, we should go for the ambitious goal to do this globally."

Perhaps the most differentiated and thought-provoking answer, raising an important argument that we had not considered beforehand, was the following:

- "I am not sure this answer should be given considering the environmental parameters only. The global optimisation problem seems to be more straightforward to design and implement, but would a customer be happy with an optimisation algorithm that considers the financial aspect as a constraint rather than an optimisation variable?"

Given these dilemmas, the solid arguments on both sides, and the far-reaching implications of this decision, we postpone this decision for the start of 2023, and will reach the final decision either at the next FLUIDOS plenary meeting or organise an online workshop dedicated to this topic exclusively.

3.2 CONTEXT AND CHALLENGES OF THE ASSESSMENT

Much more than most other economic domains, the ICT sector is characterised by a vast heterogeneity of devices, functions they perform, and domains they influence. Moreover, the sector is particularly dynamic and defined by continuous efficiency improvements, permanent paradigm shifts, and constant emergence of new classes of devices. This dynamicity implies that parts of the sector are also particularly short-lived, leading to numerous effects, among them quite diverging different lifespans of the various (categories of) devices. All these reasons define the context in which the environmental impact assessment of FLUIDOS will be performed, and bring about various challenges, which are presented in this section.

3.2.1 Defining a Functional Unit for the LCA

At the core of any LCA lies the functional unit (FU), which provides the reference to which all other data in the assessment are normalised (Weidema, Wenzel, Petersen, & Hansen, 2004) In particular, the FU provides a reference to which input and output data are normalised in the mathematical sense (ISO 14044). As its name already suggests, the FU should relate rather to the function a product fulfils rather than the product itself. This means, for example, "seating support for one person working at a computer for one year" rather than "one computer workstation chair" (Weidema, Wenzel, Petersen, & Hansen, 2004).

While defining an FU can often be quite a straightforward task, for the computing domain it is often challenging due to i) the broad heterogeneity of devices, ii) the quick dynamics of the field, iii) the intricate interplay of hardware and software, and iv) the complexity of functions performed by IT services. Moore's law, for example, which states that the number of transistors on electronic components doubles about every two years, has held roughly true for the last 50 years or so, making today's computers infinitely more powerful than those a couple of decades ago.

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The complexity of computations, however, did not stay constant over this time - otherwise today, we would perform the computations of the 1960s in virtually zero time and spending zero energy. We do no longer, however, perform the computations of the 1960s. Instead, the complexity of computations has kept up with the ever more efficient hardware, gaining in complexity and entering ever more (and in the meanwhile virtually all) domains of our societies and economies. In this context, defining a FU as the number of computations (such as 1 Teraflop, for example), while nominally fulfilling the "functionality" criterion, might not catch its essence. It has thus been argued in the past that for ICT devices and services, it should not be the functionality that the FU normalises, but the (dynamic and evolving) "typical product" - such as the latest generation of Intel processors, for example (Deng & Williams, 2011).

Solving this dilemma and proposing a meaningful FU will be one of the challenges that WP6 will need to address. As any operating system (and much more so an operating system aimed at cloud and edge computing), FLUIDOS offers a large variety of functionality. The complexity and heterogeneity of this functionality will not make this task easier, and defining one generic functional unit (or even a small and manageable set of FUs) will be one of the challenges in defining a cost-effective and energy-aware infrastructure.

3.2.2 Meaningfully Distributing the Production Phase

During the decision process for determining the least energy and GWP intensive time and place for computation, the following factors for environmental sustainability are considered: i) the current energy consumption of the available devices, ii) the environmental sustainability of energy sources measured by the GWP, iii) the energy consumption of the production phase and iv) the GWP of the production phase.

The ultimate environmental goal of FLUIDOS is the carbon-aware load distribution. In order to minimise overall GWP, FLUIDOS will distribute computing loads in a GHG-minimising way, as long as all other constraints are fulfilled. In this context, taking into account the production phase of devices introduces new challenges: Due to the severe ex-ante uncertainty about the lifespan of ICT devices (which might already fail or be decommissioned tomorrow), a conservative approach would distribute the production impact to the undisputed computation cycles, i.e., those that existed so far. In this paradigm, however, the impacts of new devices would be spread over very few cycles, resulting in a high environmental impact per cycle. Older devices would have a relatively low environmental impact per computation task, as their production impacts would be spread over many, already fulfilled tasks. This would induce a strong and undesired bias towards the usage of old devices. As a result, newer products would be underutilised, subsequently preventing efficient overall use. A less conservative approach is thus needed, one to strike a balance between the lifespan-related uncertainty and the need to consider an expected lifespan nevertheless.

For that reason, the flows calculated for the production phase need to be divided by the expected computation tasks a device will solve. Because the devices utilised for FLUIDOS are in their use phase, it is necessary to make an assessment of the expected number of computation cycles per device. As a result, to make this assessment, different characteristics of the devices need to be known, as well as typical lifespans of similar devices. This possible solution poses challenges that need to be taken into account during the preparation and implementation of the life cycle assessment.

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Firstly, the use phase of computing devices differs drastically between the type of device. While consumer electronics such as smartphones and tablets have relatively short average lifespans of a few years, the average data centre has a lifetime of over a decade (Mars, Nafe, & Linnell, 2016; Whitehead, Andrews, & Shah, 2015) . Additionally, the average use phase, especially in consumer electronics differs between brands (Makov, Fishman, Chertow, & Blass, 2019) . For that reason, the percentage of used resources and emissions allocated to the FU has to be adapted for each device.

Secondly, the distribution of the GWP among the different life cycle stages, especially the production phase and use phase, differs drastically between categories of devices. While tablets and laptops have the highest share of GWP in the production phase, this distribution changes for PCs, and for servers and data storage units the production phase constitutes a small percentage of the overall GWP (Hilty & Aebischer, 2015; Grobe, 2022) . Hence, the importance of the production phase diverges between types of devices while determining the least GWP-intensive computation.

Thirdly, due to the fast pace of development in the ICT sector, the energy efficiency of devices is improving over the years. In particular, the energy efficiency of servers and data storage units has developed rapidly over the last decades and is expected to increase further over time, as described by Koomey's Law s (Koomey, Berard, Sanchez, & Wong, 2011) . The GWP of servers and data storage units consists mainly of the energy consumption during the use phase, which accounts for 80-95% of the total GWP, which includes all life cycle stages (Grobe, 2022) . Due to the effects described above, the LCA must take into account that the replacement of existing hardware that is still functional might be more favourable in terms of GWP than continued operation.

3.2.3 Data Availability, Quality, Comparability, and Acquisition

Poor data availability and quality is a well-known problem in the field of environmental assessments of ICT devices. Main reasons are the sheer variety of devices coupled with the high dynamics of the field, but also the fact that several relevant parameters represent sensitive business information that IT and telecom companies are wary of sharing (for example the total energy consumption or the average load of data centres).

The FLUIDOS optimisation algorithm will have to deal with the poor availability and quality through a combination of data acquisition strategies, identification of suitable data sources, heuristics, and assumptions. For the momentary carbon intensity of electricity (i.e., kWh/GB) deployed in the optimisation, a decision will need to be taken whether location-based (defined by the momentary electricity mix of the region) or a market-based (i.e., taking into account possible power-purchasing agreements of renewable electricity for each FLUIDOS node) approach will be used, or perhaps both optimisation approaches to be developed, as to easily switch the optimisation among the two.

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4 BUSINESS MODELS FOR FLUID COMPUTING

4.1 SUSTAINABLE BUSINESS MODELS FOR FLUIDOS

The original Business Model Canvas by Osterwalder serves to visualize and analyze business models (Osterwalder & Pigneur, 2011). It is a widely used tool to characte rize new business models of innovations and startups.

It consists of nine business model segments. The Business Model Canvas is a practical tool that promotes understanding, discussion, creativity, and analysis. It allows discussing the future business environment already in early development stages of a new innovation in order to create a common understanding in a development team and to lay a foundation for a later market launch at an early stage. Using pre-defined key questions for each segment, a discussion can be led to fill out the Canvas in a workshop.

Based on the method of Osterwalder & Pigneur (2011), the Borderstep Institute created an adapted Sustainable Business Model Canvas (Tiemann, Fichter, & Hain, 2016), which also defines sustainability-related key questions for each segment.

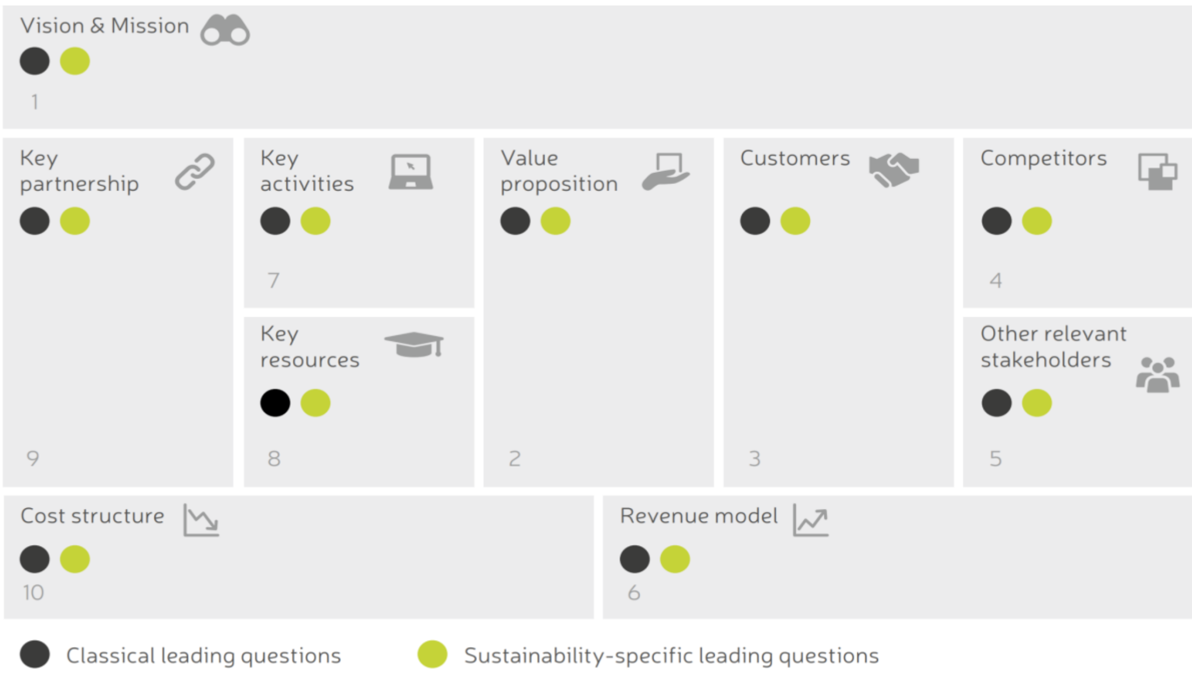

FIGURE 12: THE SUSTAINABLE BUSINESS MODEL CANVAS BASED ON (TIEMANN, FICHTER, & HAIN, 2016).

This Sustainable Business Canvas serves as a foundation for the systematic development of sustainability-oriented business models in the context of an interactive workshop. A manual, developed at the Borderstep Institute, provides guidance for conducting such workshops (Tiemann,

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Fichter, & Hain, 2016) . The workshop concept was tested and optimized over many years at the Borderstep Institute and its partners.

For FLUIDOS, which currently is a research project at a very early stage (TRL <5) first discussions are needed to describe potential roles and the basic structure of a potential business model for a future market uptake . Therefore, in task 1.3, a workshop was planned to discuss and develop a sustainable business model. The goal of this workshop was to ensure that the project partners

- are made aware of sustainability issues connected to FLUIDOS,
- get a more unified image of the actors and their roles in a FLUIDOS ecosystem and some fundamental business characteristics of FLUIDOS (like pricing models),
- carry out some discussions in the workshop, that are fundamental for the governance of the FLUIDOS research project (e.g. understanding different perspectives of project partners and planning further development),
- learn a methodology which they can apply independently in the future to elaborate sustainable business models in a systematic and structured way.

4.2 WORKSHOP ON BUSINESS MODELS - PREPARATION

According to the description of FLUIDOS in the research proposal as well as the discussions at the kick-off meeting, different actors can be defined for FLUIDOS. In a first internal survey (see here), the relevance of the different actors was examined in order to define from which perspectives business models for FLUIDOS should be discussed. As one result, the infrastructure provider was ranked at the highest importance.

Besides the prioritization, the survey also asked which type of (traditional) business actor could provide the FLUIDOS infrastructure. Options were:

- Traditional business for(self-operated) internal IT-services
- Specific IT Service providers for selling SaaS-products
- Cloud providers
- Network operators
- Natural persons

Also, requirements of potential users of the IaaS Services from FLUIDOS and potential payment models were ranked in the survey.

For the workshop in FLUIDOS, which happened quite early in the project, only some segments of the sustainable business model had been filled out, to have a more focussed discussion on these more fundamental parts:

- Vision & Mission
- Customers

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- Other relevant Stakeholder
- Value proposition
- Cost structure
- Revenue model

For the project-internal workshop, which was hold online on November 9th, 2022, a short presentation with the results of the study and an introduction to business model canvas methodology was prepared.

The actual workshop sessions were conducted on a Miro board, where participants could write notes for the various questions and to discuss them. For two important topics, the value proposition and the stakeholders, a voting will be conducted to find the most significant features that provide value to FLUIDOS and to prioritize the stakeholders. The canvas will be filled from the perspective of the infrastructure provider, which was considered the most important actor for FLUIDOS in the previously conducted survey.

4.3 RESULTS OF THE WORKSHOP

All results of the workshop are documented in the Miro board (Link: https://miro.com/app/board/uXjVPHwB3xo=/?share_link_id=462237601864)

Here, a brief summary and evaluation of the results are presented:

The guiding question for the Mission were: What mission do we pursue with FLUIDOS, taking sustainability principles into account? By which values is FLUIDOS determined?

Hereby, many different mission targets were named. A post-workshop draft consolidation (to be approved by the consortium) could look as follows:

"To build a cross-platform meta OS by tapping distributed computing resources, aggregate them and provide a computing infrastructure that creates a seamless edge-cloud computing-continuum, without compromising privacy. Building on underutilized spare ICT resources, FLUIDOS will be more cost- and resource-efficient than existing other approaches."

4.3.1 Long term goals

For the Vision, the guiding question was: "Describe your vision briefly and comprehensibly, taking sustainability principles into account: What long-term goal determines the direction for FLUIDOS?"

Hereby, very different aspects were put forward. They are present in Figure 13:

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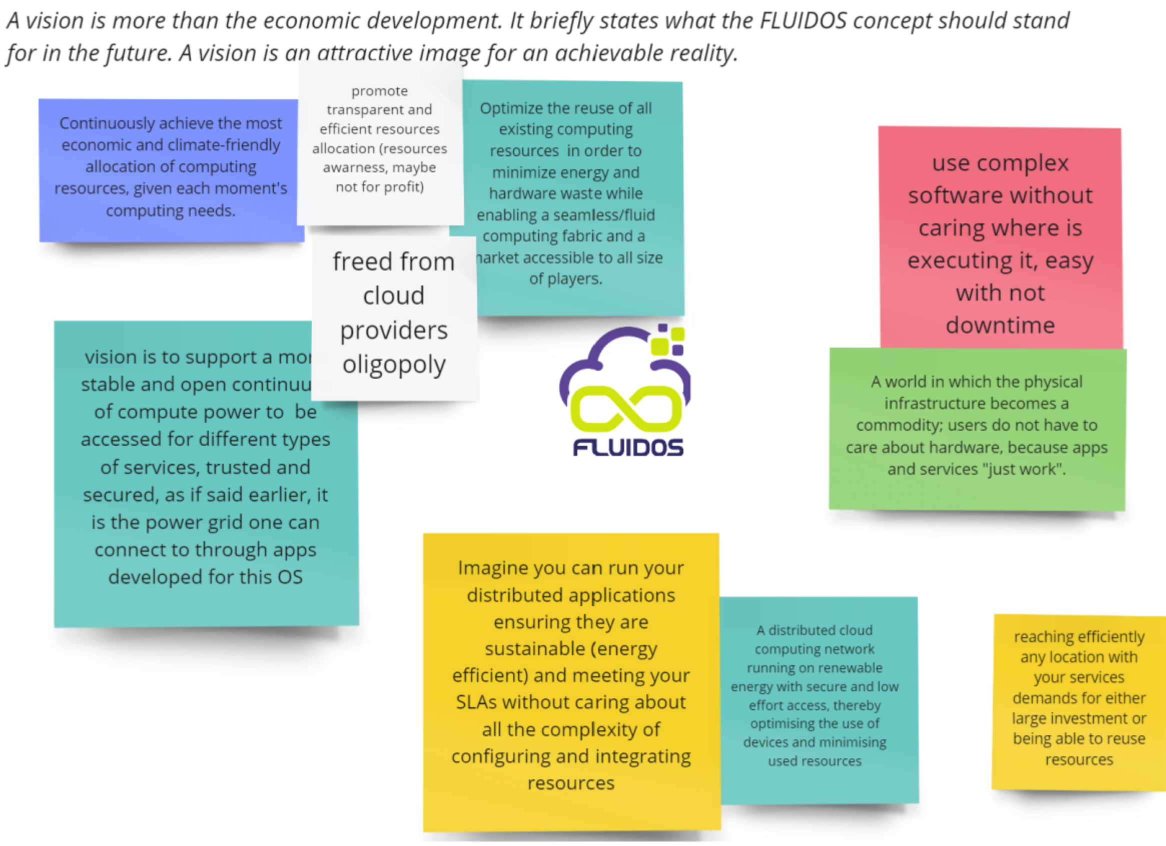

FIGURE 13: VISION STATEMENTS OF THE PARTICIPANTS

Several points are made in the vision. They can be broken down into these three overarching points:

- The detachment of the physical infrastructure and the applications running on it (and a borderless edge-cloud continuum).
- A system that provides both security
- Transparent and efficient cloud infrastructure for climate protection and higher security

4.3.2 Potential customers for FLUIDOS

In the next part of the workshop, the customer of the FLUIDOS infrastructure is discussed:

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FIGURE 14: THE CUSTOMERS OF FLUIDOS AND THE IMPORTANCE OF SUSTAINABILITY FROM THEIR PERSPECTIVE

Very different customers and application areas have been proposed for FLUIDOS:

A) Users of special applications for:

- Distributed ML training
- IoT customers with performance needs
- Robotic fleets
- Manufacturing, smart building, mobility services
- Smart city
- Critical distributed applications with high availability and reliability requirements
- Network of CCTV cameras that individually have limited capacity but collectively are capable of supporting sophisticated AI applications.
- Multi-tenant business (ports, airports, railways)
- Industry and logistics

B) Customers for FLUIDOS software:

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- Infrastructure operators as users of FLUIDOS software who want to establish a continuum between their clusters (edge/cloud).
- End users who want to define computing and storage capacity as a commodity

The reasons why sustainability might be important for these customers were also discussed at the workshop. The most important reasons are:

- Avoiding unsustainable business practices such as fossil fuel-based crypto-mining.
- For efficiency reasons, by making better use of existing resources to avoid costs
- Longer device lifetimes as capacities (CPU/Memory) are no longer limited to one physical device alone (waste avoidance and resource savings)
- The companies' employees see this as important
- For marketing reasons as well as pressure from society and other customers.

4.3.3 Stakeholders

A further topic to be discussed in business models are stakeholders (besides customers), that are relevant for the success of a business idea.

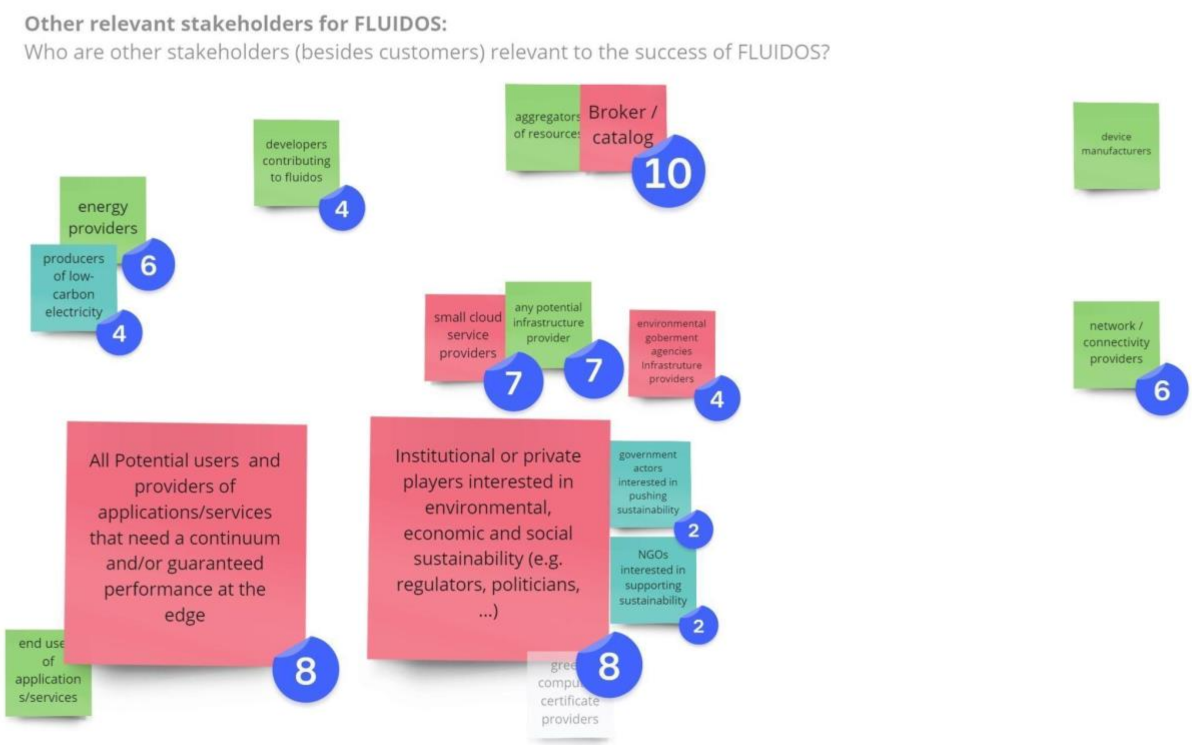

FIGURE 15: FURTHER STAKEHOLDERS FOR FLUIDOS

The stakeholders mentioned in the workshop can be divided into the following groups:

- Aggregators
- Network and cloud providers

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- Energy suppliers (low carbon)
- Developers
- ICT device manufacturers
- Various sustainability agencies (Governmental and NGO)
- Users + Providers of XaaS at the edge

For the stakeholders, a voting was conducted to rank the importance of the stakeholders against each other. Each participant could use up to 10 votes and distribute/accumulate those votes freely. As there were many similar suggestions of stakeholders, the sticky notes are grouped (Figure 15) and the votes on the sticky notes are combined. The groups are:

1. Energy providers (low carbon) - 10 votes
2. Developers - 4 votes
3. Aggregator/broker/catalog - 10 votes
4. Cloud service/infrastructure provider - 14 votes
5. Potential end-users of the service - 8 votes
6. Environmental actors (private/institutional/governmental) - 12 votes

As one note had two types "environmental government agencies, infrastructure providers"; those votes are split up 50:50 in the two categories.

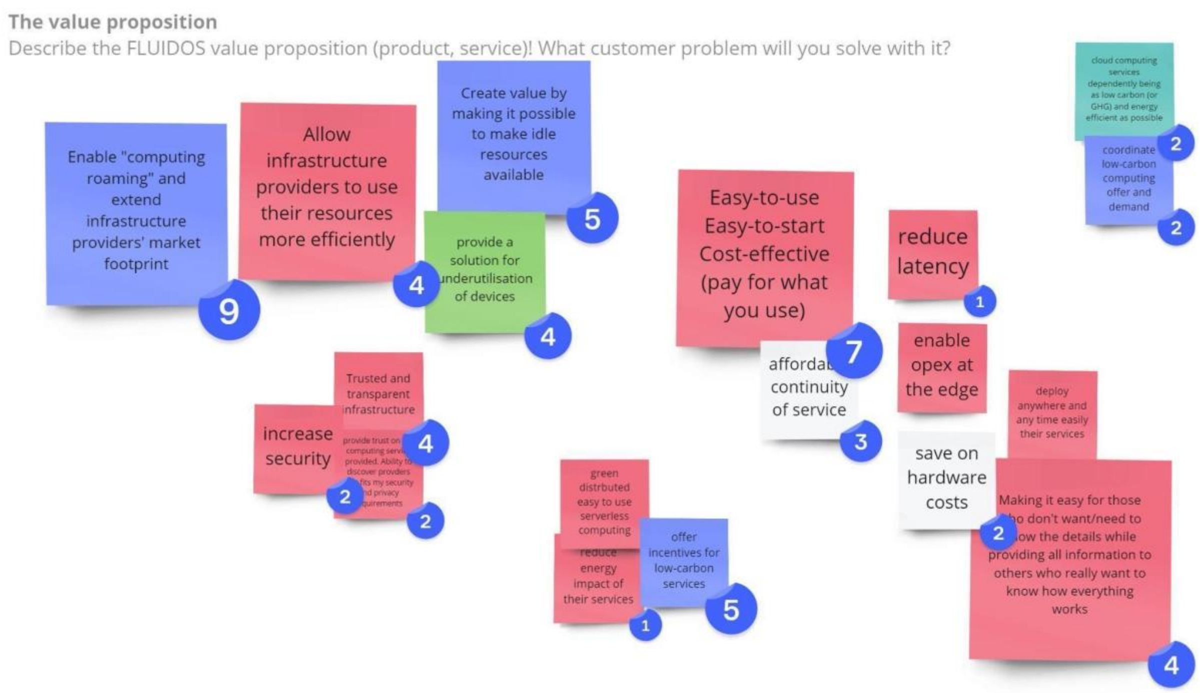

FIGURE 16: THE VALUE OF PROPOSITION

Based on the customers and the stakeholders, in the next step the value proposition was discussed. For this, the participants should put themselves in the role of one or more customers and take on their

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perspective. The aim was to describe which customer problem FLUIDOS can solve and which value proposition is relevant.

In the last step of the workshop, the revenue model was discussed. The participants basically have very different ideas about revenue. The ideas include:

- Profitability through reduced costs in infrastructure management
- Free model (e.g. provided by the government)
- Different models (light and heavy)
- Revenue dependent on environmental benefits

As payment models, the two variants pay-per-use and resource exchange were proposed.

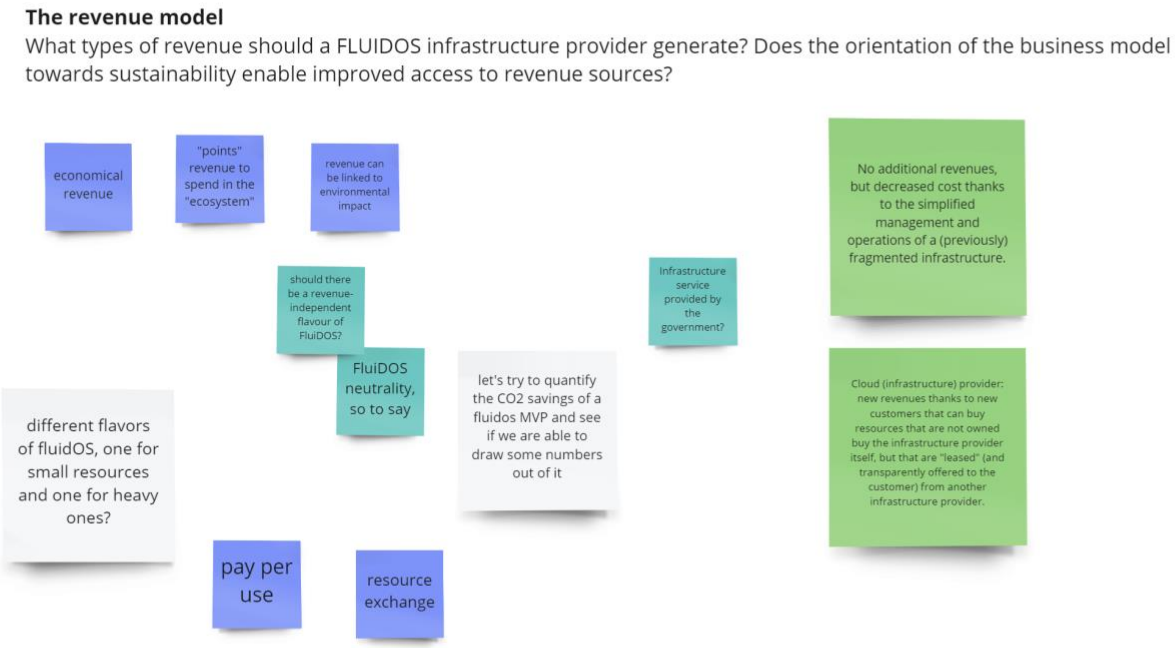

FIGURE 17: THE REVENUE MODEL

These results represent the current state of the business models in FLUIDOS. They should be used for further discussions on the business model of the other actors (e.g. aggregator and developer) and to build business models for concrete use cases.

4.3.4 Participants to the workshop

- **Fulvio Risso,** Technical University of Turin
- **Federico Michele Facca** from Martel Innovate, a digital innovation agency
- **Antonio Skarmenta,** Universityof Murcia
- **Yacine Felk** from CYSEC, a data security company
- **Chiara Bergeretti** from TOP-IX Consortium, technological innovation
- **Lorenzo Moro** from TOP-IX Consortium, technological innovation

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- **Eugenia Kypriotis** from Martel Innovate, a digital innovation agency
- **James Philpot** from European DIGITAL SME Alliance
- **Ángel Soriano** from Robotnik, a robotic company
- **Vlad Coroama**, Technical University of Berlin
- **Lily Hinkers**, Technical University of Berlin
- **Marco Zambianco** from Fondazione Bruno Kessler – FBK, a research institute
- **Leonardo Camiciotti** from TOP-IX Consortium, technological innovation
- **Andrea Cazzaniga** from Ricerca Sistema Energetico, a research company
- **Simon Hinterholzer** from Borderstep research institute

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5 CONCLUSIONS

This document discussed the need for a governance model for the FLUIDOS-like decentralized and multi-stakeholder infrastructure ecosystem. The governing principles need to ensure a balanced benefit for all stakeholders while being economically and environmentally sustainable. In this document we explored different options for sustainable models for decentralized computing and business models for fluid computing while defining the core principles for FLUIDOS Governance. The methodology used involves an online survey and a co-design workshop with project partners. The survey highlights the key stakeholders, principles, environmental sustainability, and business models that need to be considered for FLUIDOS governance. The workshop enriches the investigation and results in key points about the mission and values of FLUIDOS.

We also discussed the environmental optimization principles that should be considered by FLUIDOS to reduce energy consumption and greenhouse-gas emissions through a carbon-aware computing model and a better utilization rate of available devices. Our discussion considered a life-cycle assessment (LCA) for the determination of GHG emissions, which covers the production and use phases of devices employed in FLUIDOS. The LCA considers the emissions and resources used along all life stages of a product and assigns them to an impact category. The impact category focused on in FLUIDOS is the Global Warming Potential over 100 years (GWP-100). Further, we highlighted the challenges involved in conducting a complete life-cycle assessment. The Information and Communication Technology (ICT) sector is diverse and dynamic, making environmental impact assessment challenging. Defining a functional unit (FU), which relates to the function a product fulfils rather than the product itself, can be challenging in the computing domain due to the broad heterogeneity of devices, quick dynamics of the field, intricate interplay of hardware and software, and complexity of functions performed by IT services. Another challenge is to meaningfully distribute the production phase, considering the expected lifespan of devices and the need to consider a balance between lifespan-related uncertainty and the need to use newer products efficiently. The challenge is to assess the expected number of computation cycles per device, which differs drastically between device types. Finally, the principles and governance will be formalized in version 2 of this deliverable after interaction with external and internal stakeholders.

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