Sustainable Edge Computing

A vision for the future of edge computing in Flanders and the EU

Target audience: Flemish government 2024-2028 decision makers[1]

1. Introduction

Technological choices often go back and forth before they find an equilibrium. We're experiencing these shifts right now in the domain of compute. The 2000s and 2010s have seen a shift towards compute centralization through cloud computing. While cloud computing has important economies of scale, it also introduces challenges such as data centralization and hence privacy issues, consolidation of large technological players and unacceptable reaction times for imminent applications such as AR/VR and AGV.

While cloud computing is clearly plateauing, driven by a unique combination of rise in AI popularity but concerns about sustainability, **edge computing is expected to be the next technological wave coming at us**. Edge computing is a paradigm that enables data processing and storage at the edge of the network, closer to the sources and consumers of data. This can reduce latency, bandwidth consumption, and privacy risks, as well as enable new applications and services that require real-time, context-aware, and distributed intelligence. Edge computing can offer several benefits for different use cases and domains. Edge computing can also support the decentralization and democratization of data and computation, empowering end-users and local communities.

Given the importance of edge computing, the EU has recently presented important edge ambitions. **In the EU's digital decade objectives for 2030, 10.000 climate neutral edge nodes are being proposed.** This focus on climate neutrality is a crucial one and will **make or break this new wave**: cloud computing is able to use energy more efficiently as it can be placed closer to large renewable energy sources (e.g., water dams, large solar installations). **If edge computing wants to live up to its promises (enabling new applications, providing real data sovereignty and privacy in the face of AI), it will need to be sustainable**, ensuring that it can run climate-free despite of its decentralized deployment and use of energy-consuming AI workloads.

Flanders is very well equipped to be leading in the domain of sustainable edge computing for several reasons:

- It's **dense deployment** and strong connectivity backbone ensures that it's a perfect location for deploying a large part of edge nodes.
- Flanders has **leading industry** that will be the first sectors that will benefit from such edge computing nodes: biotechnology, manufacturing, entertainment. All sectors which need high computational loads but also require low latencies.

- Flanders has invested strongly in the **innovation components** which will make a sustainable edge computing paradigm a reality: data technology (Athumi, Digitaal Vlaanderen, Flemish Smart Data Space), semiconductors (IMEC) and AI (Flemish AI program).

However, just putting the puzzle pieces together is not sufficient. There's a **need for an ambitious edge computing program which puts the climate free nature of edge computation as number 1 priority,** and which strikes a balance between rapid innovation and use for local industry. Therefore, Flanders must create and maintain a balanced and sustainable edge computing organizational ecosystem, involving multiple actors and stakeholders with varying roles, interests, and incentives, in the public, the private and the research sectors. Ensuring the ethical and legal compliance of these solutions is paramount.

A recent study was performed by KPMG on the opportunities of edge computing for Flanders, titled "Edge is the new cloud". The study situates the edge compute innovation landscape and its associated challenges and opportunities. In this document, which complements the KPMG study, we discuss an even more **focused approach to sustainable edge compute innovation.**

2. Flemish and EU context on sustainable edge computing

Edge computing is expected to play a key role in the digital transformation of the EU, as it can support the goals of the European Green Deal, the Digital Strategy, and the EU's Data Strategy.

- The **EU's digital strategy** aims at the deployment of 10.000 climate free edge nodes but does not mention how these climate free ambitions can be reached. This is a challenge as edge compute will increasingly use AI models, which are energy intensive.
- The **EU Data Act**, a proposed regulation by the European Commission aims to create a fair data economy. The Data Act proposes measures to increase transparency and control over edge data sharing. Flanders shares the objective of the EU to support data sovereignty and has indicated through its own data strategy and initiatives such as Athumi and the Flemish Smart Data Space (FSDS), which aim to better protect personal privacy.
- The **European Green Deal** puts strong ambition levels to our carbon emissions generally and energy usage specifically. Novel technological paradigms must be driven by a need for sustainability. Tapping into local renewable energy sources, as featured in edge computing, will be critical for this.

Summarized, the EU and Flanders aim to foster a competitive and innovative edge computing ecosystem that respects its values and principles. **While all these activities advocate for a stronger investment in edge computing, addressing them in isolation risks that the joint ambitions cannot be reached.** To overcome this, the union, its member states and regions need to invest in comprehensive sustainable edge compute research and innovation program. This program must focus on building the right infrastructure and connectivity, skills and education, standards and interoperability, regulation and governance, collaboration, and coordination.

3. Application domains

The KPMG study "Edge is the new cloud" identified a wide range of application domains that are relevant for the EU in general and Flanders specifically:

- **Logistics**: If we are to create more efficient and effective freight flows, decarbonizing our economy, edge devices will need to be deployed to logistic assets like AGV's, containers, barges, trains or trucks. Indeed, localizing these assets and monitoring their state must be done locally, at the edge. Yet, this data can be highly sensitive.
- **Personal Mobility**: Our personal means of transportation are becoming increasingly digitized. Cars are often being portrayed as "sensors on wheels". Yet the way in which the – often very personal – car data is being stored and shared is currently very questionable.

 Use cases	Technische voordelen			Economische, ecologische & maatschappelijke voordelen		
	Reactiesnelheid	*Bandbreedte*	*Connectiviteit*	*Transparantie, controle, privacy & veiligheid*	*Innovatiecapaci-teit & gelijk speelveld*	*Ecologische voetafdruk*
Autonome voer- en vaartuigen	✓	✓	✓	✓		
Slimme steden / Smart Cities	✓	✓		✓	✓	✓
Health	✓			✓	✓	
Energie		✓		✓		✓
Smart home – Smart Living	✓	✓		✓	✓	✓
Smart Warehouse / Logistics		✓	✓	✓		
Cloud gaming	✓	✓	✓			
Manufacturing / Slimme fabrieken	✓		✓	✓	✓	
Onderwijs	✓	✓		✓		
Public safety / first responders	✓		✓	✓		

Figure 1 Edge computing and its advantages for several application domains, taken from the KPMG study "Edge is the new Cloud"

- **Smart cities and communities**: Edge computing can support urban planning, mobility, energy, environment, security, and public services, by enabling data-driven and context-aware solutions that leverage sensors, cameras, drones, vehicles, and other edge devices.
- **Healthcare**: Edge computing can improve health outcomes, quality of life, and access to care, by enabling remote monitoring, diagnosis, and treatment, as well as personalized and preventive medicine, based on wearable and implantable devices, smart home systems, and telemedicine platforms.
- **Agrifood**: Edge computing can enhance food security, safety, and quality, by enabling precision farming, smart irrigation, pest and disease detection, traceability, and waste reduction, based on drones, satellites, sensors, and smart packaging. Salient Flemish societal issues like nitrogen monitoring can be supported through edge compute.

- **Manufacturing and industry**: Edge computing can boost productivity, efficiency, and flexibility, by enabling smart factories, industrial internet of things, robotics, automation, and digital twins, based on sensors, actuators, machines, and edge servers.
- **Energy**: Edge computing can support the transition to a low-carbon and circular economy, by enabling smart grids, renewable energy sources, energy efficiency, and environmental monitoring, based on smart meters, microgrids, batteries, and sensors.

4. Technological edge computing concepts in scope

Edge computing is not a single technology, but a combination of several concepts and components that can be deployed and orchestrated in different ways, depending on the application requirements and the available resources. We believe that the general concepts of **data technology, (federated) machine learning and sustainable compute systems are essential to make sustainable edge computing a reality**. It's important to note that Flanders is leading in many of these technological building blocks: bringing them together can create a catalyst for further innovation.

- **Data technology** refers to the ability of individuals and organizations to control their data and make decisions about its use. Technological elements that would allow such data sovereignty include ***personal data vaults*** **such as SOLID and data spaces**. Equally important is data authenticity or the ability capacity to distinguish between data that has been created through synthetic means (e.g. generative AI) or data that has been created by a sensor. With the recently approved AI act, this will gain importance.
- Data sharing and control is only the first step. In this age of artificial intelligence, we can expect a rising need to deploy AI models on top of the data. **Federated and distribute machine learning** is a technological paradigm that assures that a centralized model can be learned, without requiring to centralize the data. Ss such, it supports data sovereignty at the edge.
- The above two technological paradigms will alleviate many of the cloud computing limitations such as increased latency and lack of data privacy. However, without any additional measures, this would result in an **unacceptable explosion of energy consumption**. The more we globally deploy edge devices, the more every watt we spend in excess will require the growth of the energy production capabilities. Especially when running computationally demanding machine learning paradigms such as federated learning or generative AI. **Sustainable compute systems** alleviate this by **scaling the application in function of the available (renewable) energy sources** instead of the other way around. This requires a modular compute system that is sometimes able to operate at kWatts level (when required and possible) but can equally scale down to mWatts level. Such elasticity can only be achieved by recent advancements in the semiconductor space such as in-memory computing, neuromorphic computing (which significantly reduce AI and data processing's energy consumption) and chiplets (which allow elastic scaling).

To realize a disruption, it's important to take a testbed approach. **Testbeds are necessary to allow the deployment and testing of edge devices at scale**. Indeed, it is only when doing so that it can be proven that the innovations work and that they can be tested to refine their design. Engineering in a closed

lab is a necessary first step, but increasing the TRL of technologies involves testing them in real-life, hence the need for real-life testbeds.

5. Recommendations for the support of Edge Computing

Flanders is well placed to take a leading role in the domain of sustainable edge computing. It holds a strong commercial ecosystem that can bring edge technology to the market in multiple domains (personal mobility, logistics, health, etc.). In addition, it holds a very competent research community, with the ability to develop the disruptive software and hardware breakthroughs that are necessary. We refer to the need to develop novel hardware technologies that allow new edge technologies to emerge. However, these new hardware paradigms should co-evolve with new and fit-for-purpose software techniques. Finally, Flanders can benefit from a strong and forward-looking public sector, which understands the future needs of its populace in terms of data sovereignty and authenticity at the edge and is especially concerned to see this supported by the appropriate innovations. By combing this triple helix of actors into a coherent program to support sustainable edge computing, Flanders will be able to make a strong global claim to increase its competitivity in the future market of edge compute. This document proposes recommendations to foster the development and adoption of edge computing solutions in Flanders, based on four strategic pillars.

- **Research and innovation** in a coherent sustainable edge computing program is needed that combines the above described technological building blocks (data technology, machine learning and sustainable compute systems). A strong emphasis needs to be put on ensuring that these solutions find their way into local industrial solutions as well.
- Sustainable edge computing requires a workforce, which combines strong knowledge in both hardware and software. This is globally often lacking. **Education and training** is required to develop and strengthen the skills and competencies of the current and future workforce and society in edge computing.
- **Policy and regulation** must be drafted to create and maintain a favorable and coherent policy and regulatory framework for edge computing. Especially the upcoming AI act, its focus on regulatory sandboxes to foster innovation should align with future edge computing ambitions.
- **Valorization and adoption** is paramount to accelerate and facilitate the valorization and adoption of edge computing solutions in different domains and sectors. As mentioned before, the testbed approach is paramount here: only by doing this at scale we're creating a playing field where local industry can tap into.

6. Relationship to ongoing programs and projects in Flanders

The **Flanders AI and cybersecurity research programs** are highly effective programs and internationally recognized research programs. They are focusing on many aspects that are of interest to the topic of data sovereignty and authenticity at the edge. However, they do not explicitly focus on these topics. We propose to supplement and further focus their efforts towards these issues through a supplementary edge program.

The **SOLID initiative** develops data technology concepts at scale, but takes a software only approach. This initiative takes the next wave and allows bringing SOLID to the edge, but putting sustainability as equally important driver.

The **Edge AI Testing and experimentation facility (TEF**), co-funded by the EU and the Flemish government, focusses in Flanders on the development on in-memory compute edge applications and allows companies and research organizations to benefit from the Testing and experimentation facilities on offer. Whereas this is highly relevant, in-memory compute it is but one paradigm that can be leveraged at the edge. We propose to establish strong collaboration with this program and to further extend its societal impact by aiming for societal uptake of high-TRL edge compute systems.

The **TEF for smart cities and communities on AI and Robotics**, also co-funded by the EU and Flanders, offers testing and experimentation facilities in Flanders for mobility applications. This project is not focused on edge compute applications yet can be used to test the new edge compute systems in real-world environments in the application domains of personal mobility and logistics.

7. Example
Your personal edge vault supporting a personalized LLM

An example of the application of the concepts that have been discussed above would be a personal edge vault that supports your very own personalized large language model (e.g., a personalized ChatGPT). Generative AI and ChatGPT, specifically, has taken the world by storm in 2023. While we've all seen the strong capabilities that these large language models (LLMs – the technology behind it) boast, there are also strong concerns behind these approaches:

- LLMs risk **data leakage**, even in the fully trained system. For example, Samsung has recently been the victim of this. After Samsung executives used confidential information to interact with ChatGPT, the confidential information was stored in ChatGPT and could be retrieved afterwards. Current (public) LLMs can therefore not be used with sensitive information.
- Current LLMs require strong data centralization, but from a privacy point of view this is not desirable. The ideal solution is a **personalized LLM, which has a lot of contextual information from me, but is only accessible by myself.**
- Training and fine-tuning LLMs are **extremely power hungry**. At this moment in time, this can only be done at the cloud level.

With the concept of sustainable edge computing, one could realize the vision of a personal edge vault that features a personalized digital assistant, with the same power of ChatGPT, but specifically tailored to the end user and his/her family. It would

- Enable individuals to **store and process their personal data locally on their own edge vault** or trusted edge nodes, rather than relying on centralized cloud servers or third-party intermediaries.

- Enable individuals to **leverage edge intelligence** to generate and analyze their personal data. As such, a personalized LLM can be built on top, which is heavily personalized, but which ensures that the data is not being shared with other players.
- Ensures that the (re-)training of such LLM can be executed locally, while ensuring a sustainability approach. Novel compute technology allows for **energy efficient AI training**. Moreover, sudden peaks in the availability of renewable energy sources (solar, wind), can generate a boost in the training process.

8. Relevance for Flemish companies

Strong support from Flemish companies is key to underline the valorisation potential of Edge computing. To assess this, we have gathered input from several key innovation players in the region. We have selected these parties according to their capacity to voice the interests of Flemish companies in the key commercial sectors in which we believe there is most potential for edge computing to be applied. Each organization has provided short statements to identify why a sustainable edge computing program would be important:

Agoria

" We stand at the cusp of a new era, one marked by the rise of the Data Economy. In this transformative landscape, our priority is to ensure that Flemish companies not only keep pace but actively participate and thrive. A defining feature of the Data Economy is the pronounced emphasis on decentralization. This shift extends beyond data itself and permeates into the very infrastructure that supports it. For years, the prevailing trend was centralization, with an increasing reliance on cloud platforms. Undoubtedly, this centralization significantly advanced the digitization of our industries.

Nonetheless, we currently witness a reevaluation of strategies among Flemish companies. They are increasingly turning their attention toward decentralized infrastructures, motivated by the need for digital sovereignty and the imperative for real-time actions at the network's edge.
This is precisely where the concept of 'edge' comes into play. Agoria firmly believes that the edge represents the solution to the current challenges our members face relating to digital infrastructure. As the federation for the Belgian technology industry, our unique position allows us to view the edge from both the supply and usage sides, revealing a multitude of opportunities for Flemish companies.

For those on the usage side, the edge promises to furnish the future infrastructure needed to actively partake in the Data Economy. Meanwhile, for those on the supply side, the edge opens doors to deeper involvement in the evolving infrastructure ecosystem that is taking shape in Flemish and European contexts.

As Agoria, we wholeheartedly endorse the imperative for Flanders to concentrate its efforts on the edge. Establishing a coherent vision and a collaborative community focused on this topic is nothing short of essential if we are to craft a success story out of this emerging infrastructure. In doing so, we aim to empower Flemish companies to not only participate in but also shape the Data Economy."

Voka

" Challenges related to sustainability, privacy, safety and reliability put a significant pressure on how companies can source, store, transfer and analyze data. The European Data Act further increases this pressure by introducing additional obligations on the transferability of data. Edge computing offers multiple benefits to adequately counter these challenges. Edge computing however comes along with several hardware and software requirements that need to be overcome. Fortunately, we have already extensive research expertise on edge computing in Flanders. However in order to really increase adoption and implementation by companies in Flanders and to seize the full potential of edqe computing, it is important to further capitalize on existing expertise and foster coordination, consolidation, and valorization across the entire value chain."

VIL

"Logistics is becoming ever more digitized and automated. Numerous applications rely on monitoring, vision, image recognition and sensor fusion technologies, amongst others … all of these require considerable computing power as well as high-performing network connections, which are often not available in real-life yard or warehouse environments.

Local data processing via edge computing is therefore an essential enabler to further automate logistics and transportation, in areas as diverse as Physical Internet, hyperloop, autonomous driving and asset state monitoring: moreover it enhances the trust of stakeholders, including SMEs, by allowing to carefully manage the sovereignty of data generated locally. Also, edge-computing will be a crucial component to support logistics concepts such as full sustainability visibility enabling individual stakeholder decision-making, dynamic eco-based last-mile control systems or the real-time dynamic adaptation of logistics networks."

MEDVIA

"MEDVIA, the healthtech spearhead cluster, is a dynamic, industry-driven membership organization based in Flanders. Our core mission is to stimulate healthtech innovations by fostering collaborations among companies, healthcare institutions, hospitals, research institutes & other key partners. Together we chart the course towards pioneering breakthroughs that can improve healthcare for all. MEDVIA . MEDVIA centers around digital technology, medical technology and biotechnology. The MEDVIA community wants to find innovative solutions in 4 focus fields: (i) digital medicine, (ii) personalized medicine, (iii) disruptive health solutions and (iv) value-based efficient healthcare. In addition, MEDVIA is coordinating an ecosystem wide action on health data in the patient journey.

It is evident that edge computing will gain more and more importance in the healthcare domain. Some examples. Healthcare will move more and more from a hospital setting to an extra muros setting, increasing remote monitoring and hence, increasing the use of edge computing. Healthcare will become more personalized and preventive, which is anchored in wearable and implantable devices. This once more emphasizes the importance of edge computing.

As MEDVIA members are both technology providers as technology end-users, it is evident that edge computing is important to the MEDVIA members. "

Flux50

Flux50 is the membership organization that helps Flanders gain international recognition as a Smart Energy Region. Flux50 facilitates cross-sector collaboration between energy, IT and building companies to enhance the competitiveness of the Flemish smart energy industry in the transition towards low carbon systems. A smart energy system needs an automated and highly monitored power system, ensuring a bidirectional flow of information between energy producers and end users and allowing for real-time transactions. Edge computing can support the smart grid by improving data processing efficiency and reducing time delays. This is for example relevant for distribution grid operators, who are transforming into active system managers that need advanced monitoring and control systems for faster and safer data processing and storing and better operation of their grids. It is also relevant for private and commercial prosumers and communities, offering flexibility and grid services for different service providers on the electricity markets. Data privacy and sovereignty are crucial for uptake and roll-out of these solutions. Technology providers need to develop smart meter appliances with higher efficiencies and less energy losses to make business models for consumers worthwhile. For many other stakeholders, such as technical installers and building companies, it is important to be aware of technological evolutions and to be prepared for changes in legislation. Finally, also in the off-shore wind sector, hybrid energy parks can benefit of edge computing to reduce far distance data communication and enhance security. Therefore, for Flux50 members, from the research side but also SMEs and industry, end users and policy makers, it is relevant to explore and test new possibilities in edge computing and to exchange knowledge trough learning networks, working groups, projects tracks from lower to higher TRL levels, living labs and larger dissemination events.

9. Conclusion

In conclusion, **sustainable edge computing is a paradigm that offers numerous benefits, including reduced latency, bandwidth consumption, and privacy risks, but addresses the energy consumption challenges when deployed naively.** With its unique combination of strengths in both semiconductors and data technology, Flanders is well-positioned to take a leading role in the domain of sustainable edge computing, with a strong commercial ecosystem, competent research community, and forward-looking public sector.

To foster the development and adoption of edge computing solutions in Flanders, a balanced and sustainable edge computing organizational program must be created, involving multiple actors and stakeholders in the public, private, and research sectors. This can be achieved through investment in research and innovation, education and training, policy and regulation, and valorization. By combining these efforts, **Flanders can make a strong global claim to increase its competitiveness in the future market of sustainable edge computing.**