Green Technologies for
5/6G Service-Based Architecture

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Final Design and Specification of Vertical Application Orchestration within the 5/6G Green Economy

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Glossary of terms and abbreviations used

Abbreviation / Term	Description
3GPP	3rd Generation Partnership Project
5QI	5G QoS Identifier
6G-IA	6G Smart Networks and Services Industry Association
AF	Application Function
AI	Artificial Intelligence
API	Application Programming Interface
BEREC	Body of European Regulators for Electronic Communications
BSS	Business Support System
BSSF	BSS Function
CO2e	Carbon Dioxide Equivalents
CPU	Central Processing Unit
CSRD	Corporate Sustainability Reporting Directive
DLA	Decarbonisation Level Agreement
EC	Energy Consumption
EdgeMF	Edge-cloud Management Function
EE	Energy Efficiency
eMBB	Enhanced Mobile Broadband
ENIF	Experiential Networked Intelligence Function
ETS	Emissions Trading System
EU	European Union
FPGA	Field Programmable Gate Array
G20	Group of 20
GHG	Greenhouse Gas
GPU	Graphics Processing Unit
GSMA	Global System for Mobile Communications Association
GST	Generic Network Slice Template
GUI	Graphical User Interface
GWP	Global Warming Potential
ICT	Information and Communications Technology
IDAF	Infrastructure Data Analytics Function
I/O	Input/Output

Abbreviation / Term	Description
IoT	Internet of Things
IT	Information Technology
JSON	JavaScript Object Notation
KPI	Key Performance Indicator
kWh	Kilowatt-hour
MDAF	Management Data Analytics Function
MILP	Mixed Integer Linear Programming
mMTC	Massive Machine-Type Communications
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
NF	Network Function
NG-RAN	Next Generation Radio Access Network
NRA	National Regulatory Authorities
NSMF	Network Slice Management Function
NSSRG	Network Slice Simultaneous Registration Group
NWDAF	Network Data Analytics Function
OSS	Operations Support System
OTT	Over-The-Top
OWL2	Web Ontology Language
PCF	Policy Control Function
PDU	Packet Data Unit
PoP	Point-of-Presence
QoS	Quality of Service
QCI	QoS Class Identifiers
RAM	Random-Access Memory
RAN	Radio Access Network
R&D	Research & Development
SBA	Service-Based Architecture
SDG	Sustainable Development Goal
SLA	Service Level Agreement
SLO	Service Level Objective
SME	Small- and Medium-sized Enterprises
SWOT	Strengths, Weaknesses, Opportunities and Threats

Abbreviation / Term	Description
UE	User Equipment
UN	United Nations
UPF	User Plane Function
URLLC	Ultra-Reliable and Low Latency Communications
VAO	Vertical Application Orchestrator
WAN	Wide Area Network

Executive Summary

The 6Green project aims to promote energy efficiency across the whole 5/6G value-chain by encouraging all stakeholders to actively reduce their carbon footprint. This deliverable reports the work done within Work Package 4, which targeted the enablement of a green 5G/6G economy through both business strategies and technological enablers.

The state of the art in terms of sustainability initiatives and specifications within the Information and Communications Technology (ICT) sector, as well as the related frameworks that can potentially facilitate a win-win 5/6G ecosystem, are used as bases for the formalisation of the Decarbonisation Level Agreement (DLA) concept. Going beyond the conventional Service Level Agreement (SLA), DLAs incorporate sustainability metrics and indicators, fully integrated in customers' vertical- and network-level requests, the so-called "intents". The 6Green Business Support System Function (BSSF) plays a central role in both intent management and facilitates (re-)negotiations between customers and providers. Moreover, an incentivisation framework is proposed to encourage upper-layer stakeholders to adopt resource-as-a-Service models and leverage energy-aware capabilities, thereby enhancing energy savings across the value chain.

This deliverable also presents a set of refined Green Business Models, developed through Lean Canvas and SWOT (Strengths, Weaknesses, Opportunities and Threats) analyses. The 6Green Lean Canvas template was completed by consortium partners, with a good representation of the different types of organisations. The evolution of these models highlights that sustainability in 5/6G ecosystems is a collaborative and adaptive process, rather than a standalone goal.

At the Vertical Layer, 6Green's approach to vertical application orchestration covers the full lifecycle management of vertical applications and introduces advanced mechanisms for: (i) application-aware network orchestration, and (ii) bidirectional (re-)negotiation among 5G/6G stakeholders. This is enabled by the 6Green Vertical Application Orchestrator (VAO), which also acts as a trusted Application Function (AF) interfacing directly with the 6Green Service-Based Architecture (SBA) to support both application- and network-aware orchestration. Furthermore, the deliverable details the development of a policy architecture and data model, presenting a set of energy-aware Vertical Layer Policies designed to optimise resource usage and sustainability.

This deliverable is incremental to 6Green deliverable D4.1 (titled "Work-in-Progress: Design and Specification of Green Business Models and Runtime Policies for 5/6G Vertical Applications").

1 Introduction

Governments and international organisations such as the Group of 20 (G20), the United Nations (UN) and the European Union (EU) are setting ambitious targets to slow down global warming, establishing a framework for action to be carried out by industry and companies. In particular, the UN Agenda 2030 [1] has defined Sustainable Development Goals (SDGs), while the European Green Deal [2] provides a roadmap for the EU to achieve net-zero greenhouse gas (GHG) emissions by 2050. The latter's key goals by 2030 include:

- Reducing GHG emissions **by at least 40%** compared to 1990 levels
- Boosting the share of renewable energy **to at least 32%**
- Improving energy efficiency **by at least 32.5%**

These factors now play a pivotal role in shaping the sustainability targets and strategies for industries and companies for the years ahead.

The Information and Communications Technology (ICT) sector is responsible for 1.4% of global GHG emissions [3], but it holds the potential to help other industries reduce emissions by 15% by 2030 [4]. Moreover, 5/6G is postulated as a key technology to address climate change with significant potential to reduce carbon emissions in several critical industries. Based on the above-mentioned studies, it is estimated that current sustainability efforts already have the potential to reduce emissions in key sectors such as Transportation, Smart Cities, Manufacturing, Energy and Buildings by 15%, a figure that grows to 20% when the potential of 5G is taken into account.

While the potential benefits of 5/6G towards vertical industries are promising, there are key challenges. First, vertical industries need to have the necessary infrastructure (i.e., 5G-compatible devices, networks and software) in place to take advantage of the technology. Telecom operators must also provide the technology necessary for sustainable management of smart networks and ensure the availability of renewable energy sources to offset carbon emissions, which requires substantial capital investments. In this respect, near-term and long-term (net-zero) targets have already been defined by operators towards reducing the GHG emissions stemming from operations and power purchase, among other things [5]-[8].

Conversely, research suggests that while customers typically expect optimal service performance and often remain unaware of the associated energy consumption or carbon footprint, many show a willingness to make compromises once informed of these impacts [9][10]. Such findings can pave the way for service providers (at the infrastructure, network and application levels) to employ energy-aware service optimisation mechanisms, while considering any trade-offs between energy efficiency and Quality of Service (QoS). Nevertheless, the customer awareness and customer-provider (re-)negotiations are key towards enabling a green economy business.

The 6Green project aims to promote energy efficiency across the whole 5/6G value-chain by driving all the stakeholders (from the ones acting at the infrastructure and network platform to vertical industries and end-users) into carbon footprint reduction, as integral parts of a *win-win Green Economy*. The *Vertical Application Orchestration* and intent-based cross-domain interactions among 5/6G stakeholders will enable the achievement of a tight proportionality between the dynamic and geographically distributed workload produced by vertical applications and network slices, and the energy consumption/carbon footprint induced to the evolved network and computing infrastructure.

Three ground-breaking innovations represent the foundation of the 6Green vision. This deliverable touches upon all three paradigms, as illustrated in Figure 1. In more detail, vertical applications will be orchestrated considering: (i) *Edge Agility* operations such as vertical application placement/migration within the edge-cloud continuum triggered by users on the move, as well as performance and energy efficiency targets; and

(ii) *Green Elasticity* operations such as workload offloading depending on latency and energy budgets, allowing for joint optimizations; while (iii) *Energy-aware Backpressure* will make all the stakeholders aware of the footprint they induce, which will also become the bases not only for vertical application lifecycle management, but also for driving the cross-domain business support operations and (re-)negotiations.

Edge Agility

This provides smart, fast, and automated **horizontal scalability** to vertical application and related slices across the 5/6G edge-cloud continuum.

Green Elasticity

This dynamically and adaptively provide energy-aware hardware-assisted acceleration to network functions and vertical applications to enable smart **vertical scalability**.

Energy-aware Backpressure

This provides **cross-domain observability** mechanisms and analytics to evaluate the energy and carbon footprint induced by a vertical application, a slice, or the overall 5/6G network on the continuum.

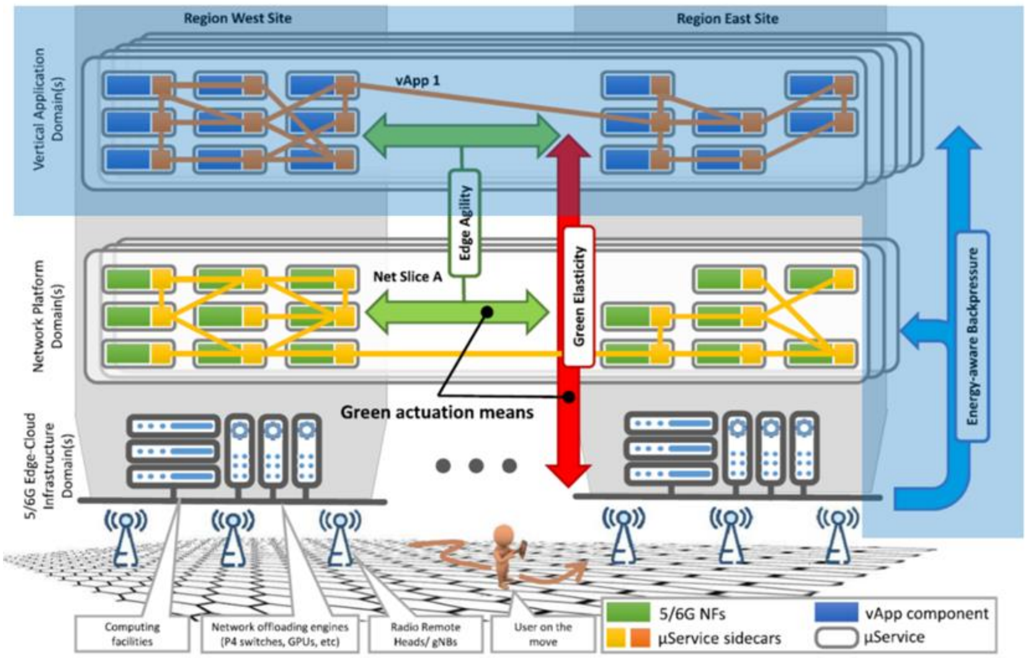

Figure 1: Relation to 6Green's three ground-breaking innovations.

The remainder of this deliverable is structured in 2 main chapters:

Chapter 2 establishes the green economy landscape and vision, identifying key stakeholders within the 5/6G ecosystem. It introduces the Decarbonisation Level Agreement (DLA), an evolution of the traditional Service Level Agreement (SLA) that integrates sustainability metrics and indicators. The 6Green Business Support System Function (BSSF) is positioned as a central component for intent management and (re-)negotiation among stakeholders. Additionally, the chapter presents an energy-aware incentivisation framework, evaluating various policy options for DLAs. Finally, a Lean Canvas approach is used to define and refine the Green Business Models proposed for 6Green.

Chapter 3 provides an overview of 6Green's approach to vertical application orchestration, introducing the 6Green Vertical Application Orchestrator (VAO) and the lifecycle management operations and workflows supported. The policy concept is also elaborated with a policies architecture, along with a set of energy-aware Vertical Layer Policies**.**

1.1 What's New in the Final Version?

This deliverable is incremental to 6Green deliverable D4.1 (titled “Work-in-Progress: Design and Specification of Green Business Models and Runtime Policies for 5/6G Vertical Applications”) [11]. The following changes have been made with respect to the previous edition.

- Section 2.1 summarises the state of the art and visions previously presented in detail, also adding a new aspect on policies towards sustainability.
- Section 2.2 is kept for completeness, and with minor revisions.
- Section 2.3 has been re-organised, keeping the metrics and indicators previously identified and further elaborating the role of the BSSF in energy-aware (re-)negotiations. A novel energy-aware incentivisation framework is also described in the section, with more details in Annex A.
- Section 2.4 is now a dedicated section for the Lean Canvas framework, with new content discussing the SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis and Lean Canvas components enhancement analysis conducted during the second half of the project. The consortium partners responses used for the analyses are presented in Annex B.
- Section 2.5 presents the refined versions of the three green business models previously proposed, including a SWOT analysis of each model. The section also discusses how the methodology validates the need for dynamic, ecosystem-aware business models.
- Section 3.1 has been revised, also adding a figure to illustrate how the VAO interacts with the 6Green SBA.
- Section 3.2 has been revised with an updated Day 0 workflow and descriptions for the different operations.
- Section 3.3 has been revised with updated Application Management actions, also adding a subsection on runtime policy workflow.
- Section 3.4 has been revised with new vertical layer policies matching the demonstrator work in Work Package 5.

2 5/6G Ecosystem and the Green Economy

In today's hyperconnected society, ICT plays a pivotal role in sustainability, as it powers the continuous operation of multiple interconnected infrastructures that support seamless connectivity and instant content access. The 5/6G ecosystem is integral to this landscape, but it also contributes significantly to energy consumption. To address this, the industry is actively working to make these technologies sustainable by design, including research efforts and initiatives such as [12] and [13] from Hexa-X-II.

This chapter presents the state of the art and future visions for enabling a green economy within the emerging 5/6G ecosystem. It identifies the key stakeholders involved and explores the formalization of the DLA concept, while examining aspects like energy-aware metrics/indicators, (re-)negotiation and incentivisation frameworks.

Moreover, the Lean Canvas Framework is employed to redesign the green business models initially defined in Deliverable D4.1 [11]. The chapter concludes with the updated models and some insights on their evolution.

2.1 State of the Art and Visions for a Sustainable 5/6G

6Green examines the state of the art in **six different perspectives**. The following provides a brief summary of what has been presented in deliverable D4.1, as well as a new perspective on *policies towards sustainability*.

Carbon Footprint Quantification

A *carbon footprint* measures the total greenhouse gas (GHG) emissions across the entire lifecycle of a product or service—from raw material extraction to disposal [14]. The **Global Warming Potential (GWP)** standardizes carbon footprints by converting different greenhouse gases into carbon dioxide equivalents (CO2e), enabling clear comparisons of their climate impact [15].

In the ICT sector, carbon emissions per unit of *energy generated* are calculated using **carbon intensity** metrics (gCO2e/kWh), which vary by country based on energy sources. Countries using *renewables* (e.g., Norway and Canada) have lower intensities, while those relying on *fossil fuels* (e.g., China and India) have higher [16]. Solar energy has a particularly low carbon intensity, making it a preferred choice for reducing GHG emissions [17].

Carbon factors help organizations to calculate their total emissions based on *energy consumed* and make informed decisions in terms of clean energy adoption. For example, if a datacentre in Germany consumes 1,000 kWh from the grid with a carbon factor of 400 gCO2e/kWh, and 500 kWh from solar panels with a carbon factor of 20 gCO2e/kWh, the total emissions would be 410,000 gCO2e (= 1,000 kWh * 400 gCO2e/kWh + 500 kWh * 20 gCO2e/kWh).

Raising Awareness and Promoting Responsible Digital Behaviour

Raising awareness of the environmental impact of digital services and promoting responsible behaviour is another key aspect towards green economy. Orange Romania's YOXO [18] is a great example, providing an all-digital experience to customers and raising awareness on the *environmental impact generated by online actions*, such as videoconferencing, video streaming, social media posts, online shopping, etc. In particular, the YOXO application introduces a *gamification experience* to the users, providing periodic insights on how YOXO users contribute to lowering carbon footprints and plastic usage, as shown in Figure 2.

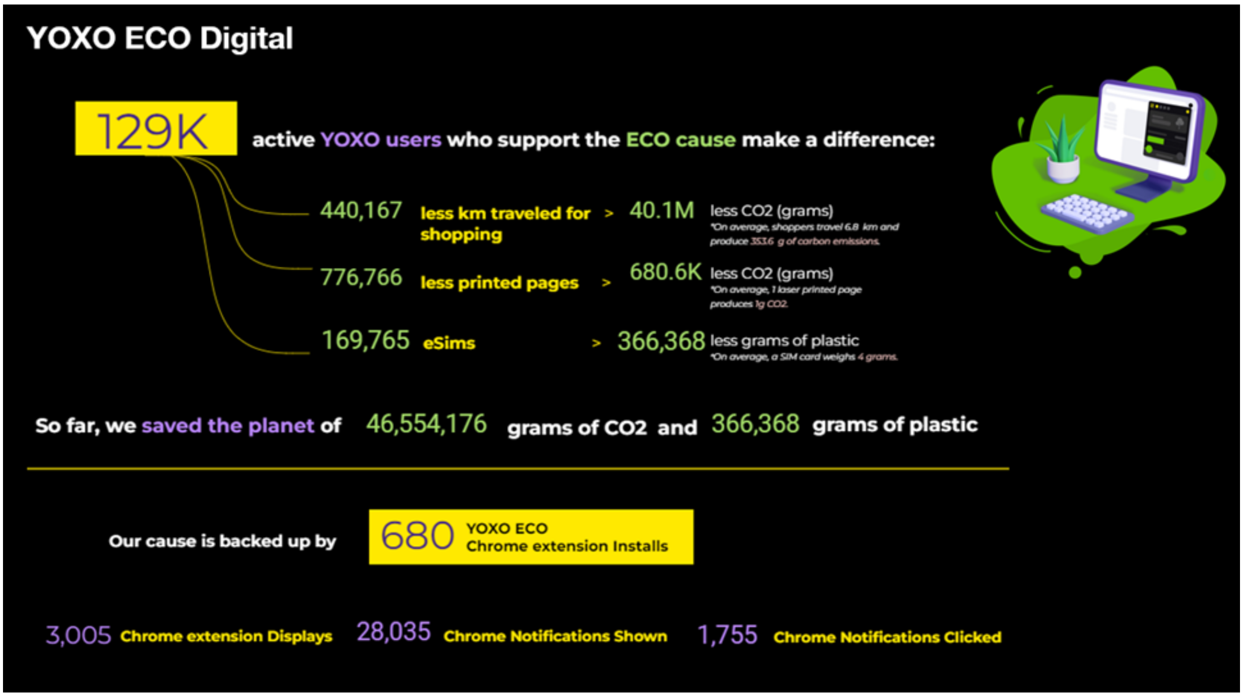

Figure 2: Environmental impact of YOXO digital product.

Policies Towards Sustainability

Policy makers have been active in promoting sustainability both at the global (e.g., **Paris Agreement [19]**) and regional (e.g., **European Green Deal**) levels. The EU has implemented Emissions Trading System (ETS) [20]—a cap-and-trade mechanism aimed at reducing greenhouse gas emissions in high-emitting sectors. It incentivizes companies to invest in cleaner technologies by placing a financial value on emissions, rewarding efficiency and penalizing excess pollution. To enhance industrial competitiveness and decarbonisation, the **Clean Industrial Deal [21]** as introduced, featuring: (i) affordable energy initiatives; (ii) demand stimulation for clean energy; (iii) Research & Development & Innovation and renewable energy funding; and (iv) supply chain and raw material security measures.

Moreover, specific industries and countries have implemented additional measures to achieve the EU sustainability objectives.

- *Automotive:* The automotive sector introduced increasingly strict regulations for new vehicles, targeting **maximum emissions** and **minimum battery performance [22]**. To accelerate fleet modernization, national governments (e.g., Germany, France, Italy, Spain) have provided **direct consumer incentives** for purchasing low-emission vehicles, supported by **eco-labels** and **bonus/malus systems** that reward clean vehicle ownership (e.g., through free parking) and penalize polluting cars [23]. On the supply side, governments have offered **subsidies and funding** for clean vehicle manufacturing and imposed **penalties** for non-compliance with emission targets [24][25].
- *Energy:* The energy sector supports the transition to a net-zero economy through **subsidies and tax incentives** for clean energy projects. Regulations promote investment in renewables via **tender processes**, **feed-in tariffs** (guaranteeing grid access at regulated prices), and **feed-in premiums** (offering above-market rates for green energy) [26]. On the demand side, governments

incentivize energy-efficient housing and heating systems [27], while **eco-labels** are mandatory for dwellings being rented or sold.

- *Chemicals & Agriculture:* The chemical and agriculture industries also have similar policies, where challenges include supply chain control, circular material management, and oversight of potentially harmful substances and processes. On the supply side, **subsidies** support investment in greener and safer production methods [28]. On the demand side, **nutritional and eco-labels** raise consumer awareness and highlight products that meet EU standards [29].

Although not traditionally considered a major environmental contributor, the ICT sector's carbon emissions are rising due to the growth in connected devices, data centers, and digitalisation. Estimates vary with some studies suggesting ICT will remain at 2-4% of global emissions, while others project it could reach 14-24% by 2030–2040, potentially hindering Europe's climate goals [30]. In terms of breakdown, most works agree that ~60% of ICT emissions are due to the production and use of terminal equipment (e.g., TVs, computers), while ICT networks account for around ~25% [30]. ICT and digitalisation are widely seen as enablers of sustainability across sectors, but concerns persist that the growing energy demand of devices and infrastructure *may offset these benefits*.

To address this, a range of **policy types** [31] have emerged to guide the ICT sector toward sustainability, targeting both demand and supply sides, as well as with some similarities as in the other industries:

- *ESG (Environmental, Social and Governance) Policies* promote sustainable business practices across industries by requiring companies to **disclose environmental data [32]** and **non-compliance can lead to reputational damage, fines, or sanctions**. Institutional investors increasingly demand ESG transparency, and many market leaders aim for net-zero emissions by 2040 [33], using carbon removal credits to offset residual emissions [34].
- *Investment Incentives Policies e*ncourage sustainable ICT infrastructure through **targeted tax exemptions** [35] and **financing**. Moreover, **green bonds** are commonly used by telecom operators to fund environmentally beneficial projects [36].
- *Sustainability Regulations for Digital Technologies and End-User Devices [37]* drive most ICT-related environmental impact and emphasize **eco-design principles [38]** rather than infrastructure.
- *Industry Awareness Policies* use **standards, research publications,** and **government reports** to promote sustainability. Standardisation bodies [39]-[42] and national regulatory authorities (NRAs) [43][44] play a key role in shaping industry understanding and practices.
- *End-User Awareness Policies* include **certification programs** and **eco-labels** to inform consumers about environmentally responsible ICT products [45]. Such schemes are an effective way to recognize achievements in energy efficiency, emissions reduction and waste reduction, typically targeting datacenters and energy-intensive devices.

Green Behaviour Intelligence and Rewarding Mechanisms

5/6G technologies are foundational to smart city development, while also playing a critical role in enhancing sustainability. In a smart city, a well-designed rewarding system for citizens encourages environmentally friendly behaviour by integrating sustainability into daily life through technology and incentives. The system should be accessible, engaging, and seamlessly embedded in city operations, cultivating a collective culture of sustainability within the community [26].

The rewarding system can be designed based on the three main smart city drivers: (i) *resource consumption*, using smart meters to track electricity, water and gas usage, as well as incentivising the use of renewables and energy-efficient appliances; (ii) *green mobility usage*, using city apps to track sustainable travel, as well as incentivising use of public transport, walking, cycling, carpooling and electric vehicles; (iii) *sustainable waste recycling*, using smart bins to identify and weigh recyclables, as well as incentivising correct sorting, composting organic waste and participation in sustainability events.

Based on these design principles, Telecom Italia developed a proof of concept of a citizen rewarding system to motivate green behaviour [47]. The **Green Index** has been developed to calculate and track individual and community sustainability efforts, leveraging Internet of Things (IoT) technology. Smart citizens earn points for each green activity tracked by the system, and the points can be redeemed as discounts on utility bills, public transport passes, vouchers for local businesses, or donations to environmental causes. A *tiered rewards system* can also be implemented where higher tiers unlock more valuable rewards, encouraging sustained and increased participation. Additionally, **Green Behaviour APIs** (Application Programming Interfaces) play a crucial role in green city applications by allowing third-party developers to access and integrate various city services and data into their own applications to further enhance sustainability (e.g., route optimisation, air quality monitoring).

An additional enhancement to the green behaviour rewards system involves estimating the network energy cost of services (e.g., video streaming, IoT communications). This provides a strong foundation for developing an incentivisation framework among 6Green stakeholders, leveraging 6Green's observability of network services and vertical applications consumptions within the smart city context.

Network Slice Selection and Energy-Driven Negotiation

Network slicing enables mobile operators to create end-to-end logical networks over shared infrastructure, each tailored to specific service requirements. Operators can deploy either a single *versatile* slice for multiple verticals, or multiple *specialized* slices for distinct business needs—for instance, a connected vehicle may use a high-bandwidth slice for infotainment, and an ultra-reliable slice for telemetry and assisted driving.

To standardize slice definitions, operators use the **Generic Network Slice Template (GST)** [48], which outlines Key Performance Indicator (KPI) names, units, granularity, and serves as a baseline for service agreements and negotiations, including roaming scenarios. Slices are selected based on **QoS Class Identifiers (QCI)** and security needs. The three main 5G service categories: (i) Enhanced Mobile Broadband (eMBB); (ii) Massive Machine-Type Communications (mMTC), and; (iii) Ultra-Reliable and Low Latency Communications (URLLC), can be further expanded into a range of QoS classes for service selectivity.

3rd Generation Partnership Project (3GPP) Release 17 [49] introduces Network Slice Simultaneous Registration Group (NSSRG), allowing a device to register with multiple slices simultaneously if they share the same NSSRG number. Moreover, 3GPP TS 28. 554 [50] defines several KPIs related to energy consumption on slices, which can be used in slice selection. For example, based on the **Generic Network Slice Energy Efficiency**, a User Equipment (UE) registered to two slices can be "moved" from one slice to another when a threshold is crossed in a slice in order to preserve UE QoS or even to free existing slice of subscribers to decrease the load.

Energy efficiency is becoming a key factor in slice negotiation, especially in 6G. This includes:

- *Energy-Aware Slice Allocation:* setting energy limits and requirements for slices during negotiation and resource allocation.
- *Dynamic Energy Optimization:* incorporating techniques like sleep modes, dynamic power management and resource consolidation into the negotiation process.
- *Energy-Efficient QoS Trade-offs:* negotiating QoS parameters that align with energy-efficient practices to balance performance with energy savings.

- *Energy Monitoring and Reporting:* providing transparency on slice energy use and allowing users to make informed decisions.
- *Energy-Aware Lifecycle Management:* negotiating energy-aware policies for slice adaptation, scaling, and termination.
- *Collaboration for Energy-Efficient Solutions:* encouraging industry-wide cooperation for the development energy-aware negotiation frameworks and adoption of sustainable practices.

Zero-Touch Assessment and Elaboration of Decarbonisation Level Agreements

Telecommunication providers aiming to meet Decarbonisation Level Agreements (DLAs) must adopt a systematic and automated approach, grounded in common reporting standards and agreed taxonomies. A key example is the Corporate Sustainability Reporting Directive (CSRD) by the European Commission, which *standardizes sustainability reporting* to ensure consistency and comparability, as well as introduces a *digital taxonomy* for structured, automated, and scalable data processing. These will enable zero-touch automation and serve as a model for the telecommunication sector's efforts in DLA.

A parallel can be drawn from the SPECIAL project [51], which used a detailed taxonomy to automate user consent processing in privacy management—demonstrating how structured taxonomies enhance efficiency and consistency. A similar approach can be adopted the assessment and elaboration of DLAs. Two critical aspects must be considered for an effective implementation: (i) the *integration* of DLAs with performance and regulatory requirements, and (ii) the *dynamic nature* of DLAs with respect to evolving environmental targets, technological advancements, market conditions, etc.

Many theoretical studies have demonstrated the potential of **logic-based approaches** for handling these challenges, particularly those leveraging encoded fragments of OWL2 (Web Ontology Language) due to strengths in key objectives (i.e., correctness and completeness, coherent reasoning, interoperability). However, *notable limitations on feasibility and scalability* have been found for large-scale networks. On top of that, *latency* associated with assessments and elaborations diverges as the number of customers increases due to specialised reasoners. As an alternative, **rule-based engines** are lighter and inherently scalable compared to traditional reasoners, showing much better scalability performance in various challenging telco scenarios.

As part of the 6Green project, we propose an innovative **hybrid architecture** that leverages *rule-based systems for real-time operations* while reserving *logic-based assessments for offline verification.* This approach allows telecommunication providers to more effectively manage the growing complexity of modern networks. While OWL2-based logic approaches offer strong guarantees for policy coherence, correctness, and interoperability, their scalability limitations in large-scale environments present practical challenges. In contrast, rule-based engines offer a scalable, flexible, and efficient alternative for real-time processing. By combining the strengths of both paradigms, telco providers can build a more balanced, responsive, and robust system for automated DLA assessments and elaborations—enabling smarter, more sustainable network management.

2.2 Stakeholders

This section outlines the key stakeholders in the 5/6G ecosystem and examines how green business models influence their roles and operations. All stakeholders are envisioned as active participants in a Green Economy, where operational efficiency and usage costs are closely linked to network and application demands, as well as end-user traffic.

6Green's Energy-Aware Backpressure paradigm is a key concept that enables vertical propagation of energy and carbon-related KPIs across the value chain. This approach ensures that each stakeholder can monitor and optimize their contributions to sustainability by leveraging 6Green's new network platform capabilities and business models.

Figure 3 illustrates five key stakeholders and their interactions within the Green Economy framework: (i) the Infrastructure Provider, (ii) the Network Platform Provider, (iii) the Vertical Application Provider, (iv) the End User, and (v) the Policy Maker. While the 6Green ecosystem primarily focuses on the first three, the End User and Policy Maker roles are also presented for completeness.

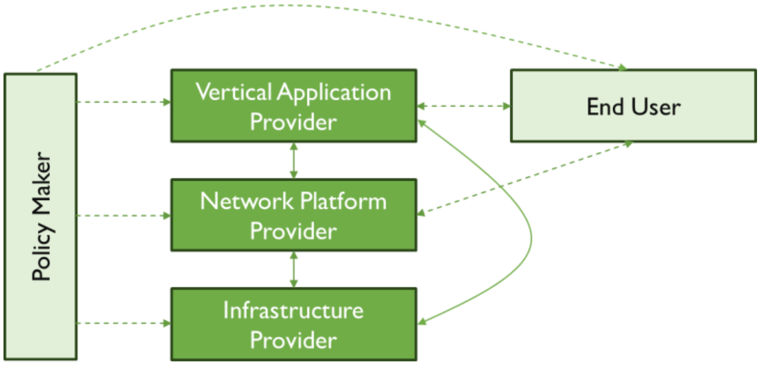

Figure 3: Stakeholder interactions.

Infrastructure Provider

The Infrastructure Provider role extends to several domains of the telecom infrastructure, from the Radio Access Network (RAN, e.g., towers, radio equipment, power supply), the Transport Network (e.g., copper and/or fibre networks), and the Core Network / Information Technology (IT) (e.g., datacentre facilities). Infrastructure may be delivered end-to-end by a **telecom operator** or distributed across multiple entities (e.g., RAN by telecoms, datacenters by **hyperscalers**). Providers may also offer infrastructure as-a-Service to other operators and enterprises.

This stakeholder bears **direct energy costs and benefits**, which are influenced by the demands and agreements with upper-layer stakeholders. Overprovisioning limits opportunities for energy optimization at the infrastructure level as resources are statically dimensioned to handle peak usage requirements, continuously consuming energy even in off-peak hours. The 6Green business models and Energy-Aware Backpressure seek to propagate energy awareness and energy-aware capabilities towards upper stakeholders, as well as motivate environmentally conscious behaviours through incentivization.

Network Platform Provider

The Network Platform Provider role maps to **Mobile Network Operators (MNOs)** and **Mobile Virtual Network Operators (MVNOs)**, delivering 5/6G connectivity services on top of the infrastructure layer. Their responsibilities span several network domains, from radio spectrum management and Wide Area Network (WAN) access, through 5G Core operations, to running IT workloads for business support and operation management.

Functioning as **tenants** of the infrastructure, they contribute to energy consumption through deployed software (e.g., network slices, Management and Orchestration (MANO), Operations Support System / Business Support System (OSS/BSS)) and data volumes.

Unlike traditional overprovisioned networks, 5G slicing and multi-tenancy enable dynamic resource allocation, improving energy efficiency. The 6Green business models and Energy-Aware Backpressure aim to: (i) expose energy metrics and capabilities from the infrastructure to the network platform layer; (ii) enable upper-layer stakeholders (e.g., vertical industries, end users) to renegotiate resources and services based on energy-performance trade-offs; and (iii) incentivise sustainable choices, such as using renewable energy, hardware offloading, sleep modes, and proximity-based optimizations

Vertical Application Provider

The Vertical Application Provider maps to **Application Service Providers, Digital Service Providers** and **Over-the-top (OTT) Providers**, delivering services at the vertical layer. These providers rely on both the underlying network platforms and datacentre facilities for connectivity and application hosting, respectively.

This stakeholder acts as a **tenant** of edge-cloud infrastructure, hosting (distributed) application components, as well as an **enterprise customer** of Network Platform Providers, requiring connectivity between application components and end users. The 6Green business models and Energy-aware Backpressure will enable the vertical layer to: (i) expose application-level performance and operational metrics with Network Platform Providers for automated network optimization; and (ii) provide analytics and incentives to End Users, encouraging energy-efficient service usage and renegotiation of service parameters (e.g., placement, performance). Given that application performance highly depends on network Service Level Agreements (SLAs), *service bundling* may be offered by Network Platform Providers to Vertical Application Providers and/or End Users, aligning connectivity and service delivery with energy efficiency goals.

End User

The End User role maps to **individuals or groups** who consume application services over the 5/6G network. They may hold separate or bundled service agreements with: (i) the Network Platform Provider, for the network connectivity; and (ii) the Vertical Application Provider, for the application service.

Through the 6Green business models and Energy-aware Backpressure, End Users will gain: (i) observability of the energy and carbon footprint of the services they use; and (ii) access to energy-aware options and incentives during service selection or renegotiation. This empowers them to make informed, environmentally conscious choices, contributing to the overall sustainability of the 5/6G ecosystem.

Policy Maker

The Policy Maker role maps to **local, national and international governments and regulatory bodies**. They play a crucial role in driving environmentally conscious behaviour across the ecosystem by offering incentives such as reduced or waived taxes, exclusive pricing models and other benefits towards the aforementioned 5/6G stakeholders.

In contrast to the other stakeholders, Policy Makers will not rely on the 6Green business models and Energy-aware Backpressure, but can motivate active participation in the green economy. Their incentives will ensure that the providers will benefit from the savings and/or green initiatives adopted, while being able to escalate the benefits to customers.

2.3 Decarbonisation Level Agreement

Decarbonisation Level Agreements (DLAs) introduce a sustainability-focused framework into business agreements, integrating energy usage and carbon footprint considerations among stakeholders (with the exception of the Policy Maker). They build upon traditional SLAs by embedding environmental accountability into service delivery, influencing both the **requirements ("what")** and **execution ("how")** of services.

The DLA can be considered as an extension of the classical SLAs established between customers and providers to guide the execution and compliance of services agreed among them, presented in three dimensions:

Decarbonisation

This dimension defines the environmental intent of the service, covering three aspects: (i) identifying the suitable *terminology and scope*; (ii) highlighting *impact for customers* if targets are not met; and (iii) establishing *viable green targets* for service providers.

Level

This dimension defines the framework for measuring and evaluating the green targets requested by the customer, considering three aspects: (i) differentiating *objectives (measurable) and expectations (non-measurable)*; (ii) specifying *mechanisms for KPI retrieval*; and (iii) ensuring *transparent, consistent and meaningful metrics*.

Agreement

This dimension focuses on governance and enforcement, considering two aspects: (i) establishing *mechanisms for stakeholders to (re-)negotiate and commit* to the agreement; and (ii) establishing *mechanisms for enforcing compliance and accountability*.

2.3.1 Energy-aware Metrics and Indicators

6Green builds its DLA framework by analysing existing standardization initiatives, not only to reuse established approaches but also to identify gaps where 6Green can contribute to advancing sustainability specifications.

Using network slicing as a starting point, it is assumed that customers will request network slices from the 6Green SBA control framework with sustainability intents through the DLAs. In fact, the latest version of GST (Generic Network Slice Template) includes an optional energy efficiency attribute as shown in Figure 4. This attribute describes whether the network slice supports the energy efficiency KPI. As can be seen, this attribute is very high level, not providing sufficient granularity nor detail regarding expected slice behaviour.

Energy efficiency	
Measurement unit	NA
Allowed Values	Not Supported Supported
Tags	Character attributes / Operational KPI

Presence	
Mandatory	
Conditional	
Optional	X

Figure 4: Energy efficiency attribute definition in the GST.

Gap 1: GSMA vs 3GPP Specifications

Global System for Mobile Communications Association (GSMA)'s GST is expected to feed the 3GPP Management Systems to generate concrete slice profiles and enforce slice characteristics. Analysing 3GPP specifications it is possible to get further details about energy and power characteristics of slices. 3GPP TS 28.554 [50] defines a number of Energy Efficiency (EE) and Energy Consumption (EC) KPIs, among them:

- EE KPIs:
    - Generic Network Slice EE
    - EE of eMBB network slice
    - EE of URLLC network slice
    - EE of mMTC network slice
    - Next Generation RAN (NG-RAN) data EE
    - 5G Core EE
- EC KPIs:
    - Network slice EC
    - Network Function EC
    - 5G Core EC
    - NG-RAN EC

For simplicity, the generic KPIs for both EE and EC are considered.

The **Generic Network Slice EE KPI** defined in 3GPP TS 28.554 (and already introduced in 6Green D3.1) is given as follows:

$$Generic\ Network\ Slice\ EE = \frac{Performance\ of\ network\ slice\ (P_{ns})}{Energy\ Consumption\ of\ network\ slice\ (EC_{ns})} \quad (1)$$

where P_{ns} is defined per type of network slice, while EC_{ns} is defined independently from any type of network slice. For one unit of EC_{ns}, a network slice becomes more energy efficient as P_{ns} increases.

Gap 2: Energy Origin and Sustainability Indicators

While being useful, these metrics are not enough for expressing the DLA expectations of customers, as they only relate to the **pure energy consumption but not to the origin of the energy** used. In order to properly define metrics related to the origin of the energy, 6Green incorporates sustainability indicators from the Body of European Regulators for Electronic Communications (BEREC) in [43], including: (i) energy consumption, aligned with 3GPP's EC indicator; (ii) carbon emissions; (iii) energy efficiency, aligned with 3GPP's EE indicator; and (iv) use of renewable energy (as a percentage). These indicators allow customers to express decarbonisation expectations more comprehensively within DLAs, going beyond raw consumption to include carbon emissions and renewable energy usage.

2.3.2 Energy-aware (Re-)Negotiation

Within the 6Green architecture, DLAs must be integrated into the process for requesting network slices, including SLAs and slice characteristics. This is facilitated through the Business Slice Selection Function (BSSF), which acts as an intent-based interface for customers to express high-level service requirements.

Following the approach in 3GPP TS 28.312, 6Green adopts a similar syntax for expressing intents but extends the semantics to include green KPIs beyond RAN energy efficiency. These include:

- *SliceEnergyConsumption:* specifying a threshold for energy consumption.
- *SliceCarbonEmission:* specifying a threshold for carbon emissions.
- *SliceEnergyEfficiency:* specifying a threshold for energy efficiency (e.g., bits per Joule).
- *SliceUseRenewableEnergy:* specifying a threshold for the ratio of renewable energy used, optionally also the renewable energy source.

These targets are integrated into the standardized intent information model defined in 3GPP TS 28.312, where each target follows the format of (*targetName*, *targetCondition*, *targetValueRange*) and can be contextualised with specific conditions under which the targets must be achieved. However, in this specification (also in 3GPP TS 28.554) the scenarios defined target the 5G Core and the RAN domains. In 6Green, definition of the energy efficiency for the RAN scenario was adapted to align with the project's needs, expanding the scope from RAN-focused metrics to network slice and vertical application management.

6Green also supports dynamic (re-)negotiation of slice parameters and edge-cloud resources to align with energy and carbon-aware policies. Key capabilities include:

- SLA/DLA (re-)negotiation by the Application Functions (AFs)
- Joint adaptation of network slices and vertical application components
- Support for edge agility and green elasticity in 5G/6G slices and vertical applications
- AI-driven runtime policy management

These mechanisms aim to balance user demands with energy efficiency, contributing to sustainable network infrastructures.

Role of the BSSF

From the functional behaviour perspective, the BSSF will process the slice intent, including both SLA and DLA, to further translate them for an enriched network slice request towards the Experiential Networked Intelligence Function (ENIF). Such an enriched slice request considers constraints applicable to the intended slice according to policies predefined in the BSS by the provider, which could be particular per customer type.

The BSSF is also in charge of reporting back to the customer the metrics associated with the requested network slice, in relation to either the SLA or the DLA. This functional behaviour is under development. Once verticals are enabled to request specific targets for the aforementioned indicators, which are interrelated at different levels, navigating these relationships makes it possible to identify the implications of one indicator's effect on the others [52].

Particularly, the use of renewable energy is inversely related to the carbon emissions, while the renewable energy percentage is orthogonal to energy consumption and energy efficiency, not showing any relationships. On the other hand, as per the definition in [50] of energy efficiency, the relationship with energy consumption is clear. A less efficient network in terms of energy will consume more energy. And in consequence, for a fixed value of the use of renewable energy, more energy consumption implies higher carbon emissions. Apart from this clear relationship, it is possible to navigate among the three indicators (energy efficiency, energy consumption and carbon emissions) to understand the dynamics of a system following the axis depicted in Figure 5.

Looking at Figure 5, it is possible to understand the interplay of these three indicators, and to what extent it can be concordant or contradictory in the expression of a DLA. For instance, for a given energy consumption, it is possible to increase the energy efficiency of the network slice by supporting more traffic on it—that is, by increasing its performance. This takes into consideration the current state-of-the-art device and network element implementations where the device's energy consumption is nowadays dominated by the consumption when the device is idle, with non-substantial variation based on the traffic delivered. The only way of achieving some proportionality of the energy consumed and the traffic carried out by a device is to switch off (or sleep) modular elements of the equipment, such as entire line cards (e.g., as proposed in [53]).

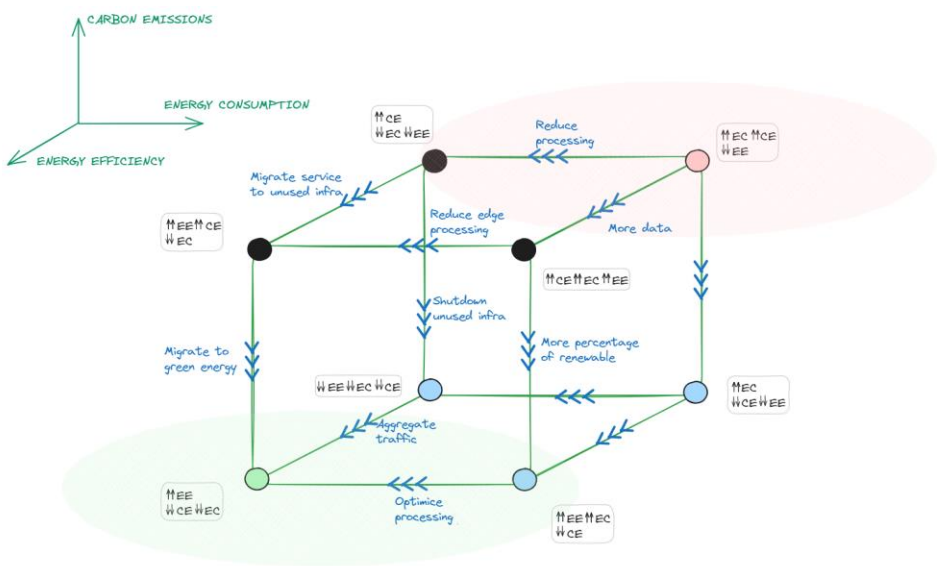

Figure 5: Interplay between energy efficiency (EE), energy consumption (EC) and carbon emission (CE) indicators.

2.3.3 Energy-aware Incentivisation Framework

While 5/6G networks are increasingly capable of measuring and enabling sustainability indicators, technical capability alone is insufficient to drive adoption of greener services. The 6Green ecosystem enables the exposure of sustainability KPIs of network infrastructure and services, and sustainability-aware interaction between all the stakeholders involved in the provision of vertical applications and services on top of 5/6G network slices. Key stakeholders—Infrastructure Providers and Network Platform Providers—operate under diverse objectives and constraints, often prioritizing cost and performance over environmental impact. This misalignment can lead to suboptimal sustainability outcomes. To address this, **effective technical and economic mechanisms** are needed to incentivise the *deployment, operation* and *selection* of **green network slices**. Without such incentives, sustainability goals are unlikely to be met.

Building on existing literature, a Mixed Integer Linear Programming (MILP)-based techno-economic incentivisation framework is proposed within 6Green to model the dynamics of vertical application deployment over 6G slices, evaluating the cost-effectiveness of green ICT strategies and illustrating how perverse incentives influence the dynamics of the ecosystem. The case of a Network Platform Provider that can request infrastructure resources from multiple Infrastructure Providers to deploy network slices on demand has been examined with realistic power-consumption and carbon-emission profiles based on existing studies [54].

In a nutshell, Figure 6 summarises the architecture of the Energy-aware Incentivisation Framework. For a series of slice orders submitted to the Network Platform Provider, the model returns whether each slice is accepted or rejected, an optimal allocation of virtual resources of accepted slices to relevant Infrastructure Providers, infrastructure utilisation, the operational profit for the Network Platform Provider, and the estimated environmental footprint.

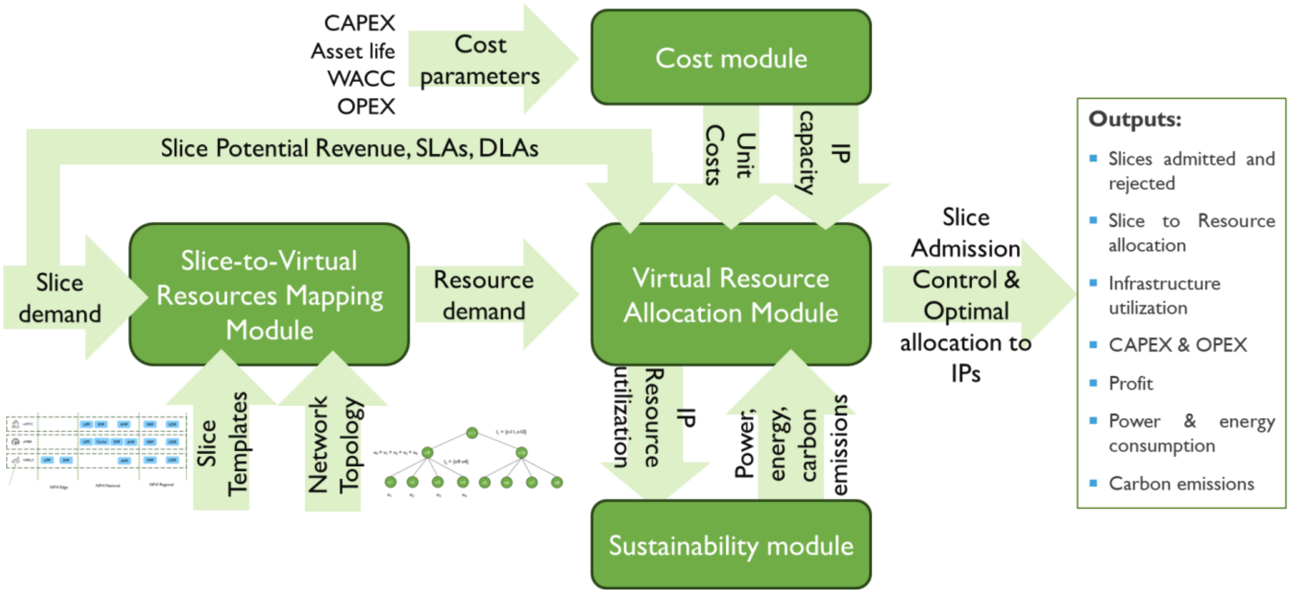

Figure 6: Energy-aware Incentivisation Framework proposed by 6Green.

This is achieved in two steps:

Step 1 involves *mapping slice orders to virtual resources* and returns the demand for virtual resources needed to fulfil the required slice orders, according to the requirements of their slice templates.
Step 2 performs an *optimal allocation of virtual resources to available infrastructure* supplied by Infrastructure Providers, considering their cost, their environmental footprint, and the constraints imposed by SLAs and DLAs. To solve the resource allocation problem described above, we resort to MILP.

Although technological capabilities to monitor and reduce emissions are evolving, market dynamics often hinder investment in greener infrastructure, particularly when the return on investment remains unclear or when green energy solutions are more expensive than conventional ones. In such cases, policy interventions become essential to realign incentives throughout the value chain. To explore this challenge, **four policy options** have been evaluated using this framework:

1. **Laissez-faire** – No intervention.
2. **Green subsidies** – Financial incentives for low-emission infrastructure.
3. **Uniform DLA** – Standard decarbonization requirements across services.
4. **Tiered DLA** – Differentiated green service levels with premium options.

These represent a spectrum of regulatory and market-based tools to internalise the sustainability cost in mobile network operations.

While effective in promoting greener outcomes, subsidies are uncommon in the telecommunications sector. DLAs offer a more sector-aligned instruments. Combined with sustainability KPI monitoring, DLAs enable stakeholders in the ecosystem and regulators to consider sustainability in network operation in exchange of higher costs that need to somehow be internalised by the value chain. The tiered DLA scenario, which distinguishes between standard and green premium services, offers a particularly promising compromise. It enables market mechanisms to function, letting environmentally aware users opt for more sustainable services—particularly in verticals where service quality or environmental impact are strategic differentiators. Even if this approach does not scale universally, it opens the door to more sophisticated market-based sustainability mechanisms.

However, evaluation results show that if DLA constraints are too aggressive, the system may not be able to serve all demands due to the limited capacity of green infrastructures. A well-anticipated and progressive decarbonization glide path could be a way to mitigate this risk, giving stakeholders time to adapt to increasingly restrictive NRA (National Regulatory Authorities)-driven DLAs and invest in new, more efficient, or net-zero technologies.

More details on the framework, evaluation methodology and results are presented in Annex A.

2.4 Lean Canvas Framework

The Lean Canvas framework serves as a pivotal tool for the 6Green project to structure and refine its green business models. Initially proposed to address the unique challenges of sustainability in 5G/6G ecosystems, the 6Green Lean Canvas template shown in Table 1 enables a concise yet comprehensive analysis of key elements like value propositions, customer segments, and cost structures. It is particularly well-suited for identifying risks and opportunities in innovative projects like 6Green, where environmental sustainability and operational efficiency intersect.

Table 1: Lean Canvas template for 6Green.

<table>
<tr><th>Problem</th><th>Solution</th><th>Unique Value Proposition</th><th>Unfair Advantage</th><th>Customer Segments</th></tr>
<tr><td>Top 3 problems</td><td>Top 3 features</td><td>Single, clear and compelling message that states why you are different and worth buying</td><td>Can’t be easily copied or bought</td><td>Target Customers</td></tr>
<tr><th>Existing Alternatives</th><th>Key Metrics</th><th>High-Level Concept</th><th>Channels</th><th>Early Adopters</th></tr>
<tr><td>List how these problems are solved today</td><td>Key activities you measure</td><td>List your X for Y analogy
(e.g. YouTube = Flickr for videos)</td><td>Path to customers</td><td>List the characteristics of your ideal customers</td></tr>
<tr><th colspan="2">Cost Structure</th><th colspan="3">Revenue Streams</th></tr>
<tr><td colspan="2">List your fixed and variable costs
Customer acquisition costs
Distribution costs
Hosting
People
Etc.</td><td colspan="3">List your sources of revenue
Revenue Model
Life Time Value
Revenue
Gross Margin</td></tr>
</table>

The Lean Canvas template has been distributed within the consortium and feedback from ten partners—including network operators, tech providers, small- and medium-sized enterprises (SMEs), academia, and research institutions—was synthesized to refine the business models introduced earlier in the project [11]. These inputs provide a diverse perspective on the project's potential impact and challenges. This effort not only validates the original framework but also enriches it with real-world data and stakeholder insights, ensuring that the models remain relevant and actionable.

The findings from the Lean Canvas analysis will significantly influence two critical areas:

- **Refinement of green business models** based on *Strengths, Weaknesses, Opportunities and Threats (SWOT)* insights; and
- **Identification of actionable changes** aligned with market needs and sustainability goals.

By integrating stakeholder feedback, the project is better equipped to address challenges such as regulatory constraints and competitive pressures, while leveraging opportunities in sustainability-driven innovation.

2.4.1 SWOT Analysis

The SWOT analysis is a widely used strategic planning tool that evaluates internal and external factors impacting a project or business.

Strengths:

1. **Innovative Solutions**: Each consortium partner presents unique, innovative solutions aimed at reducing energy consumption and carbon footprints in 5/6G networks, showcasing a strong commitment to sustainability.
2. **Expertise and Experience**: The partners possess extensive expertise in telecommunications, ICT infrastructure, and energy-efficient technologies, which enhances credibility and the potential for successful implementation.
3. **Diverse Customer Segments**: The solutions target a wide range of customer segments, including telecom operators, vertical industries, and end-users, which broadens the market reach.
4. **Collaborative Approach**: The consortium's collaborative nature allows for sharing knowledge, resources, and best practices, leading to more robust solutions.

Weaknesses:

1. **High Development Costs**: The cost structure indicates significant Research & Development (R&D) and infrastructure costs, which may pose financial challenges, especially for smaller partners.
2. **Complexity of Implementation**: The solutions involve advanced technologies and methodologies that may require extensive training and adaptation from customers, potentially slowing adoption.
3. **Dependence on Regulatory Support**: The success of many solutions relies on favorable regulatory environments and incentives, which may not always be guaranteed.

Opportunities:

1. **Growing Demand for Sustainability**: There is an increasing global focus on sustainability and reducing carbon footprints, creating a favorable market environment for the consortium's solutions.
2. **Technological Advancements**: Rapid advancements in artificial intelligence (AI), machine learning, and edge computing present opportunities for further innovation and enhancement of the proposed solutions.
3. **Partnerships and Collaborations**: The potential for forming strategic partnerships with other industry players, research institutions, and regulatory bodies can enhance the consortium's capabilities and market presence.

Threats:

1. **Intense Competition**: The telecommunications and ICT sectors are highly competitive, with numerous players offering similar solutions, which could dilute market share.
2. **Regulatory Changes**: Changes in regulations or government policies regarding telecommunications and energy consumption could impact on the feasibility and attractiveness of the proposed solutions.
3. **Market Resistance**: There may be resistance from traditional telecom operators and industries that are accustomed to existing practices and may be hesitant to adopt new technologies.

In the 6Green project, the SWOT analysis provides a structured evaluation of the consortium’s energy-efficient solutions. It highlights areas of expertise and market potential, while acknowledging barriers like high costs and policy dependencies. Together with the Lean Canvas framework, it supports the development of robust, adaptable strategies for promoting green business models in 5/6G networks.

The SWOT analysis revealed that the 6Green consortium has a strong foundation with innovative solutions and expertise, but it must navigate challenges related to costs, implementation complexity, and competition. By leveraging opportunities in the growing sustainability market and forming strategic partnerships, the consortium partners can enhance their market position and drive the adoption of energy-efficient 5/6G networks. This analysis can guide the consortium in refining its strategies, addressing weaknesses, and capitalizing on opportunities to ensure successful project outcomes.

2.4.2 Enhancement of Lean Canvas Components

In a targeted analysis, a deeper exploration of how the Lean Canvas framework can be optimized to support green business models within the 6Green project has been conducted. It emphasizes the importance of tailoring value propositions to highlight sustainability metrics, identifying customer segments that prioritize environmental responsibility, and exploring innovative revenue streams linked to energy efficiency and carbon reduction outcomes. Additionally, the approach integrates feedback loops and KPIs to enable ongoing refinement and ensure alignment with shifting market dynamics and stakeholder expectations.

By enhancing the Lean Canvas components, the project establishes a robust framework for developing actionable and sustainable business models. The refined components will serve as a foundation for addressing challenges identified in the earlier SWOT analysis while driving innovation in energy-aware policies and incentivization mechanisms across stakeholders in the telecommunications sector.

Value Proposition Enhancement Strategy

- **Incorporate Flexibility and Adaptability**: The Lean Canvas should emphasize the ability of 6Green solutions to adapt to changing market demands and technological advancements. This can be articulated as a commitment to continuous improvement and responsiveness to customer feedback.
- **Highlight Sustainability**: Given the increasing focus on sustainability, the value proposition should explicitly state how 6Green technologies contribute to reducing carbon footprints and enhancing energy efficiency. This aligns with the strategic implication that sustainability is a key driver in the evolving ecosystem.

Customer Segments Enhancement Strategy

- **Expand Target Segments**: Based on the whitepaper's insights [58], the Lean Canvas should identify emerging customer segments, such as technology partners, regulatory bodies, and sustainability-focused organizations. This expansion can help capture a broader market and foster collaboration.
- **Segment by Sustainability Goals**: Classifying customers based on their sustainability objectives can tailor marketing efforts and product offerings, making them more relevant to specific needs.

Channels Enhancement Strategy

- **Utilize Digital Platforms**: The Lean Canvas should incorporate digital channels, such as online platforms and social media, to reach tech-savvy customers and engage with them effectively. This aligns with the strategic implication of adapting to new communication methods.
- **Leverage Partnerships for Distribution**: Collaborating with existing players in the telecommunications ecosystem can provide access to established distribution channels, enhancing market penetration.

Revenue Streams Enhancement Strategy

- **Introduce Subscription Models**: The Lean Canvas can explore subscription-based revenue models that provide ongoing services, such as monitoring and optimization of energy usage. This aligns with the whitepaper's emphasis on new revenue opportunities.
- **Performance-Based Pricing**: Implementing pricing strategies that tie costs to sustainability outcomes (e.g., reduced energy consumption) can attract customers who are focused on achieving specific environmental goals.

Cost Structure Enhancement Strategy

- **Analyze Cost Implications of New Roles**: The Lean Canvas should reflect the potential changes in cost structures as the project adapts to new roles within the ecosystem. This includes evaluating the costs associated with expanding into new customer segments or adopting new technologies.
- **Focus on Economies of Scale**: Highlighting strategies to achieve economies of scale through partnerships or shared resources can help mitigate high development costs and improve profitability.

Key Metrics Enhancement Strategy

- **Incorporate Sustainability Metrics**: The Lean Canvas should include metrics that measure sustainability outcomes, such as carbon emissions reduced or energy savings achieved. This aligns with the strategic implication of tracking new metrics in response to changing ecosystem dynamics.
- **Customer Satisfaction and Engagement**: Metrics related to customer feedback and engagement can provide insights into how well the solutions meet market needs and can guide future improvements.

2.5 Green Business Models

Deliverable D4.1 [11] introduced three preliminary green business models designed to align with the 6Green project's sustainability objectives. These models—**Service-Oriented**, **Partnership-Based**, and **Adoption Strategy**—serve as foundational frameworks for promoting sustainability across the 5/6G ecosystem.

- **Service-Oriented Model**: focuses on delivering *energy-efficient telecom services* tailored to environmentally conscious businesses and consumers. It explores *premium offerings* that integrate green metrics, such as carbon footprint reduction, into SLAs.
- **Partnership-Based Model**: emphasizes *collaboration between stakeholders*—including energy companies, tech firms, and environmental organizations—to create a synergistic ecosystem that leverages shared resources and expertise for mutual benefit. For instance, partnerships with renewable energy providers can enhance network operations while reducing operational costs and environmental impact.
- **Adoption Strategy Model**: promotes *innovative usage patterns* and incentivises *eco-friendly practices* among users, such as optimized data packages for reduced energy consumption during peak hours.

These business models are now being revisited in light of the Lean Canvas analysis, incorporating insights from SWOT results and enhancement strategies. This iterative approach ensures that the green business models remain adaptable to market dynamics while fostering collaboration among stakeholders to achieve the 6Green project's overarching goals of energy efficiency and carbon footprint reduction.

The following sections delve into the three refined green business models—Service-Oriented, Partnership-Based, and Adoption Strategy—each tailored to specific aspects of the 6Green project's objectives.

2.5.1 Model 1: Service-Oriented

The **Service-Oriented Model** positions sustainability as a core value proposition by integrating green metrics into SLAs. The following SWOT analysis assesses its feasibility and potential impact within the 5G/6G ecosystem.

- **Strengths**: The innovative nature of this model aligns well with the strengths identified in the SWOT analysis, particularly the expertise and commitment to sustainability. This can enhance customer trust and adoption.
- **Weaknesses**: The high development costs may hinder the initial rollout of these services. Addressing this through strategic pricing or phased implementation could mitigate this weakness.
- **Opportunities**: The growing demand for sustainable services presents a significant opportunity for this model. Marketing efforts can emphasize the environmental benefits to attract eco-conscious customers.
- **Threats**: Intense competition may require differentiation strategies, such as unique service features or superior customer support, to maintain market share.

2.5.2 Model 2: Partnership-Based

The **Partnership-Based Model** leverages partnerships to reduce operational costs and carbon footprints through joint ventures and resource sharing while fostering innovation. The following SWOT analysis explores the strategic advantages and challenges associated with this collaborative approach.

- **Strengths**: The collaborative approach of this model leverages the consortium's strengths, such as expertise and shared resources, enhancing its viability.

- **Weaknesses**: The complexity of managing partnerships and aligning goals may pose challenges. Clear communication and defined roles within partnerships can help mitigate this issue.
- **Opportunities**: Forming strategic alliances with energy companies and tech firms can amplify the model's impact and reach. This aligns with the identified opportunity for collaboration.
- **Threats**: Regulatory changes could affect partnership dynamics. Staying informed about regulatory trends and adapting partnerships accordingly will be crucial.

2.5.3 Model 3: Adoption Strategy

The **Adoption Strategy Model** aligns customer engagement with sustainability goals by encouraging behaviors such as reduced data usage during peak hours or offering optimized data packages for energy efficiency. The following SWOT analysis examines how this strategy can drive user adoption while addressing market challenges.

- **Strengths**: The focus on innovative usage strategies is supported by the consortium's strengths in technology and sustainability, making it a compelling offering.
- **Weaknesses**: The potential resistance to change from customers may slow adoption. Educational campaigns and incentives can help overcome this barrier.
- **Opportunities**: The increasing awareness of sustainability among consumers presents a favorable environment for promoting energy-efficient practices. This model can capitalize on this trend through targeted marketing.
- **Threats**: Market resistance and competition may challenge the adoption strategy. Continuous engagement with customers and showcasing the benefits of energy-efficient practices will be essential to counteract this threat.

The SWOT analysis results reinforce the relevance of the defined green business models while also highlighting areas for improvement. The strengths of the consortium can be leveraged to enhance the service-oriented and partnership-based models, while addressing weaknesses through strategic planning and customer engagement. Opportunities in the sustainability market can be capitalized on, particularly in the adoption strategy, while threats from competition and regulatory changes necessitate proactive measures. Overall, the analysis suggests that the green business models are well-positioned to succeed, but they will require adaptation and responsiveness to the dynamic market environment.

2.5.4 Evolution of Green Business Models Through Lean Canvas and Ecosystem Alignment

The **Service-Oriented**, **Partnership-Based**, and **Adoption Strategy** models have evolved significantly since D4.1, driven by insights from Lean Canvas and aligned with the 6G Smart Networks and Services Industry Association (6G-IA) White Paper on emerging 5G ecosystem business models [55].

The key changes are mainly due to:

- **Ecosystem Complexity**: The transition from linear value chains to ecosystem-based value networks (as highlighted in the 6G-IA white paper) necessitated a shift. Traditional telecom models, focused on vendor-operator relationships, could not address the interdependencies of disaggregated 5/6G technologies, softwarisation, and multi-stakeholder collaboration. The Lean Canvas analysis revealed that siloed approaches risked inefficiency in addressing sustainability goals and market demands.

- **Sustainability Imperatives**: Enhancement analysis of Lean Canvas components (e.g., value propositions, cost structures) exposed gaps in aligning business models with environmental metrics. For example, the original **Service-Oriented Model** lacked mechanisms to quantify carbon reduction. Feedback from consortium partners emphasized integrating sustainability KPIs (e.g., energy savings per service unit) directly into revenue streams and customer agreements.
- **Stakeholder Collaboration**: The **Partnership-Based Model** evolved to reflect the white paper's emphasis on value networks over transactional partnerships. Initial models underestimated the need for dynamic risk-sharing and co-innovation frameworks. Lean Canvas findings showed that 7 out of 10 partners prioritized joint R&D for energy efficiency, leading to redesigned governance structures and profit-sharing mechanisms.
- **Market Dynamics**: The **Adoption Strategy Model** shifted from generic user incentives to ecosystem-driven behavioral nudges. The Lean Canvas highlighted that vertical industries (e.g., smart manufacturing) require tailored solutions, aligning with the white paper's call for "vertical ecosystems" that embed 5/6G services into sector-specific workflows.

The Lean Canvas analysis validated the need for adaptive business modeling in three ways: (i) **value proposition** expanded to include regulators and sustainability-driven enterprises (e.g., telecom operators now position energy efficiency as a regulatory compliance tool, not just a cost-saving measure); (ii) **cost structure** are optimized via shared infrastructure and platform-based solutions; and (iii) new **revenue streams** (e.g., performance-based pricing tied to carbon reduction) emerged from the iterations to mirror sustainability-oriented monetization.

Moreover, the redesigned models align with the white paper's five-step framework:

- **Expand**: identified new roles (e.g., green-certification bodies) within the ecosystem.
- **Focus**: prioritized carbon reduction as a core value proposition across all models.
- **Design**: integrated tools like sustainability model canvassing to map stakeholder dependencies.
- **Business Case Development**: validated models via pilot deployments with vertical industries.
- **Iterate**: established feedback loops using Lean Canvas KPIs (e.g., partner engagement scores).

The **Service-Oriented**, **Partnership-Based**, and **Adoption Strategy** models have evolved in line with the ecosystem shift from linear value chains to value networks and with the growing emphasis on sustainability metrics and incentives across 5/6G, as outlined by the 6G-IA white papers on emerging business models [55][58] The Lean Canvas exercise and SWOT synthesis (presented in Section 2.4 and Annex B, respectively) confirmed that disaggregation, softwarisation and multi-actor coordination require business constructs that make sustainability both measurable and actionable across roles. In particular, the revised models explicitly integrate decarbonisation indicators aligned with BEREC's reporting framework [43], adopt intent and KPI vocabularies consistent with GSMA GST and 3GPP energy-related KPIs [48][50], and embed market mechanisms that reflect techno-economic feasibility under realistic power and emissions profiles [54] and policy constraints (see Annex A).

The methodology, firstly, led to the operationalisation of a DLA-aware intent catalogue that extends slice requests with sustainability semantics aligned with BEREC's indicators and 3GPP's energy-related KPIs. These DLA fields, namely energy consumption, carbon emissions, energy efficiency, and use of renewable energy, are reflected in the VAO-BSSF interactions and Day-0 Slice Intent mechanism (described in Sections 3.1 and 3.2.1), as well as consumed by runtime policies and actions at the Vertical Layer (described in Sections 3.3 and 3.4)—thereby closing the loop between negotiation and enforcement. This alignment also addresses the well-known gap between the high-level GST energy attributes and the operational KPIs required for lifecycle management, as described in Section 2.3.1.

Secondly, the **Partnership-Based** model converged into an incentivisation framework that was formalised and evaluated as a MILP (described in Section 2.3.3 and Annex A), using empirical power consumption and carbon intensity profiles from the literature [54] and standard KPI definitions from GSMA and 3GPP. The framework explores policy choices such as Laissez-faire, subsidisation of green infrastructure, uniform DLAs, and tiered DLAs with premium pricing, demonstrating how each option affects acceptance decisions, allocation of virtual resources, operational cost and environmental footprint under demand scaling. The analysis indicates that tiered DLAs and glide-path constraints can better align environmental outcomes with market viability when combined with transparent measurement, reporting, and verification of sustainability indicators [32][43] and with adequate capacity planning for greener resources.

Third, the **Adoption Strategy** model was translated into enforceable Vertical Layer policies and workflows, including energy-aware scaling and migration, as well as scale-to-zero with automatic reactivation (described in Sections 3.3 and 3.4). These policies combine application-level metrics with network and infrastructure analytics and use the VAO policy data model and orchestration loop to trigger actions that respect negotiated intents and KPI thresholds. This brings into operation the Energy-Aware Backpressure paradigm by binding policy triggers to energy and emissions indicators that are attributable to slices, functions and application components, and is consistent with the state-of-the-art in slice selection and negotiation under energy constraints [48]-[50].

Beyond 6Green, actor-specific guidance follows from these findings, as well as from the broader policy and standardisation context.

- **Infrastructure Providers** can publish machine-readable power and carbon-intensity profiles per site and per resource class and expose authenticated telemetry consistent with recognized methodologies for ICT environmental assessment [39][41] and with sustainability disclosure requirements [32]. They can increase the share of renewable energy through power purchase agreements and storage in line with the European Green Deal [2] and the Clean Industrial Deal [21], and they can signal the availability of greener capacity windows to upstream schedulers and orchestrators, which reflects the capacity constraints and demand dynamics observed in the policy scenarios evaluated in Annex A.
- **Network Platform Providers** can productise DLA-aware service catalogues that include standard, low-carbon and net-zero tiers mapped to GST and 3GPP KPI definitions, implement measurement, reporting, and verification that binds slices and applications to energy, emissions, efficiency and renewable-share indicators [32][42], as well as enable (re-)negotiation workflows through the BSSF in accordance with the lifecycle management operations described in Sections 3.1 and 3.2.
- **Vertical Application Providers** can design with policy hooks for latency, throughput, energy and carbon objectives, tag workloads and data flows for footprint attribution using BEREC-aligned indicators and expose green options to End Users, building on evidence that awareness and incentivisation can influence End User behaviour [18]. Standardisation bodies and industry fora can extend GST's energy attribute beyond a Boolean flag to thresholds and targets that reflect energy consumption, carbon emissions, energy efficiency and renewable share, as well as continue to standardise telemetry schemas and northbound intents that are interoperable with analytics functions and policy engines within the SBA.

- **Policy Makers and NRAs** can recognise DLA constructs as verifiable instruments by requiring minimal sustainability telemetry for wholesale and retail offers, prefer glide-path DLAs and tiered green services where appropriate, as well as consider targeted, time-bound incentives in line with existing policy toolkits to address cost barriers and green-capacity bottlenecks [2][20][21] and as supported by the policy scenario analysis in Annex A.
- **Procurement bodies and ecosystem governance arrangements** can weigh energy, emissions, efficiency and renewable-share KPIs in rewards and adopt risk- and reward-sharing mechanisms that support value networks as advocated in ecosystem business model work [55][58].

A practical roadmap can be developed aligns with the above sources and with the mechanisms established in this deliverable. In a first phase, organisations can baseline telemetry and adopt a minimal DLA catalogue that reuses established indicators and KPIs, while rolling out a Vertical Layer policy cookbook for energy-aware scaling and placement with the VAO workflow. In a second phase, they can introduce tiered services and (re-)negotiation workflows that reflect the policy options assessed in Annex A, align sustainability reporting with corporate disclosure requirements [32], and pilot green premiums—where justified by customer segments and service contexts [55][58]. In a third phase, they can progressively tighten DLA thresholds along a glide path, extend cross-actor reporting, and invest in additional green capacity to address the saturation effects identified in the policy scenarios in Annex A, while maintaining compatibility with GST and 3GPP KPIs, as well as with Measurement, Reporting and Verification practices [43][48][50].

3 Vertical Application Orchestration in 6Green

Vertical Application Orchestration is a framework designed to manage the deployment and runtime operation of vertical applications, ensuring elasticity and adherence to high-level application policies. It effectively decouples and abstracts the application layer management procedures from network layer management, while providing application awareness to the underlying slice creation and management systems. It ensures compatibility with any structured slice management and network orchestration solutions.

Interfacing with the frontend user is important for onboarding requested application components, to collect the application-level requests and to transform them into resources intents, ensuring that these meet the functional and operational requirements of vertical applications. The following aspects of vertical application orchestration are **mandatory**:

Automation

One of the primary goals of vertical application orchestration is to automate repetitive tasks, reducing the need for manual intervention. This includes automated deployment, scaling and updates of applications.

Deployment Management

Orchestration tools help manage the deployment of applications across different environments, such as development, testing, staging and production. This ensures consistent and reliable application behaviour.

Configuration Management

Orchestration manages the configuration of application components, ensuring they are correctly set up and can communicate with each other effectively.

Resource Allocation

It involves managing and allocating the necessary computational resources, such as central processing unit (CPU), memory, and storage, to different application components to optimize performance and efficiency.

Scalability

Orchestration tools provide mechanisms for scaling applications up or down based on demand. This ensures that applications can handle varying loads without performance degradation.

Fault Tolerance and Recovery

Orchestration includes mechanisms for detecting failures and automatically recovering from them, ensuring high availability and resilience of applications.

User Interface and API Integration

Modern orchestration tools often provide intuitive user interfaces and APIs, allowing developers and operations teams to easily manage and interact with the orchestration system.

3.1 The 6Green VAO

6Green leverages a Vertical Application Orchestrator (VAO) designed to ensure seamless integration and interoperability between application and network orchestration layers, as well as application awareness within the 6Green Service-based Architecture (SBA). The VAO is meant to handle the complete lifecycle management of vertical applications, requesting both the resources in the edge-cloud continuum and the network slice configuration, triggering Green Elasticity and Edge Agility operations at the Vertical Layer according to the current/expected workload (e.g., exploiting diurnal fluctuations, user mobility, etc.).

6Green aims to transition from legacy top-down approaches developed in previous projects (e.g., MATILDA [56], 5G-INDUCE [57]), where the VAO asks for network slices in an infrastructure-agnostic fashion and the platform rigidly sets up and maintains them, into a **fully bidirectional** and more dynamic intent-based system, allowing the VAO to renegotiate its intents based on energy-related KPIs and according to the Energy-aware Backpressure information flows.

Figure 7 depicts the interaction between the VAO and the 6Green SBA. In the 6Green design, the VAO implements a **trusted** Application Function (AF) that serves as the entry point for vertical application intents, including deployment requirements, performance objectives and energy-efficiency constraints. As an extended 3GPP AF, it will interact with various Network Functions (NFs) within the 6Green SBA to enable both application-aware network orchestration and network-aware application orchestration.

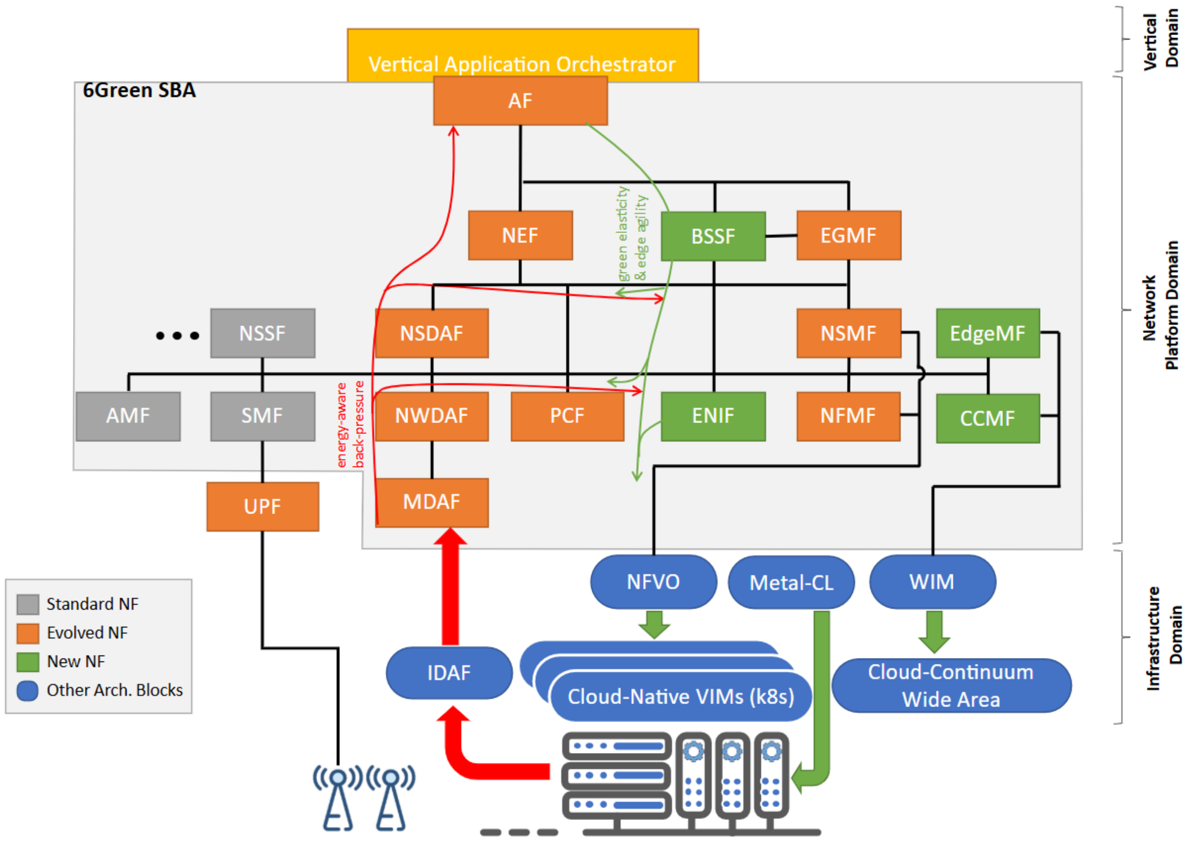

Figure 7: How the VAO interacts with the 6Green SBA.

The VAO/AF interfaces directly with the BSSF, the NF that interprets the high-level slice intents received from a customer and translates the corresponding actions within the SBA. This also involves engaging the Experiential Networked Intelligence Function (ENIF) to ensure optimized workload placement based on energy and resource availability. The delegation path is illustrated in Figure 7 using green arrows, which denote operations related to Green Elasticity and Edge Agility. In addition, the VAO/AF also interfaces with either Network Data Analytics Function (NWDAF), Management Data Analytics Function (MDAF) or Infrastructure Data Analytics Function (IDAF) to obtain infrastructure analytics and resource usage indicators, enabling feedback loops that help drive vertical application adaptation decisions. The delegation path for this is illustrated by the red arrow, representing operations related to Energy-aware Backpressure. Overall, this architecture ensures that vertical application requirements, expressed via the VAO, are translated into dynamic and energy-efficient deployment strategies within the SBA, with the BSSF serving as a main point for (re-)negotiations.

Figure 8 illustrates the VAO internal architecture, which is divided into two layers:

Application Composition Layer

The Application Composition Layer is a critical part of the orchestrator, designed to support the creation and onboarding of vertical applications through a structured methodology and targeted Graphical User Interfaces (GUIs), as well as facilitates the definition of application policies.

The **Application Composition** module enables the authoring of abstract representations of cloud applications, which include various requirements in the form of constraints. To facilitate this, service providers package the microservices that implement the business logic into a format suitable for publication in the application catalogue.

During the application composition phase, each application component undergoes design-time validation to ensure the integrity and consistency of its model. This process also guarantees the preservation of all properties, specifically:

- Metadata regarding minimum infrastructural requirements
- Metadata regarding deployment preferences
- Metadata regarding configuration parameters during component initialization
- Mutable configuration parameters during runtime
- Exposed and required interfaces

The **Vertical QoS Parameter Editor** module is implemented to allow service providers to define and enforce constraints essential for the optimal operation of vertical applications. These constraints are diverse in nature and are systematically captured and formalized by the module to ensure consistent application behaviour across varying deployment environments. Generally, these constraints can be divided into two main categories:

- *Cloud-related* constraints focus on (e.g., memory, CPUs, storage, and input/output (I/O) throughput) and deployment (e.g., geographical location, specific device characteristics, such as the need for Field Programmable Gate Arrays (FPGAs) or graphical processing units (GPUs)) requirements.
- *Non-cloud-related* constraints focus on network and operational parameters. These constraints set minimum or maximum thresholds for aspects like end-to-end latency or deployment time. Additionally, they define desired QoS classifiers based on the performance of the available programmable resources.

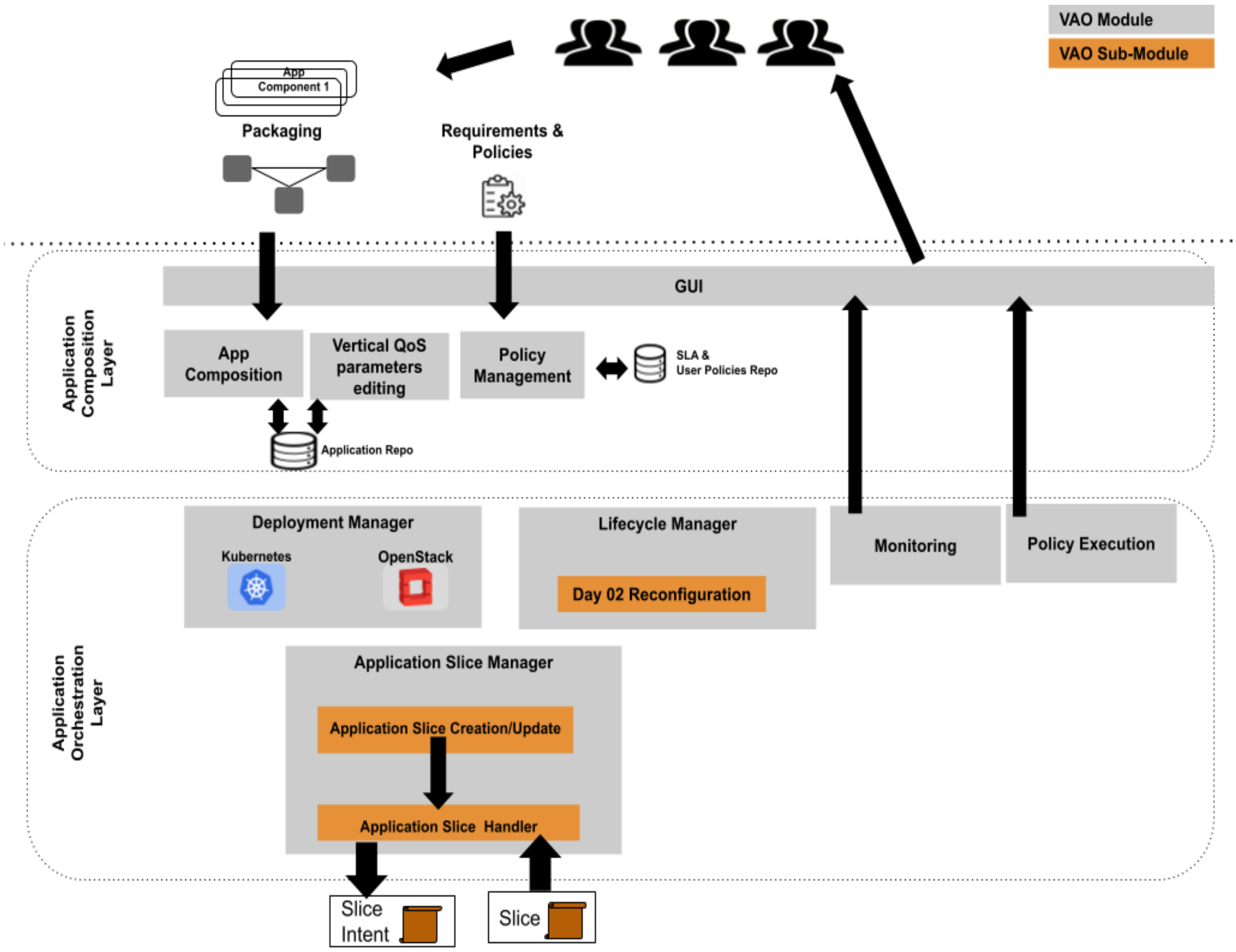

Figure 8: VAO internal architecture.

The **Policy Management** module supports runtime reconfiguration of the vertical applications after the initial deployment. This reconfiguration, referred to as a policy, aims to meet specific business goals encapsulated in an SLA. To achieve these goals, various actions may need to interact with the control plane. Examples of such actions include allocating additional resources, spawning new instances of cloud-native components, renegotiating the entire slice and other actions. The actions are triggered by rules based on monitoring data and facilitated by the orchestration loop. The supported actions combine the programmability offered by the virtualized infrastructure and its integration into the orchestration control plane.

Application Orchestration Layer

The Application Orchestration Layer provides operational capabilities on top programmable resources to enable and sustain vertical application deployments. It comprises several specialized modules, each responsible for distinct orchestration functions described as follows.

The **Deployment Manager** module is responsible for executing the initial deployment of the vertical application graph onto programmable infrastructure. It interfaces with the underlying registered infrastructure through an abstract management API, enabling fundamental virtualization operations such as tenant selection/creation and namespace management. This module leverages industry-leading virtualization technologies to ensure efficient and reliable deployment.

The **Lifecycle Manager** module maintains the operational state of deployed vertical applications. Operating as a closed control loop, it continuously evaluates resource availability, deployment requests, and reconfiguration needs. It encapsulates orchestration business logic and acts as a centralized entity, influencing the scheduling of vertical application components.

The **Application Slice Manager** module oversees the complete lifecycle of vertical applications, which can also be seen as "application slices" over a shared virtualized environment. Its operations follow a structured sequence:

1. **Initiation** – Receiving and validating application slice requests.
2. **Instantiation** – Creating and verifying the virtualized environment.
3. **Operation** – Managing the application slice during its active phase.
4. **Deprovisioning** – Releasing resources when the application slice is no longer needed.

During instantiation, it programmatically allocates and configures resources to support the vertical application's lifecycle within the virtualized environment.

The **Policy Execution** module serves as the backend of the **Policy Management** module. It processes authored rules, evaluates them, and coordinates with the **Lifecycle Manager** to enact changes in the operational state of vertical application components. In the 6Green framework, policies are categorized based on their influence either on the initial deployment or ongoing runtime behaviour. Policies are defined as rule-action pairs and serve as inputs to the **Lifecycle Manager**.

Last but not least, the **Monitoring** module is responsible for collecting application-related metrics using active monitoring probes. These probes provide real-time insights into application performance and resource utilization, supporting informed orchestration decisions.

3.2 Vertical Application Lifecycle Management

The complete lifecycle of vertical applications generally includes Day-0/1/2/N stages. The 6Green project developed a reference architecture and specific mechanisms for automating the Day-0/1/2/N operations at the Vertical Layer in a policy-driven fashion that will also be propagated to the Network Platform.

The VAO supports the Day-0/1/2/N operations listed below. While the Day-0 stage was initially more mature, all stages have now been thoroughly elaborated in this deliverable.

Day-0

This stage includes all operations done before and up to the initial deployment of a vertical application, such as (but not limited to):

- application design and onboarding of deployment artefacts to a repository;
- performance and energy constraints elicitation and classification;
- edge-cloud resources request, negotiation and ordering for the deployment of vertical application components;
- network slice request, negotiation and ordering according to the application-level requirements; and
- vertical application deployment onto the edge-cloud Point-of-Presence (PoP) selected.

Day-1

This stage includes all the necessary configurations to enable an application service, such as (but not limited to):

- external endpoint exposure to enable chaining of geographically distributed vertical application components, as well as to make the service reachable from a UE;
- attaching to a 5/6G network slice;
- subscription to metric monitoring; and
- requesting initial QoS control and traffic prioritisation policies to the Network Platform.

Day-2

This stage includes all the runtime operations done after Day-1, such as (but not limited to):

- monitoring performance- and energy-related metrics attributable to the vertical application;
- scaling in/out of application instances;
- edge-cloud resources renegotiation (e.g., increase/decrease allowable capacities, use of hardware-accelerators);
- migration/placement optimisation within the edge-cloud continuum based on either performance or energy constraints;
- network attachment modifications resulting in network slice renegotiations and reconfigurations (e.g., change of User Plane Function (UPF) location/implementation); and
- requesting updated/new QoS control and traffic prioritisation policies to the Network Platform for the vertical application.

Day-N

This stage includes all the necessary operations to decommission an application service, such as (but not limited to):

- detaching from the network and requesting slice decommissioning (if dedicated to vertical application); and
- uninstallation of vertical application components across the edge-cloud continuum.

3.2.1 Day-0 Operations

The initial request that triggers a vertical application deployment comes from the Vertical Application Provider that interacts with the VAO via the GUI. In this interaction, the Vertical Application Provider will ask for the deployment of the desired vertical application, the PoP/s for that deployment along with computational and networking requirements. After that, the VAO, acting as an AF, will send these requirements to the BSSF based on the Slice Intent mechanism, which is pivotal for requesting the creation of an application-aware network slice, taking into account the specified computational, networking, QoS and energy requirements as defined by the Vertical Application Provider. This mechanism also ensures that the network slice is tailored to meet the precise needs of the application, facilitating optimal performance and resource utilisation.

The Day-0 stage encompasses three key phases, illustrated in Figure 9.

Phase 0: Formulation

The initial step involves converting a vertical application definition into a slice intent. The process begins with the Vertical Application Provider onboarding the vertical application through the VAO and specifying high-level requirements about the vertical application. At the same time, the VAO must identify the programmable resources that the vertical application will require. To accomplish this, the VAO (acting as an AF) contacts the BSSF, which in turn communicates with the Edge-cloud Management Function (EdgeMF) to retrieve a list of geographical areas (PoPs) available for deployment. Once the available locations are retrieved, the VAO displays them to the Vertical Application Provider for selection. After reviewing the options, the Vertical Application Provider selects the desired PoPs and then submits the initial vertical application deployment request to the VAO, including the computational, networking and location (the selected PoPs) constraints. Using this complete set of requirements, the VAO prepares the necessary data to construct the slice intent, which will then be sent to the BSSF.

Phase 1: Realisation

The second phase begins with the VAO (acting as an AF) submitting the slice intent to the northbound API of the BSSF, detailing the required resources, configurations, and application constraints. Upon receiving the slice intent, the BSSF begins the process of creating the application-aware network slice. To achieve an optimized deployment, the BSSF first contacts the ENIF with a request to place the components described in the slice intent, enforcing the computational constraints. The ENIF then performs an internal optimization process to determine the most efficient placement of these components, within the selected PoP specified by the slice intent, considering factors such as resource availability, latency and performance targets. After completing this analysis, the ENIF returns the optimized placement data to the BSSF, including the credentials needed to access the target infrastructure (e.g., Kubernetes clusters or nodes). Then, BSSF proceeds to request the instantiation of the network slice by contacting the Network Slice Management Function (NSMF). This step enforces the networking constraints defined in the slice intent, ensuring that the necessary network resources are allocated and the network slice is configured in alignment with the deployment requirements. Once the NSMF completes the network slice instantiation, it returns the result to the BSSF, completing the realisation phase.

Phase 2: Deployment

The final phase begins when the BSSF notifies the VAO/AF that the network slice instantiation has been successfully completed, while also providing the network slice details, including the credentials of the selected infrastructure (such as Kubernetes cluster credentials and target worker node) in the requested PoP. At this point, the VAO takes over the process to deploy the target vertical application. Using the configuration and resource details provided by the BSSF, the VAO initiates the deployment of the vertical application on the target infrastructure and attached to the network slice. This ensures that the application runs in an environment that is aligned with the specified computational, networking and QoS requirements. Once the deployment is complete and the vertical application is operational, the VAO notifies the Vertical Application Provider that the service is ready. This marks the completion of the Day-0 workflow, with the vertical application now running on a fully tailored and optimized application-aware network slice.

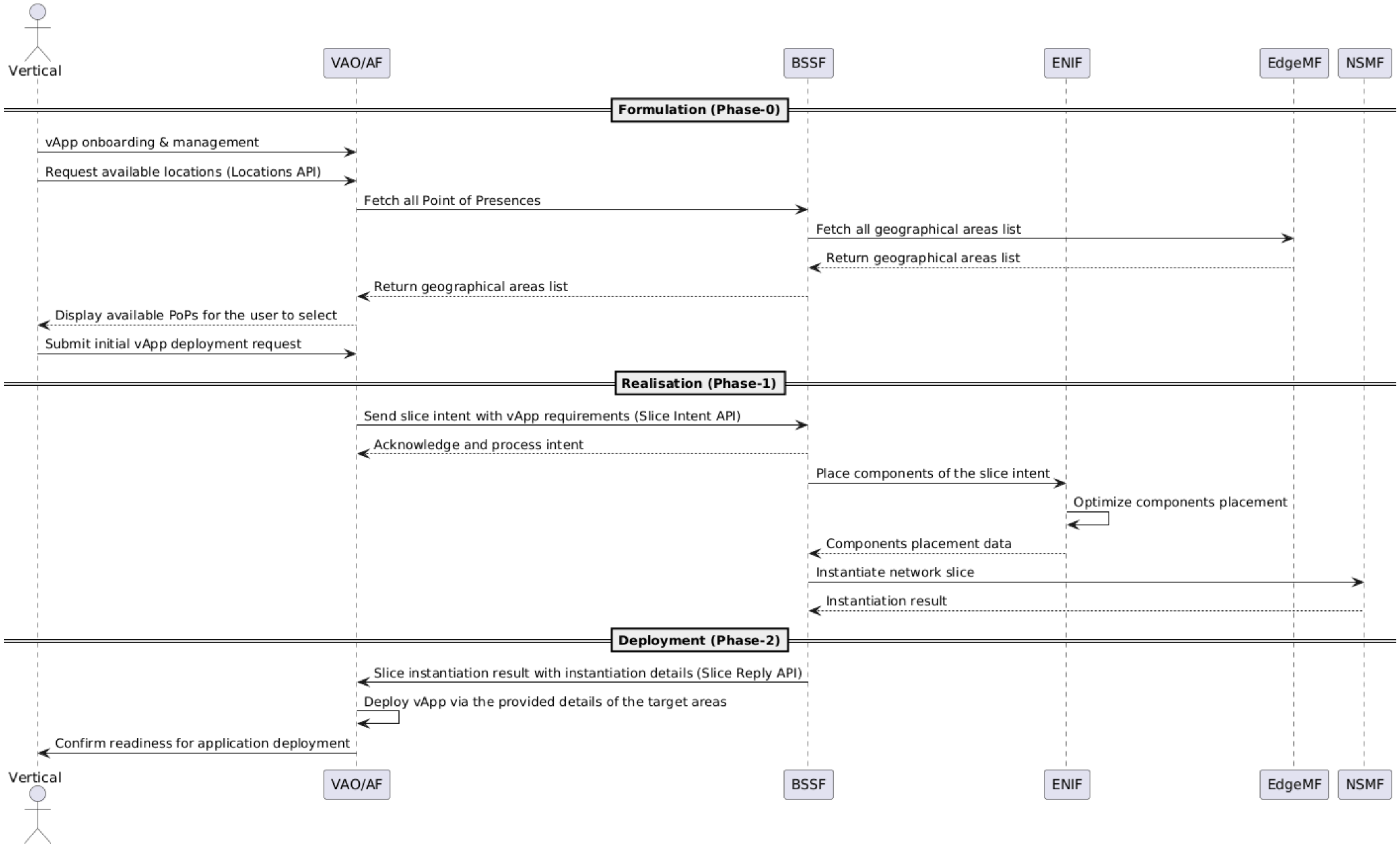

Figure 9: Day-0 workflows at the Vertical Layer.

In a nutshell, the **Slice Intent** mechanism consists of a set of constraints that must be fulfilled by the 6Green SBA to meet the requirements of the Vertical Application Provider. The fulfilment of these constraints relies on solving the theoretical optimization problem formed by aggregating all the provided constraints, based on the intent translation and optimization mechanisms supported by ENIF. The process involves the following steps:

1. **Constraint Classification**
   Constraints are defined and classified as either soft or hard. Soft constraints are preferable but not essential, whereas hard constraints must be met without exception.

2. **Notification**
   The Vertical Application Provider is informed through the GUI about the success or failure of resource allocation.

   - **Success**: If all hard constraints (and as many soft constraints as possible) are met, the Vertical Application Provider is notified of successful resource allocation.
   - **Failure**: If one or more hard constraints cannot be fulfilled, the user is notified of the failure. The Vertical Application Provider can then review and modify the set of requirements, potentially relaxing some constraints or reclassifying them as soft before attempting another deployment.

By following these steps, the **Slice Intent** mechanism ensures that network slices are provisioned in alignment with the specific requirements of each application. It achieves a balance between satisfying mandatory constraints and optimizing desirable ones, thereby enhancing the efficiency and adaptability of network resource allocation. This structured approach not only improves service delivery and user satisfaction but also effectively bridges the gap between application demands and network capabilities—ensuring that applications are deployed in environments fully optimized for their operational needs.

3.2.2 Day-1 Operations

Once the vertical application has been deployed, it needs to be configured first before the service becomes available for its users. Below are the Day-1 operations explored within the project.

Chaining of vertical application components

For geographically distributed vertical applications, all components deployed across the edge-cloud continuum need to have endpoints that are exposed accordingly to peer components, as well as to the End Users, to enable the end-to-end application service.

5/6G network slice attachment

Necessary configurations within the 6Green SBA should be done to specify the UPF/s and Data Networks to be used for the application service. This allows for keeping traffic locally for services deployed at the edge, close to the End Users.

Subscription to metrics monitoring

The AF can subscribe to relevant network-, management- and infrastructure-level metrics from NWDAF, MDAF and IDAF, respectively, for driving Vertical Layer policies.

Although many of the Day-1 operations are automatically enabled by the Slice Intent mechanism during Day-0, maintaining the separation between the two stages remains important. Day-0 is dedicated to the provisioning and instantiation of resources: reserving compute, instantiating the network slice, optimizing placements, and deploying the vertical application from the VAO onto the selected PoPs. In contrast, Day-1 starts once the application has been deployed, focusing on service activation and configuration. Some of these steps are already prepared during Day-0: for instance, the 5/6G network slice attachment is automatically configured by the NSMF when instantiating the slice and binding it to the selected Kubernetes cluster, and the subscription to monitoring is facilitated by the slice reply, which provides credentials and Prometheus endpoints for collecting data from NWDAF, MDAF, IDAF or any other component. Likewise, chaining becomes effective at Day-1, as the platform activates the endpoints exposed during deployment so that components can interconnect according to the vertical application graph.

3.2.3 Day-2 Operations

Day-2 operations are runtime adaptations that may occur either as part of (i) policies specified in the initial agreement, such as latency constraints and energy budgets, among others; or (ii) renegotiations towards the Network Platform and the compute infrastructure when the original allocation no longer satisfies the vertical application's needs. In the latter case, these renegotiations can be expressed as a slice update, referencing the slice intent as the basis for adjusting resources and constraints. Although the exact requirements for runtime actions may vary by use case and renegotiation approach, the necessary mechanisms are already in place to support these capabilities.

Below are representative examples of Day-2 operations leveraging cross-layer monitoring and analytics. These monitoring-driven runtime actions mark a first step toward fully automated operations. A wide range of metrics can be collected across different layers, enabling enforcement of Day-2 policies or triggering dynamic renegotiations as needed.

- *Application-level* metrics such as number of users, number of video streams, end-to-end latency, etc. can be used as bases to trigger actions like scaling of application (component) instances.
- *Network-level* metrics coming from the 6Green SBA and corresponding analytics are consolidated in the NWDAF and can be exposed to drive network-aware application orchestration. For example, handover events due to user mobility can be used as basis for migration/placement of application components across the edge-cloud continuum.
- *Infrastructure-level* metrics such as resource (CPU, random-access memory (RAM), disk, GPU) utilisation and power/energy consumption attributable to a vertical application (component) are available from IDAF, which can be used as bases to trigger actions like hardware offloading, sleep modes, etc.

3.2.4 Day-N operations

For a graceful vertical application service termination, there are a number of operations that needs to be done at both Network Platform and Infrastructure layers. Below are some indicative examples of Day-N operations that can be explored within the project.

5/6G network slice detachment

Within the 6Green SBA, all configurations and Network Platform artefacts related to the vertical application service should be gracefully removed. If a network slice / UPF has been deployed and configured for dedicated use by the service, slice / UPF decommissioning should also be requested to release the Network Platform resources.

Vertical application components uninstallation

All vertical application components across the edge-cloud continuum need to be completely uninstalled, this means that all configuration/deployment artefacts within the compute infrastructure must be gracefully deleted in the required order.

3.3 Vertical Layer Policy Definition

In Cloud computing, SLAs are commonly used to define policies that guide the lifecycle management of software components deployed on Cloud platforms, including vertical applications. Each SLA comprises one or more Service Level Objectives (SLOs), which specify target values or acceptable ranges for specific performance metrics. These SLOs are then bound to actions through policies, which are executed by an orchestrator—either integrated within the Cloud platform or provided by an external component such as the VAO.

Figure 10 illustrates this concept using an example of an elasticity strategy. In current production environments, it is typical to define one policy per metric—for instance, monitoring average CPU or memory usage, or throughput, to trigger scaling actions. However, emerging approaches are beginning to adopt composite metric profiles, where multiple metrics are combined to form a profile, and policies are defined per profile. This shift enables context-aware orchestration strategies.

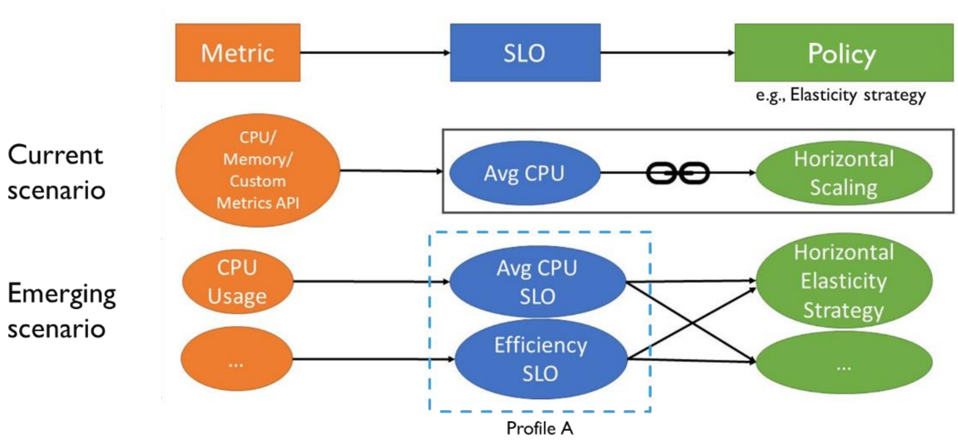

Figure 10: Policies as a concept.

While the VAO provides robust capabilities for Vertical Layer management, certain policies cannot be enforced directly, as they fall within different administrative domains. For example, the VAO does not manage network-related resources, which are controlled by the underlying Network Platform. The VAO is only responsible for policies strictly related to the Vertical Layer, such as application (component) scaling or serverless migration, and acts as an AF to delegate network-related policies to other SBA NFs through BSSF. For instance, network resource management is delegated to the NSMF, while network slice and Packet Data Unit (PDU) session related policies are handled by the Policy Control Function (PCF).

3.3.1 Policies Architecture

Each vertical application component is inherently associated with specific minimum requirements, expressed as hard constraints. These constraints are critical and must be met; otherwise, any deployment is rendered invalid. In addition to these essential constraints, the Vertical Application Provider may define additional guidelines or instructions that govern how the vertical application should behave—both prior to deployment and during runtime.

These instructions are referred to as policies, and are categorized based on their scope of influence:

- **Design-Time policies** affect the initial deployment configuration. They are defined using equality or inequality expressions based on constraints set in the **Vertical QoS Parameter Editor**. These policies are evaluated by a heuristic optimization solver before runtime to generate near-optimal deployment plans. One of these candidate plans is selected and managed by the **Lifecycle Manager** and the **Deployment Manager**.

- **Runtime policies** govern the application's behaviour during execution. They are evaluated concurrently and are formally expressed as sets of rules and actions. Each rule represents an SLO that outlines the desired state at either the vertical application graph or component level. Achieving or addressing deviations from these SLOs requires specific actions interpreted by the orchestration engine.

This distinction enables more structured and adaptive management of vertical applications throughout their lifecycle. Both types of policies must be authored and validated in a type-safe manner, a task handled by the **Policy Management** (frontend). The policies are stored in a repository and can be accessed by the **Lifecycle Manager** and the **Deployment Manager**, as their definitions are necessary for activating and managing required services. Figure 8 illustrates the policies architecture for vertical applications.

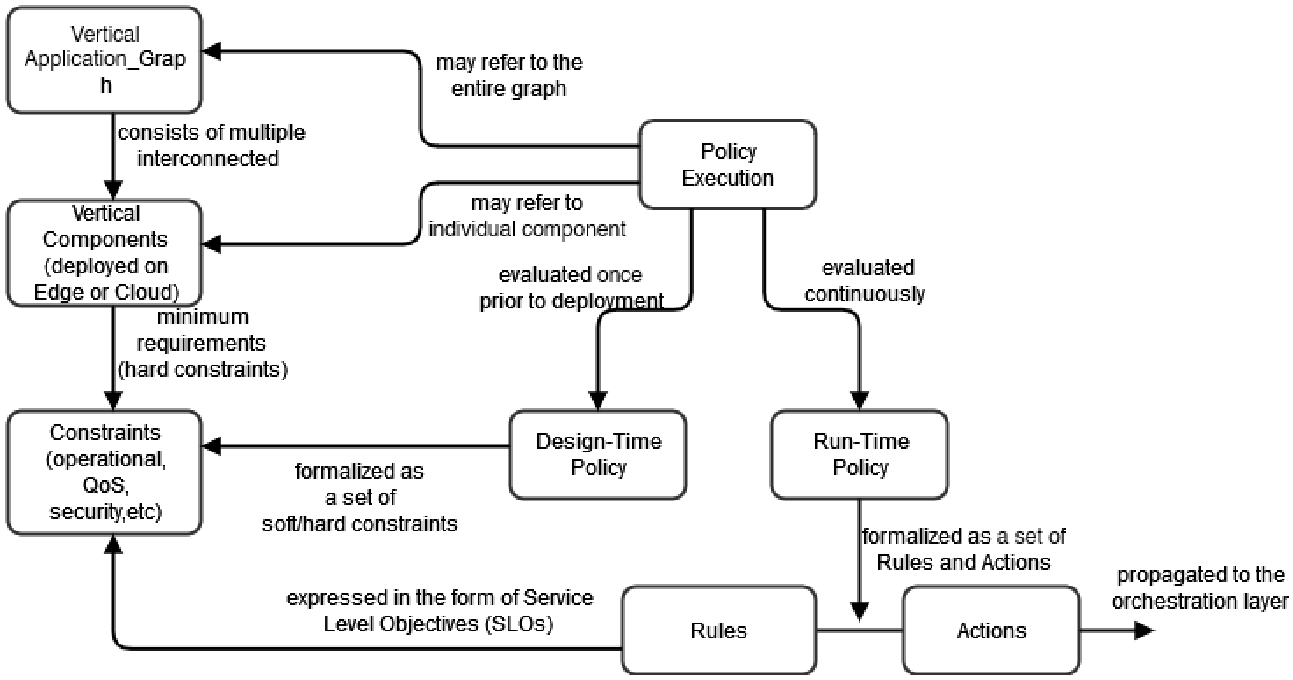

Figure 11: Policies architecture.

3.3.2 Design-Time Policies

The VAO supports various Design-Time policies with soft/hard constraints that can be associated with the vertical application deployments.

Compute and Storage Requirements

These specify detailed compute and storage needs for each vertical application component. This includes parameters such as the number of CPU cores, the amount of RAM, and the required disk space per component. These specifications ensure that the applications have sufficient resources to operate efficiently.

Networking KPIs

These parameters ensure compliance with specific SLAs by defining key networking KPIs such as maximum latency, minimum throughput, number of PDU sessions, and slice profiles (e.g., eMBB). They also specify 5G slice isolation levels (physical, virtual, or none), QoS flow and profile definitions (e.g., 5G QoS Identifier (5QI)), and both guaranteed and maximum bitrates for UEs and allowed for PDUs.

Location Requirements

By accessing the registry of Edge and Cloud datacenters managed and registered within EdgeMF, the VAO gains comprehensive visibility into these facilities. Through the API exposed by the BSSF, the VAO can retrieve detailed information about all available PoPs hosting Cloud or Edge resources across the compute continuum. This data is then made available to Vertical Application Providers, enabling them to design and deploy vertical applications to target datacenter locations, optimizing performance and resource utilization.

Elasticity Requirements

These enable the independent orchestration and scaling of application components in response to specific events or conditions. For example, vertical applications can automatically scale out (add more instances) or scale in (remove instances) and can even be migrated in a serverless manner to the most optimal location provided by the platform, based on demand. This dynamic behaviour ensures efficient resource utilization and sustained performance during peak loads. Elasticity requirements can be linked to metrics provided by the NWDAF or IDAF, enabling informed and adaptive scaling decisions.

Special Processing Requirements

These may include the requirements for particular hardware devices (e.g., GPUs for high-performance computing tasks or system libraries). In addition, the choice of the Cloud platform technology can also be guided by these requirements, supporting platforms such as Kubernetes or OpenStack.

3.3.3 Runtime Policies

Runtime policies are defined by policy rules and actions, as described as follows.

Policy Rule Data Model

The policy rule data model is central to the effective functioning of the policy definition and management. It defines the structure of a policy rule, ensuring that all necessary information is captured and can be processed by the system. The data model typically includes the following elements:

1. **Rule Identifier**: A unique identifier for each policy rule.
2. **Conditions**: The specific conditions that trigger the rule. These could include metrics such as CPU usage, memory consumption, network latency or custom-defined events. Additionally, computation-related metrics provided by the 6GREEN platform, such as energy efficiency indicators, carbon footprint estimations and workload distribution efficiency, can also serve as triggers for policy enforcement or adaptation.
3. **Actions**: These refer to the actions triggered when predefined conditions are met. Such actions may include scaling resources up or down, adjusting QoS parameters, serverless migration to the optimal location and enabling green monitoring options (i.e., supporting automatic scaling to zero for applications with no active traffic, enhancing energy efficiency).
4. **Priority**: The priority level of the rule, which determines the order in which rules are applied when multiple conditions are met simultaneously.
5. **Validity Period**: The time period during which the rule is active. This allows for time-based policies that can adapt to predictable changes in demand or operational schedules.
6. **Target Application**: The specific vertical application(s) to which the rule applies.

Below is the JavaScript Object Notation (JSON) schema example that defines a policy rule.

```
{
    "ruleId": "genericPolicyRule",
    "conditions":
    [
        {
            "metricType": "QoSMetricType.EndToEndDelay",
            "metricId": "metricIdentifier",
            "window": "1m",
            "calculation": "average($metric.getValue())",
            "threshold": ">= 40",
            "entryPoint": "MonitoringStream"
        }
    ],
    "actions":
    [
        {
            "actionType": "NetworkLinkFunction.ProvideDedicatedBandwidth",
            "target": "targetIdentifier",
            "parameters":
            {
                "bandwidth": 200
            }
        }
    ],
    "priority": 1,
    "validityPeriod": "2024-01-01T00:00:00Z/2024-12-31T23:59:59Z",
    "targetApp": "clientServerRtp"
}
```


Listing 1: JSON schema example defining a policy rule.

Actions

In the context of 6Green, policy rules can trigger specific actions to manage and optimize performance and resource allocation. These actions are strictly limited by the orchestration capabilities the platform can support. The actions can be categorized into several types:

Resource Management Actions

- Resource Scaling:
    - Scale Up: Increase the allocation of resources such as CPU, memory, or storage to a particular application component.
    - Scale Down: Decrease the allocation of resources to a particular application component.

Network Management Actions

These affect the QoS characteristics like:

- Bandwidth Management:
    - Provide Dedicated Bandwidth: Allocate a specific amount of bandwidth to ensure a particular QoS.
    - Adjust Bandwidth Allocation: Dynamically modify the bandwidth allocation based on current network conditions and requirements.
- Latency Management:
    - Prioritize Traffic: Give higher priority to certain types of traffic to reduce latency.
    - Delay Traffic: Intentionally delay low-priority traffic to ensure high-priority traffic meets latency requirements.

- PDU Sessions Management:
  - Change PDU sessions characteristics or add new session.

Application Management Actions

- Deployment and Configuration:
  - Deploy and Scale Components: Launch new instances of vertical application components as needed, with scale-in and scale-out capabilities to optimize resource utilization and performance based on demand.
  - Reconfigure Components: Adjust the configuration of running vertical application components to optimize performance or meet new requirements.
- Application Mobility:
  - Serverless Migration: Enable the serverless relocation of application components to the most appropriate infrastructure target within a given location (e.g., within an edge or core site). This migration is driven by the 6Green platform intelligence component, namely the ENIF, which selects the optimal infrastructure based on performance, load, latency, or energy efficiency requirements. This allows dynamic and transparent movement of workloads without manual intervention or service disruption.
- Green Monitoring:
  - Enable Scale-to-Zero: Activated by policy based on real-time traffic monitoring, this allows the platform to suspend idle components when no traffic is detected for a define period in order to reduce energy consumption.
  - Auto Reactivation: When traffic resumes, the platform automatically restarts the component to restore service without manual intervention, ensuring seamless continuity and energy efficiency.

Runtime Policy Workflow

Once a runtime policy rule is defined using the structure described above, either instantiated through the data model (see Listing 1) or configured via the VAO/AF GUI, the VAO follows an internal multi-stage workflow to ensure real-time enforcement and execution of the policy, as illustrated in Figure 12.

The process begins when the Vertical Application Provider defines a policy rule by selecting relevant metrics, conditions, and actions applicable to a specific vertical application through the VAO GUI. The VAO internally communicates with the **Policy Execution** to register and submit the policy rule. To support condition validation, the **Policy Execution** retrieves relevant metric definitions from the **Monitoring** function.

After submission, the **Policy Execution** configures alert mechanisms within the **Monitoring** system based on the specified conditions. The **Monitoring** function continuously observes live system metrics (e.g., latency, CPU usage, bandwidth) to evaluate whether any defined condition is met. When a condition becomes true, such as average latency exceeding a threshold, **Monitoring** raises an alert, which is relayed back to the **Policy Execution**.

Upon verifying the alert, the **Policy Execution** initiates the corresponding action by notifying the **Lifecycle Manager**. The **Lifecycle Manager** recalculates resources or performs the necessary orchestration logic. If the action involves network slicing or service quality changes, the **Lifecycle Manager** interacts with the BSSF to update the slice intent. The BSSF, similarly to the slice intent case, contacts the ENIF with a request to (re)assess, if necessary, the components described in the updated slice intent. The ENIF also performs an internal optimization process to determine the most efficient placement for the updated components. After completing the analysis, the ENIF returns the optimized placement data, which may also be unchanged from the original intent, to the BSSF. On the other hand, if the action involves a network slice reconfiguration, the BSSF contacts the NSMF to initiate the update in line with the revised deployment requirements, included in the slice update request. Once the NSMF completes the slice reconfiguration, it returns the result to the BSSF. Once the slice is successfully updated, the BSSF sends a confirmation back to the AF, which then executes the final application-level action for the vertical application and notifies the Vertical Application Provider of the successful operation.

This runtime workflow ensures that policy rules are not only declaratively defined but also proactively monitored and automatically enforced. It enables responsive, intelligent, and energy-aware management of cloud-native applications within the 6Green platform.

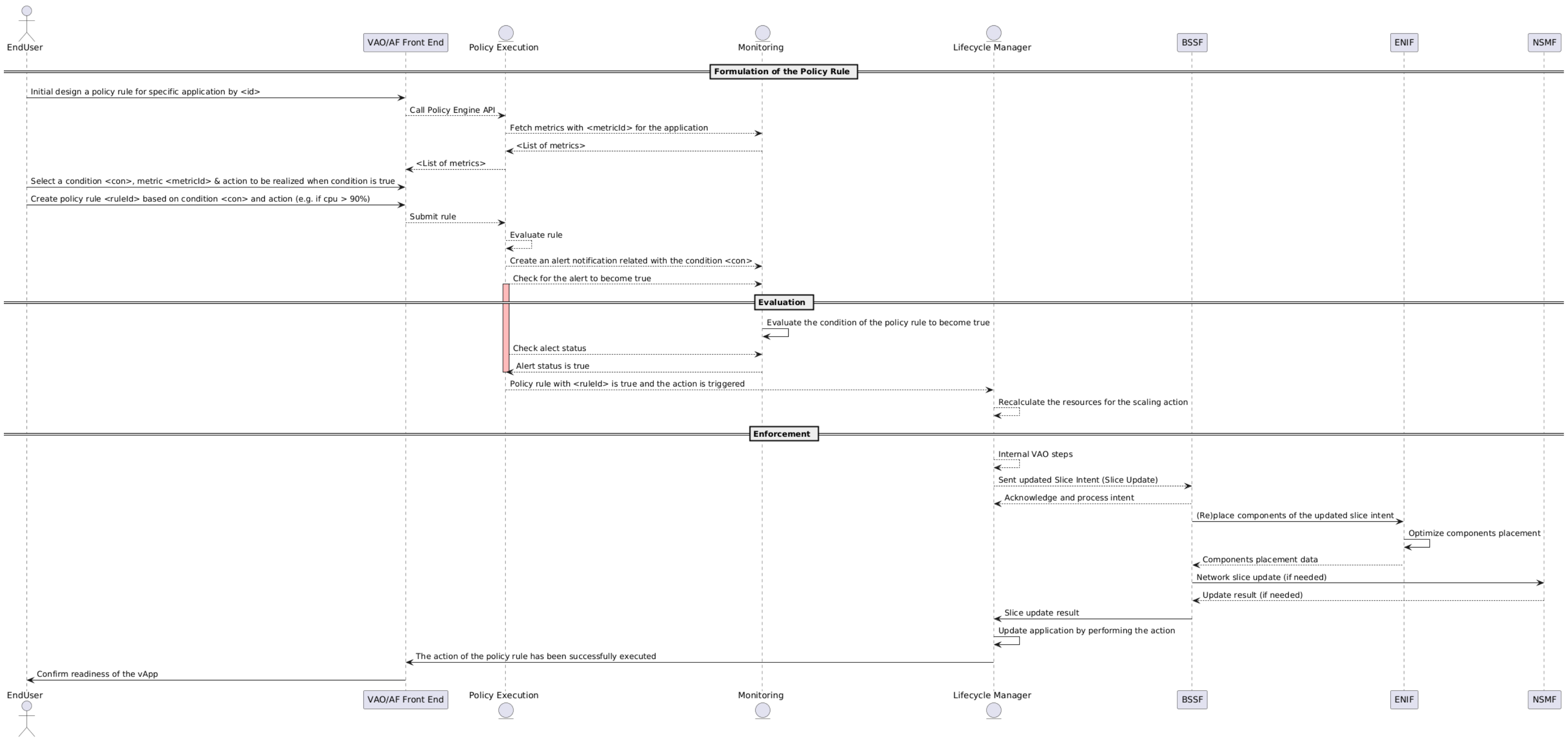

Figure 12: Runtime policy workflow for the vertical application.

3.4 Vertical Layer Policies

The VAO's policy schema defines supported policy actions, which are presented below along with their corresponding policy rules.

3.4.1 Policy 1: Green Scale Out & Migration

The following rule triggers a scale-out action that results in the deployment of 4 replicas of an application container, based on the validation of a specific metric (`"metricId": "g3394209-bc42-xa34-dddrt3-x5326893"`). However, this is not a conventional scale-out operation. Instead, it represents an advanced, green and intelligent scale-out mechanism. In this case, the new replicas are not simply instantiated but may be migrated to the most suitable infrastructure instances within the same location (e.g., within an edge or core site). The selection is based on factors such as performance, load, latency and energy efficiency. The decision-making process for identifying the optimal target infrastructure is handled by the 6Green platform's intelligence component, namely the ENIF.


```
{
    "ruleid": "434a2fde_24d3_4abd_9b67_d7e8e2f661a3",
    "name": "2024-04-18 19:14:25.332201",
    "applicationHexId": "m5azbkx8dz",
    "applicationInstanceHexId": "az3diy5u92",
    "expression":
    {
        "componentNodeInstanceHexID": "ggk523xgb",
        "metricId": "g3394209-bc42-xa34-dddrt3-x5326893",
        "operand": "LESS_THAN",
        "threshold": "30.0"
    },
    "action":
    {
        "componentNodeInstanceHexID": "k8c4yr59ge",
        "type": "SCALE_OUT",
        "workersNumber": 4
    },
    "prometheusConfig":
    {
        "prometheusIp": "http://localhost",
        "prometheusPort": "30000",
        "namespace": "levelseven"
    },
    "kubernetesConfig":
    {
        "masterUrl": "https://192.168.100.4:16443",
        "certificateAuthorityData": "...",
        "clientCertificateData": "...",
        "configMapNamespace": "monitoring",
        "configMapName": "prometheus-server-conf"
    }
}
```


Listing 2: Scaling out replicas.

3.4.2 Policy 2: Green Scale In & Migration

The following rule triggers a scale-in action that reduces the number of application container instances from 2 to 1 when a specific metric (`"metricId": "d9394209-c7e7-44d1-9ae2-4832cf782e2e"`) exceeds a defined threshold for example, a value greater than 0.01, which may indicate a reduced demand. However, this is not a conventional scale-in operation. Instead, it represents an advanced scale-in mechanism in which the remaining replica may be migrated to the most suitable infrastructure instance. The selection of the optimal infrastructure is based on factors such as performance, load, latency or energy efficiency, and is determined by the 6Green platform's intelligence component, namely the ENIF.

```
{
    "ruleid": "434a2fde_24d3_4abd_9b67_d7e8e2f661a3",
    "name": "2024-06-18 10:14:25.508301",
    "applicationHexId": "m5azbkx8dz",
    "applicationInstanceHexId": "az3diy5u92",
    "expression":
    {
        "componentNodeInstanceHexID": "k8c4yr59ge",
        "metricId": "d9394209-c7e7-44d1-9ae2-4832cf782e2e",
        "operand": "GREATER_THAN",
        "threshold": "0.01"
    },
    "action":
    {
        "componentNodeInstanceHexID": "k8c4yr59ge",
        "type": "SCALE_IN",
        "workersNumber": 1
    },
    "prometheusConfig":
    {
        "prometheusIp": "http://localhost",
        "prometheusPort": "30000",
        "namespace": "uc6nmcli9"
    },
    "kubernetesConfig":
    {
        "masterUrl": "https://192.168.100.4:16443",
        "certificateAuthorityData": "...",
        "clientCertificateData": "...",
        "configMapNamespace": "monitoring",
        "configMapName": "prometheus-server-conf"
    }
}
```

Listing 3: Scaling in replicas.

3.4.3 Policy 3: Enabling Energy-Aware Scaling to Zero

This policy action enables green monitoring for a specific application component. When applied, it activates the platform's ability to monitor the component's traffic activity. If no traffic is detected for a defined period, the platform automatically scales the component down to zero instances, reducing energy consumption. When traffic resumes, the platform transparently restores the component to maintain service continuity.

The enable/disable operation of this policy is controlled by the VAO frontend, from which the vertical application is deployed. The VAO sends a POST request to the platform to activate or deactivate the monitoring of a component's traffic activity. The decision to scale to zero and reactivation is fully managed by the platform's runtime environment. This policy can be enabled or disabled dynamically per component by the Vertical Application Provider, allowing fine-grained control over energy-aware behaviour based on application needs or operational priorities.

The POST request uses the following JSON format:


```
{
  "clusterId": "cluster-01",
  "namespace": "green-test",
  "podName": "app-service-pod-1",
  "timeout": "300s"
}
```


Listing 4: Enabling traffic-aware green monitoring (scaling to zero).

In this request, `"clusterId"` identifies the Kubernetes cluster ID provided by the platform to the VAO for deployment, which is where the component is hosted. In addition, `"namespace"` specifies the namespace of the component within the cluster, while the `"podName"` refers to the specific pod associated with the component to be monitored and deployed from the VAO as part of the vertical application. Finally, the `"timeout"` defines the monitoring period which the component will be scaled to zero if no traffic is detected.

4 Conclusions

Sustainability has become a top priority across nearly all industries. In the ICT sector, efforts are intensifying to meet specific SDGs and achieve net-zero targets. Beyond its own commitments, the ICT sector is uniquely positioned to enable sustainable transformation across vertical industries, especially in the context of digitalisation. However, realising this potential requires active collaboration among all stakeholders in the evolving 5/6G ecosystem. A shared commitment to a win-win green economy is essential.

In this respect, the 6Green project has mapped out the key stakeholders within the 5G/6G ecosystem and analysed their interactions. It also explored how these relationships must evolve to support sustainable operations and development. Critical to this evolution are:

- Customer awareness of the carbon footprint associated with digital services.
- Energy-aware capabilities embedded in the platform.
- Customer-provider (re-)negotiations that promote environmentally conscious behaviours across all layers of the ecosystem.

To support this, the Decarbonisation Level Agreement (DLA) concept has been formalised. DLA defines relevant sustainability metrics and indicators, as well as outlines how the 6Green SBA will manage green intents and facilitate (re-)negotiations. Furthermore, an incentivisation framework has been proposed and evaluated to encourage the deployment, operation, and selection of green network slices. To shape and refine the proposed Green Business Models, 6Green employed strategic tools such as Lean Canvas, SWOT analysis and ecosystem strategies. The evolution of these models underscores that sustainability in 5G/B5G ecosystems is not a standalone objective but a collaborative, adaptive process.

Focusing on the Vertical Layer, 6Green's approach to vertical application orchestration encompasses full lifecycle management of vertical applications, while also enabling advanced mechanisms and workflows to support: (i) application-aware network orchestration, and (ii) bidirectional (re-)negotiation among the Vertical Application Provider, Network Platform Provider, and (compute) Infrastructure Provider. This orchestration is facilitated by the 6Green VAO, which also functions as a trusted AF to directly interact with the 6Green SBA. Furthermore, the concept of policies has been elaborated through the development of a policy architecture and data model, then defining a set of energy-aware Vertical Layer Policies tailored to optimize resource usage and sustainability.

References

[1] UN, "The 17 goals" [Online].
Available: https://sdgs.un.org/goals

[2] European Commission, "The European Green Deal" [Online].
Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/story-von-der-leyen-commission/european-green-deal_en

[3] Ericsson, "Connectivity and climate change: Examining the role of digital communications in combating climate change" [Online].
Available: https://www.ericsson.com/4ab228/assets/local/about-ericsson/sustainability-and-corporate-responsibility/environment/accelerate-5g-report-27102021.pdf

[4] Ericsson, "ICT's potential to reduce greenhouse gas emissions in 2030" [Online].
Available: https://www.ericsson.com/en/reports-and-papers/research-papers/exploring-the-effects-of-ict-solutions-on-ghg-emissions-in-2030

[5] "Telenor Annual Report 2023" [Online].
Available: https://www.telenor.com/binaries/investors/reports-and-information/annual/annual-report-2023/Annual%20Report%202023-English.pdf

[6] "TIM Annual Report 2023" [Online].
Available: https://www.gruppotim.it/content/dam/gt/investitori/doc---report-finanziari/2023/TIM-Annual-Report-2023.pdf

[7] "Telefonica Consolidated Management Report 2023" [Online].
Available: https://www.telefonica.com/en/wp-content/uploads/sites/5/2024/03/management-sustainability-report-2023.pdf

[8] "Orange First Half 2023 Financial Report" [Online].
Available: https://gallery.orange.com/finance/#lang=en&om=77ea5b88-d8da-49d5-a4bf-e57d70dbe153&v =c0f80cda-537f-4e05-8143-4b1780328968

[9] T. Hoßfeld, M. Varela, L. Skorin-Kapov and P. E. Heegaard, "What is the trade-off between CO2 emission and videoconferencing QoE?", ACM SIGMM Records [Online].
Available: https://records.sigmm.org/2022/03/31/what-is-the-trade-off-betweenco2-emission-and-video-conferencing-qoe/

[10] V. Gnanasekaran, H. T. Fridtun, H. Hatlen, M. M. Langøy, A. Syrstad, S. Subramanian, and K. De Moor, "Digital carbon footprint awareness among digital natives: an exploratory study" [Online].
Available: https://ntnuopen.ntnu.no/ntnuxmlui/bitstream/handle/11250/2985003/919-Article%2bText-2210-1-10-20211115.pdf?sequence=1

[11] 6Green D4.1, "Work-in-Progress: Design and Specification of Green Business Models and Runtime Policies for 5/6G Vertical Applications", June 2024.

[12] Hexa-X-II D1.1, "Environmental, social, and economic drivers and goals for 6G", June 2023 [Online].
Available: https://hexa-x-ii.eu/wp-content/uploads/2023/07/Hexa-X-II_D1.1_final-website.pdf

[13] Hexa-X-II D1.3, "Environmental and social view on 6G", March 2024 [Online].
Available: https://hexa-x-ii.eu/wp-content/uploads/2024/03/Hexa-X-II_D1.3_v1.00_GA_approved.pdf

[14] "Carbon Footprint" [Online].
Available: https://css.umich.edu/sites/default/files/2023-10/Carbon%20Footprint_CSS09-05.pdf

[15] "Global Warming Potentials (GWPs) / CO2-equivalent (CO2e) and the importance of time horizons" [Online].
Available: https://www.edf.org/sites/default/files/content/emission_equivalency_tool_documentation__methodology_23062022.pdf

[16] D. Polverini, N. Espinosa, U. Eynard, E. Leccisi, F. Ardente and F. Mathieux, "Assessing the carbon footprint of photovoltaic modules through the EU Ecodesign Directive", Solar Energy, vol. 257, 2023, pp. 1-9.

[17] Schlömer S., et al., "Annex III: Technology-specific cost and performance parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change," [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)], 2014. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA [Online].
Available: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf

[18] "YOXO: It's easier to be ECO" [Online].
Available: https://www.yoxo.ro/eco/

[19] "The Paris Agreement" [Online].
Available: https://unfccc.int/process-and-meetings/the-paris-agreement

[20] "EU Emissions Trading System" [Online].
Available: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

[21] "Clean Industrial Deal" [Online].
Available: https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en

[22] "Euro 7: Council adopts new rules on emission limits for cars, vans and trucks" [Online].
Available: https://www.consilium.europa.eu/en/press/press-releases/2024/04/12/euro-7-council-adopts-new-rules-on-emission-limits-for-cars-vans-and-trucks/

[23] "Anti-pollution measures" [Online].
Available: https://www.service-public.fr/particuliers/vosdroits/N18131

[24] "Expansion of the charging infrastructure in Germany" [Online].
Available: https://greenair.eco/en/newsroom/expansion-of-the-charging-infrastructure-in-germany-2024

[25] "ProLogium Welcomes The Green Light Given By The European Commission For Public Grant For Its Gigafactory Project In Dunkirk" [Online].
Available: https://prologium.com/prologium-welcomes-the-green-light-given-by-the-european-commission-for-public-grant-for-its-gigafactory-project-in-dunkirk/

[26] C. Fruhmann and A. Tuerk, "Renewable Energy Support Policies in Europe", Climate Policy Info Hub 16, p. 2010, 2014.

[27] S. Prysiazhniuk, "New rules for heat pumps in the Netherlands 2025-2026" [Online].
Available: https://www.bricknest.nl/en/blog/nieuwe-regels-warmtepompen-nederland-2025-2026

[28] "Common Agricultural Policy - Performance" [Online]. Available: https://commission.europa.eu/strategy-and-policy/eu-budget/performance-and-reporting/ programme-performance-statements/common-agricultural-policy-performance_en

[29] G. Fortuna, "Italy to Challenge Nutri-Score with Constitution" [Online]. Available: https://www.euronews.com/health/2024/05/03/italy-to-challenge-nutri-score-with-constitution

[30] I. Godlovitch, A. Louguet, D. Baischew, M. Wissner and A. Pirlot, "Environmental impact of electronic communications" WIK Consult and Ramboll, Study for BEREC

[31] J. Martinez, E. Wilkinson, L. Lazaro, "Enforcement, empowerment or engagement? How leading regulators are encouraging sustainability in the ICT sector" Axon Partners Group, White Paper, May 2025.

[32] "Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022" [Online]. Available: https://eur-lex.europa.eu/eli/dir/2022/2464/oj/eng

[33] Orange Group, "Net zero carbon by 2040" [Online]. Available: https://www.orange.com/en/commitments/to-the-environment/net-zero-carbon-by-2040

[34] Telefónica Group, "'Net Zero' against climate change" [Online]. Available: https://www.telefonica.com/en/communication-room/blog/net-zero-against-climate-change/

[35] "TICFE/CSPE: Le taux r´eduit en faveur des datacenters" [Online]. Available: https://www.enerlex-avocat.fr/fr/actualites-juridique/id-109-ticfe-cspe-le-taux-reduit-en-faveur-des-datacenters

[36] "Telefónica, the Largest Green Issuer in the ICT Sector" [Online]. Available: https://www.telefonica.com/en/communication-room/press-room/telefonica-the-largest-green-issuer-in-the-ict-sector/

[37] "Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE)" [Online]. Available: https://eur-lex.europa.eu/eli/dir/2012/19/oj/eng

[38] "Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products" [Online]. Available: https://eur-lex.europa.eu/eli/reg/2024/1781/oj/eng

[39] "ITU-T L.1400 (03/2023) - Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies" [Online]. Available: https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-L.1400-202303-I!!PDF-E&type=items

[40] "ITU-T L.1300 (06/2014) - Best practices for green data centres" [Online]. Available: https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-L.1300-201406-I!!PDF-E&type=items

[41] "ITU-T L.1410 (11/2024) - Methodology for environmental life cycle assessments of information and communication technology goods, networks and services" [Online]. Available: https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-L.1410-202411-I!!PDF-E&type=items

[42] "ITU-T L.1350 (10/2016) - Energy efficiency metrics of a base station site" [Online]. Available: https://www.itu.int/rec/dologin_pub.asp?lang=e&id=T-REC-L.1350-201610-I!!PDF-E&type=items

[43] BEREC, "Report on Sustainability Indicators for Electronic Communications Networks and Services", BoR (23) 166, October 2023 [Online].

Available: https://www.berec.europa.eu/system/files/2023-10/BoR%20%2823%29%20166%20Final%20Report%20on%20sustainability%20indicators%20for%20ECN%20ECS.pdf

[44] D. Schien, P. Shabajee, J. Chandaria, D. Williams, C. Preist, "Using behavioural data to assess the environmental impact of electricity consumption of alternate television service distribution platforms" Environmental Impact Assessment Review 91, 106661, 2021

[45] "Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU" [Online]. Available: https://eur-lex.europa.eu/eli/reg/2017/1369/oj/eng

[46] "Green and Smart Technologies for Smart Cities" R. Sharma, V. Govindaraj and M. N. Mladenovic, Eds. Springer, 2020.

[47] A. Casella, V. D'Amico, G. La Torre and Nicola Mondello, "CO-2023-01930 - Sviluppo di Proof of Concept per Sustainable Green Cities", TIM Internal Report, Nov. 2023.

[48] GSMA, "Generic Network Slice Template", version 9.0, April 2023 [Online]. Available: https://www.gsma.com/newsroom/wp-content/uploads/NG.116-v9.0-1.pdf

[49] 3GPP TS 29.531, "3rd Generation Partnership Project; Technical Specification Group Core Network and Terminals; 5G System; Network Slice Selection Services; Stage 3 (Release 17)", V17.11.0, September 2024.

[50] 3GPP TS 28.554, "Management and orchestration; 5G end to end Key Performance Indicators (KPI)", v17.15.0, September 2024.

[51] "D2.1 - Policy Language V1", SPECIAL project [Online]. Available: https://zenodo.org/records/2549576

[52] L. M. Contreras, G. S. Illán and J. V. Martínez, "Decarbonization Level Agreements in the Provision of Transport Network Slices," 2025 28th Conference on Innovation in Clouds, Internet and Networks (ICIN), Paris, France, 2025, pp. 69-73.

[53] D. Otten, A. Brundiers, T. Schüller and N. Aschenbruck, "Green Segment Routing for Improved Sustainability of Backbone Networks," 2023 IEEE 48th Conference on Local Computer Networks (LCN), Daytona Beach, FL, USA, 2023.

[54] R. Bolla, R. Bruschi, F. Davoli, C. Lombardo and N.S. Martinelli, "Analyzing the power consumption in cloud-native 5/6g ecosystems" 2023 IEEE International Conference on Communications Workshops, pp. 611–617, 2023.

[55] H-S. Hallingby, et al., "Emerging 5G Ecosystem Business Models", 6G-IA White Paper [Online]. Available: https://zenodo.org/records/7640478

[56] "MATILDA: A Holistic, Innovative Framework for the Design, Development and Orchestration of 5G-ready Applications and Network Services over Slices Programmable Infrastructure" [Online]. Available: https://cordis.europa.eu/project/id/761898

[57] "5G-INDUCE: Open Cooperative 5G Experimentation Platforms for the Industrial Sector Network Applications" [Online]. Available: https://www.5g-induce.eu/

[58] 6G-IA, "5G and Beyond 5G Ecosystem Business Modelling (2023)". [Online]. Available: https://5g-ppp.eu/white-paper-5g-and-beyond-5g-ecosystem-business-modelling-5g-ppp-wg-leaders/

Annex A

MILP-based Techno-economic Incentivisation Framework

Mixed Integer Linear Programming (MILP) models are well suited for incentivising the deployment and selection of green network slices because they allow for the joint optimisation of binary decisions (slice admission) and continuous variables (resource allocation), subject to a set of linear constraints representing capacity, environmental and operational service requirements. This approach guarantees optimal solutions for moderate problem sizes and provides a flexible framework to incorporate additional business or technical constraints as needed.

The MILP model is implemented in Python using the PuLP library, which provides a user-friendly interface to define decision variables, constraints and objective functions, as well as supports a range of commercial and open-source solvers. Data preprocessing and scenario management are handled with `pandas`, while power and emissions calculations are modularised for clarity and reusability. The overall workflow—reading input data, defining the MILP, solving and extracting results—enables reproducible and extensible experimentation with different network, demand, and sustainability scenarios.

The following sections summarise the concepts and formulation of the framework and the MILP problem, and develops further the concepts summarised in Section 2.3.3.

Slicing and virtual resources

Network slices refer to purely virtual 5/6G networks, a collection of virtual network functions (VNFs) running on top of a network of Network Functions Virtualisation Infrastructure (NFVI) nodes, $n \in N$, interconnected by bidirectional links $l = \{n_1, n_2\} \mid n_1, n_2 \in N$, connecting VNFs running on n_1 and n_2. We will denote by L the set of all network links and by $T = \{N, L\}$ the undirected connected graph that defines the topology of the network. We will generally refer to nodes and links as '*network resources*' $r \in R = N \cup L$ (NFVI nodes and links).

5G networks are hierarchical, with edge nodes close to end users that concentrate their traffic in several levels, up to data centers that provide nationwide or regional services to end users. Slice templates define the virtual resources (VNFs and links) required by a slice (VR_s) at each network level to comply with the SLAs of the slice. such as minimum/average throughput, maximum latency, etc.

For each virtual resource, the slice demand parameters and the slice coverage determine the demand for physical resources ($d_r(\cdot)$). The unit in which this demand is measured depends on the type of resource, typically the number of vCPU (normalised virtual CPUs) for NFVI, GB for memory usage, TB for storage, or Gbps for network links. Demand drivers also differ between types of resources, and some papers have measured how virtual resources consume physical resources depending on different demand parameters 0. For example, User Plane Functions (UPFs) for URLLC slices, and servers providing these services consume resources according to the average number of users and their average throughput, whereas 5G Core platforms dealing with signalling consume resources depending just on the number of users.

The following section describes the different modules of the framework (see Figure 6).

Slice-to-Virtual Resources Mapping Module

The first step of the model takes as input the slice orders received by the Network Platform Provider (NPP), including their parameters, SLAs and DLAs. Based on the type of slice, the model lists virtual resources required to fulfil SLAs, maps them to the network topology, and dimensions the demand for physical network resources. Figure 13 graphically describes the process of mapping slices and their virtual resources to physical resources in a network topology.

A network slice order s belongs to a template and must specify its geographic coverage as a list of nodes $N_s \subseteq N$, its potential income I_s in this period, and a set of demand parameters $DP_{s,vr}$ to dimension virtual resources (nodes or links) required to fulfil the order (e.g., unit bandwidth consumption per user at different levels in eMBB templates). We assume that I_s represents net revenues (i.e., returns, allowances, sales costs and discounts should be removed), and that SLAs are secured by scheduling all virtual resource, hence we neglect penalties for non-compliance with SLAs.

Slice templates determine which virtual resources are required at different network levels and can also specify usage parameters applicable to all slices of that type (e.g., unit processing per user required in the 5G mobile core). Thus, given a network slice order, we can map the required virtual resources according to the template to specific VNFs and connectivity demands in the network topology to comply with the target coverage and SLAs of the slice. We will denote the matrix that binds the demand for virtual resources to that for network resources of a slice s by $\mathbf{D_s} = \{d_{s,vr,r}(u_r, DP_{s,vr})\}_{vr\in VR_s, r\in R}$. By aggregating the demand for virtual resources in a network resource, we obtain the demand for a network resource due to the slice s, $d_{s,r}$. By aggregating the demand of all slices in a network resource, we obtain the total demand for such resource d_r.

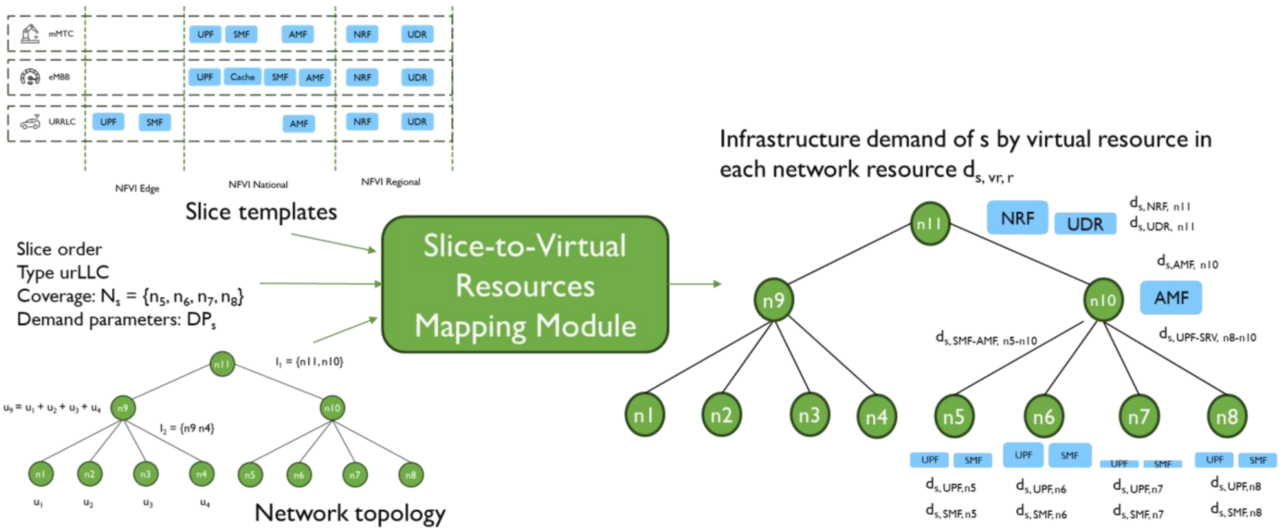

Figure 13: Slice orders and slice resource mapping.

Virtual Resource Allocation Module

NPPs must select between competing infrastructure resources capable of hosting virtual resources demanded by network slices. This process is known as Virtual resource allocation. Without loss of generality, we will assume that IPs offer overlapping resources and extend the notation for network resources r to r,o, where $o \in O$ denotes the IP providing resource r, up to maximum capacity $C_{r,o}$. The output of this process is the virtual resource demand allocated to each IP, denoted as $da_{s,vr,r,o}$.

The resource allocation matrix maps slice virtual resource demands to available network resources provided by IPs, and specifies the percentage of demand of a virtual resource vr allocated to IP resource r,o. It is denoted by $a_{s,vr,r,o} \in [0,1]$, $vr \in VR_s$, $r \in R$, $o \in O$. The demand for a resource r allocated to IP o is given by $da_{s,r,o} = \sum_{vr\in VR_s} a_{s,vr,r,o} \cdot d_{s,vr,r}$.

In heavy demand scenarios, NPPs may decide to relocate virtual resources from congested nodes to alternative nodes with excess capacity-which may have an impact on QoS (e.g., more latency if relocated to upper nodes in the hierarchy) and on SLAs or even to reject the slice order. In this annex, we do not allow relocations and NPPs must make the decision y_s about whether to accept the slice ($y_s = 1$), and obtain income from it at the cost of allocating all its demands for network resources, or reject it ($y_s = 0$) and give up its potential revenue.

Among all possible allocations of resources to IPs, a rational NPP would choose those maximising its profit, given by the income of the accepted slices $y_s \cdot I_s$ minus the cost of resources needed to implement them according to the cost module. For this purpose, we define and solve a MILP problem, which will need to take into consideration the following constraints.

- The demand allocated to a IP's resource cannot exceed its maximum capacity. We call it the *Maximum capacity constraint*.
- Slices cannot be partially allocated, we call this the *Slice fulfilment condition*.
- Slice allocation must satisfy its SLAs, which we assume granted if it is accepted.
- Slice allocation must satisfy its DLAs, according to the KPI estimates returned by the sustainability module.
- *Maximum capacity constraint.* Eventually, the demand allocated to a resource must be less than its available maximum capacity, that is, $\forall r \in R, o \in O, da_{r,o} \leq C_r$.
- *Slice fulfilment condition.* Since the NPP cannot relocate demands to different network resources, slices must be fully allocated if accepted, which means that all demand must be allocated to IPs, that is, $y_s = 1 \Rightarrow \forall r,\ \sum_{o \in O} da_{s,vr,r,o} = d_{s,vr,r}$ or alternatively $\sum_{o \in O} a_{s,vr,r,o} = 1$. If rejected ($y_s = 0$), then $da_{s,vr,r,o} = a_{s,vr,r,o} = 0$.

Cost Module

We assume that IPs charge NPPs on a cost-plus basis. This hypothesis is realistic for regulated oligopolistic infrastructure markets, but eventually this pricing will depend on the level of competition at the level of infrastructures and network service and on the market power of IPs and NPPs.

To calculate the CAPEX of network computing resources, we resort to market-based prices for a reference server architecture, and we calculate its capacity based on its specifications 0. We annualised CAPEX using financial annuity and adding a cost of capital equal to twice the weighted average cost of capital (WACC) defined by NRAs in Spain [A2], and we use typical asset lives of regulatory cost models [A3]. OPEX is added by using a reference mark-up to network CAPEX, based on references of bottom-up models to set cost-based charges for wholesale services.

Regarding the capacity of network resources, we consider these an input in the current version of the model. In future versions, we will include functionality to allow IPs to adapt and grow their infrastructure according to the demand, and cost-volume curves to estimate cost as a function of demand.

Sustainability Module

Network resources consume power and energy. IPs may provide an energy-efficient infrastructure that can be sustainable, and the sustainability module is responsible for informing the *Virtual resource allocation module* about the power and energy consumption and carbon emissions of resources for the latter to optimise resource allocation for compliance with the slices DLAs.

The *power consumption* of a network resource will be a function of i) the nominal maximum power consumption of a network resource when fully used ($PCmax_{r,o}[kW]$), ii) the *power consumption profile* that relates resource utilisation and power consumption ($PCp_{r,o}(\cdot)$), and iii) its actual utilisation $Ru_{r,o}$.

We define *resource utilisation* of resource *r* of IP *o* as $Ru_{r,o} = da_{r,o}/C_{r,o} \in [0,1]$. The power consumption profile is subadditive, its domain is [0,1] (none to full utilisation) and its range is [0,1] (none to nominal power consumption). Hence, the power consumption will be calculated as $PC_{r,o}[kW] = PCmax_{r,o} \cdot PCp_{r,o}(Ru_{r,o})$. In the model, we will use an empirical power consumption profile for active equipment that considers fixed power consumption and saturates to the maximum nominal power for high utilisation above 80% [A4].

Energy consumption reflects power consumption over time. It can be easily estimated for a resource *r,o* in a certain period Δt as $EC_{r,o}[kWh] = PC_{r,o} \cdot \Delta t$.

Depending on the amount of energy produced by renewable energies, power consumption can translate into the emission of GHG. To capture this, we define the *carbon emissions* of a resource as $CE_{r,o} = CIp_{r,o}(PC_{r,o}) \cdot \Delta t$, where *CIp* refers to the *carbon intensity profile* that relates the carbon intensity, measured in GHG/s, and the power consumption of that resource.

Figure 14 shows different examples of carbon intensity profiles. Subfigure (a) shows an ideal purely green infrastructure (e.g., powered only by solar cells and batteries) that does not emit GHG to the atmosphere, i.e. $CI(PC_n) = 0$. If a node is powered by the grid, we can assume that carbon emissions will be proportional to power consumption, that is, $CI = k \cdot PC$, as shown in Subfigure (b). The slope of the CI profile will depend on the mix of generation sources employed by the electricity company. There can also be mixed solutions, where IPs own self-powered infrastructure is capable of providing GHG-emission-free power up to a maximum threshold PC_t, and resort to the grid to accommodate additional power consumption. In this case, $CI = 0$ if $PC < PC_t$, $CI = k \cdot (PC - PC_t)$ if $PC \geq PC_t$), as shown in Subfigure (c).

In this annex, we consider the DLA restrictions for *maximum power consumption* and *maximum carbon emissions* of a slice. However, the definition of DLAs allows future restrictions to ensure a minimum percentage of renewable energy consumption, minimum energy, or carbon emissions efficiency.

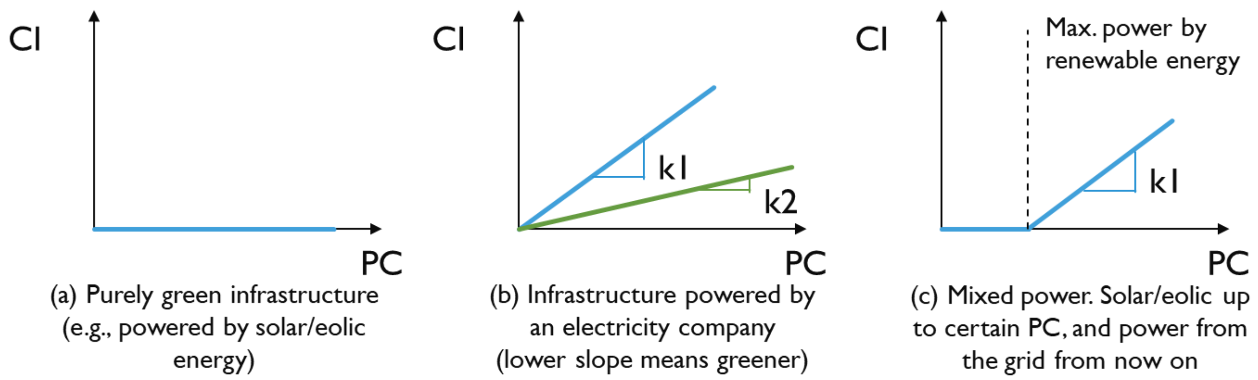

Figure 14: Carbon intensity (CI) profiles as a function of infrastructure power consumption (PC).

Problem formulation

The NPP optimisation problem can be expressed as follows:

$$\max_{a_{s,vr,r,o} y_s} \left\{ \sum_{s \in S} \left[y_s \cdot I_s - \sum_{r \in R} \sum_{o \in O} c_{r,o} \cdot \sum_{vr \in VR_s} a_{s,vr,r,o} \cdot d_{s,vr,r} \right] \right\}$$

Subject to:

Maximum capacity:

$$\sum_{s \in S} da_{s,r,o} \leq C_{r,o}, \forall r \in R, \forall o \in O$$

Maximum power consumption:

$$\sum_{r \in R,\, o \in O} \left(PC_{r,o} \cdot \frac{da_{s,r,o}}{\sum_{s \in S} da_{s,r,o}} \right) \leq PC_s^{max}, \qquad \forall s \in S$$

Carbon emissions:

$$\sum_{r \in R,\, o \in O} \left(CE_{r,o} \cdot \frac{da_{s,r,o}}{\sum_{s \in S} da_{s,r,o}} \right) \leq CE_s^{max}, \qquad \forall s \in S$$

Slice fulfilment condition:

$$\sum_{o \in O} a_{s,vr,r,o} = y_s, \qquad \forall s \in S, \forall r \in R, \forall vr \in VR_s$$

Where:

$y_s \in \{0,1\}$: binary decision variable, 1 if slice s is accepted, 0 otherwise.

$a_{s,vr,r,o} \in [0,1]$: continuous decision variable, fraction demand of virtual resource vr of slice s for resource r of IP o.

$I_s \in \mathbb{R},\ I_s \geq 0$: parameter, income for slice s.

$d_{s,vr,r} \in \mathbb{R},\ d_{s,vr,r} \geq 0$: parameter, demand for resource r by v. resource vr of slice s.

$da_{s,r,o} = \sum_{vr \in VR_s} a_{s,vr,r,o} \cdot d_{s,vr,r}$: Demand for resource r of IP o by slice s

$c_{r,o} \in \mathbb{R},\ c_{r,o} \geq 0$: parameter, unit cost of resource r of IP o.

$C_{r,o} \in \mathbb{R},\ C_{r,o} \geq 0$: parameter, maximum capacity of resource r of IP o.

$PC_{r,o} \in \mathbb{R},\ PC_{r,o} \geq 0$: parameter, nominal power consumption of resource r of IP o.

$PC_s^{max} \in \mathbb{R}, PC_s^{max} \geq 0$: parameter, maximum power allowed for slice s.

$CE_{r,o} \in \mathbb{R}, CE_{r,o} \geq 0$: parameter, nominal carbon emissions of resource r of IP o.

$CE_s^{max} \in \mathbb{R}, CE_s^{max} \geq 0$: parameter, maximum carbon emissions for slice s.

S: set of all service slices.

VRs: set of all virtual resources required by slice s

R: set of all resources.

O: set of infrastructure providers.

Assessment of policy options

To illustrate how sustainability policies can incentivise investment in greener infrastructure, we model scenarios where an NPP orchestrates and delivers a range of advanced 5G services to its end users and corporate clients. The NPP does not own physical infrastructure, but must select between two competing IPs to fulfil the resource and connectivity needs required for its service portfolio. The NPP offers three service categories, belonging in different slice types:

eMBB (enhanced Mobile Broadband) 5G Services. The NPP delivers high-speed, high-capacity broadband connectivity to users within a targeted geographic area. eMBB slices are designed to support data-intensive applications such as seamless HD video streaming, mobile cloud computing, and connected smart offices, meeting the high throughput and reliability expectations of both consumers and enterprises.

URLLC (Ultra-Reliable Low Latency Communications) for corporate clients in the manufacturing sector. Tailored to support factories with robotised production lines and automated warehouse logistics, where real-time control, ultra-low latency, and high reliability are essential for continuous yet moderate data throughput, URLLC slices enable efficient and safe operation of industrial robots and logistics systems, minimizing downtime and operational risks.

mMTC (Massive Machine-Type Communications) to real estate companies highly automated buildings. These clients require reliable connectivity for a large number of sensors and actuators, enabling advanced domotics and IoT-driven services for both business tenants and residential users. The mMTC slice is optimized for massive device connectivity with low individual throughput requirements, supporting the digital transformation of smart buildings.

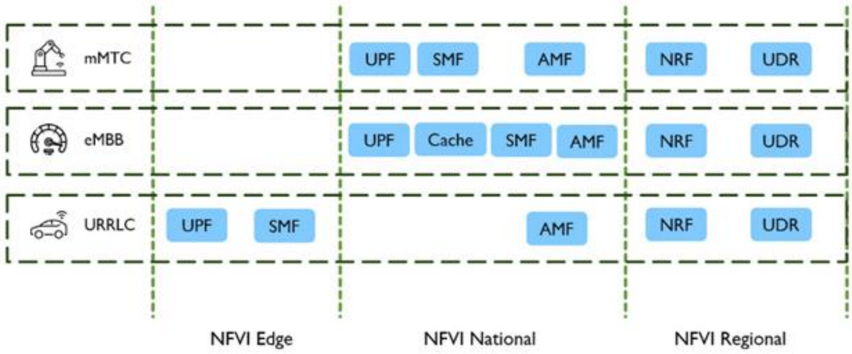

Figure 15: Slice templates and virtual resources by network level.

Figure 15 depicts virtual resources required by the slice templates of each service category. 6G slicing enables the NPP to dynamically adapt to varying user and enterprise requirements, efficiently allocate resources, and maintain differentiated service levels. Moreover, DLAs allow the NPP to consider sustainability issues when selecting a suitable provider to meet the requirements of network slices. Bottom-up awareness of operational and sustainability KPIs allows the NPP and end customers to monitor SLAs and DLAs and enables guaranteed green services and applications.

Baseline hypotheses used in all scenarios, *Network topology*. Without loss of generality, we can assume a hierarchical 5/6G network where nodes are arranged in three levels:

- Level 1 refers to nodes at the regional level, points of presence (PoPs) shared by many operators and over-the-top (OTT) players from different jurisdictions.
- Level 2 refers to national service centres of telcos in their national core networks.
- Level 3 (local) refers to the edge of the network and includes nodes next to centralised units (CUs) of the RAN that can run processing tasks close to end users.

In a certain time frame, a network node n provides service to u end users in the vicinity of that node, an input that reflects the geography and the expected demand. Each node in a level connected to at least one node in the upper level, and nodes in the upper layer fully meshed. Therefore, the number of users that rely on the upper network nodes can be calculated bottom-up as the sum of the users of the adjacent nodes in the lower level. The number of users depending on a link will be the number of users depending on the lowest level node it connects.

The following table summarises the inputs of the model and the references used to feed them.

Table 2: Model inputs.

Input	Current Data	Reference
Server Typology and Computation		
CoreVNFI BasicPhysical Server	HPE DL380 Gen11, 2x Xeon 6760P, 512GB DDR5, 2x NVMe 3.84TB, 2x Nvidia ConnectX-6	0
vCPUs per Physical Server	128 physical cores → 256 vCPUs	0
vCPUs Allocated for Virtualisation	10% reserved for HA cluster	0
CAPEX VNFI Basic Physical Server	27,600eper server, ~230 vCPUs allocatable	Vendor/Market, 0
VNFI Lifecycle	7 years	Cost model [A3]
WACC	11%	[A2]
OPEX Mark-up	10% of CAPEX	Cost model [A3]
Energy and Environmental		
Carbon Emissions per kWh	30(NO),174(ES),662(PL) gCO_2e/kWh	[A5]
Energy OPEX	0.29e/kWhavg.(EU), 0.11–0.37e/kWh range	[A6]
Power Consumption vs Utilisation	Non-linear, abrupt growth >70%	[A4]
GHG emission profiles	Typical theoretical curves	Assumption
Network Topology and Traffic		
Network Topology	8 hierarchical nodes (synthetic)	–
Users per EDGE node	100,000–400,000	Assumption
Users per Slice	800,000–1,000,000	Assumption
Unit Throughput for Slices	URLLC: 0.022, mMTC: 0.007, eMBB: 7.78 Mbps/user	[A7]
Resource units and drivers for link type	Mbps, based on slice traffic and users	0
5G Slicing and Templates		
5G Network Slice VNF replica capacity	Per VNF: users/traffic/replicas	0, [48]
5GNetwork SliceVNF resource consumption	Estimated vCPU usage per VNF	0, [48]
SLA requirements per slice	GSMA definitions (throughput, latency)	[48]
GSMA NESTs	uRLLC, eMBB, mMTC templates	[48]
Temporal Granularity	1 hour	0
Slice order unit revenue	Cost + 30% margin	Assumption
Slice requests (DLA, SLA)	May include max. energy/carbon	Assumption
Max VNFI capacity per level	Edge < National < Regional	[A8]

IP Competition. Each scenario features two IPs with identical technical portfolios (e.g., vCPUs, bandwidth, coverage), establishing a neutral baseline for competition. Any differentiation between IPs arises solely from their cost structures, energy sourcing, or sustainability-related constraints as defined in each specific case.

Demand Scaling. The model explores a wide range of operating conditions by scaling the demand for each slice type from 10% to 300% of the baseline. This allows analysis of behaviour under typical and stress test conditions, revealing how allocation strategies and provider selection may change as demand intensifies.

Resource Capacity Adjustment. Resource capacities for each IP are initially dimensioned so that either provider, operating alone, can satisfy the entire baseline demand at the most constrained node. To further minimize the influence of capacity bottlenecks and focus the analysis on economic and sustainability-driven decisions, this baseline is then doubled in the model. However, it is important to note that at the highest demand scaling (e.g., 300%), even this augmented capacity may not suffice for a single IP to serve all demand alone, thus realistically reflecting the need for cooperation or load balancing at extreme loads.

KPI Monitoring: Key performance indicators—including total cost, energy consumption, carbon emissions, and resource allocation per IP—are systematically measured for each scenario and presented as results. This comprehensive monitoring supports a robust evaluation of the efficiency, sustainability, and economic trade-offs in different experimental cases.

Based on the common inputs and hypotheses defined above, we have set a baseline scenario where the two IPs are equivalent and operate with similar cost, energy efficiency and carbon intensity. This resembles a common situation in mature competitive telecom markets, where concur-rent IPs are unaware or unable to exploit sustainability as a competitive advantage.

Then, we run the model with varying situations to test the policies. In all of them:

- IP1 will represent in all cases a conventional "grey" provider with baseline costs and higher carbon emissions.
- IP2 will become "green" by investing in sustainable telecom infrastructure at a 20% higher cost relative to IP1 in exchange for operating at zero emissions.

We estimate the resources allocated, costs, energy consumption and carbon emissions of IP1 and IP2 in four additional scenarios that reflect different policy options to incentivise greener networks, inspired by our preliminary policy review in Section 2.1, and compare to the baseline. The policy options analysed are as follows.

Policy Option 1: *Laissez-faire*. Policy makers do not apply any incentive policy. IP2 cost increases 20%, which translates into 20% higher infrastructure wholesale prices. This scenario reflects a plausible situation where IPs test green investment seeking to differentiate or to meet their ESG objectives.

Policy Option 2: Subsidisation of Green Infrastructure. Investment in net zero-emitting telecom infrastructures is actively subsidised through direct subsidies or tax exemptions. As a result, subsidies compensate for the cost increase of IP2 due to the investment in greener energy sources, and the wholesale charges of both IPs are balanced. Direct subsidisation of green investment projects has been actively used in other industries and hence could be a policy option in the telecommunications market.

Policy Option 3: Introduction of uniform DLAs. Policy makers impose a *glide path* on maximum carbon emissions through the use of DLAs applied to network slices, requiring NPPs to reduce emissions associated with their network services by 25%, primarily by contracting green infrastructure for slice deployment. Progressive tightening of environmental and energy consumption limits has long been a feature of greening policies, and glide paths have been effectively used by telecommunication NRAs in various countries to steadily advance policy objectives, such as reducing interconnection charges, while avoiding abrupt industry disruptions and providing stakeholders with time to adapt to regulatory changes.

Policy Option 4: Tiered DLAs for premium services. Consumers demonstrate willingness to pay a price premium for greener services, which incentivises VAPs to offer sustainable services with stricter carbon requirements enforced through DLAs. In particular, green VAP slice requests that include net-zero emission DLAs are treated as premium services and receive a 30% revenue uplift, reflecting the higher value placed on sustainability by end users.

The following table summarises the definitions and parameters of the different scenarios. To evaluate policy options, we assess the behaviour of stakeholders and the outcomes of the resource allocation process, illustrating the dynamics and trade-offs that emerge in a multi-actor 6G ecosystem. For each scenario, we test different levels of demand, ranging from 10 % to 300 % of the baseline demand. For each demand level, we plot and compare to the baseline the following KPIs: the vCPUs scheduled by each IP, the cost incurred by the NPP (in e), the energy consumption (in kWh) and the resulting carbon emissions (in kg CO_2).

Table 3: Definitions and parameters of the different scenarios.

Scenario	Green slice premium?	IP1 vs. IP2 costs	IP1 vs IP2 GHG Emissions	DLA limits
Baseline	No	Equal	Equal	No
PO1: *Laissez-faire*	No	IP2 + 20%	IP2 = 0	No
PO2: Subsidisation	No	Equal(subsid.)	IP2 = 0	No
PO3: Introducing DLAs	No	IP2 + 20%	IP2 = 0	Yes
PO4: DLA + Green Premium	Yes	IP2 + 20%	IP2 = 0	Yes

Results

Policy Option 1: Laissez-faire results in minimal use of green infrastructure and maximum reliance on high-emission providers, as shown in Figure 16. Green providers are only used when high-emission providers, such as IP1, can no longer meet demand due to capacity limitations. The system naturally converges towards configurations that are economically efficient but environmentally suboptimal, highlighting the need for policy interventions to internalise sustainability considerations within the 6G value chain.

Policy Option 2: Subsidisation of Green Infrastructure. The results in Figure 17 show a clear increase in the share of demand assigned to IP2 compared to the laissez-faire policy option. Although no explicit emissions cap is enforced, the availability of a greener alternative at no additional cost encourages the system to select the environmentally preferable option more frequently. Consequently, overall carbon emissions are halved, as IP2 operates at zero carbon emissions, while total operational costs remain stable, as the additional expenditure is absorbed by the subsidy rather than passed along the value chain.

Importantly, this policy option provides targeted financial compensation, with the subsidy acting as a market-aligned mechanism. However, the effectiveness of this approach depends critically on how the subsidy is designed and delivered. If subsidies are too broad or poorly targeted, they risk being economically inefficient or failing to promote genuinely greener technologies. In addition, this approach relies on the availability of public funding or incentive schemes, which may not always be feasible or politically viable.

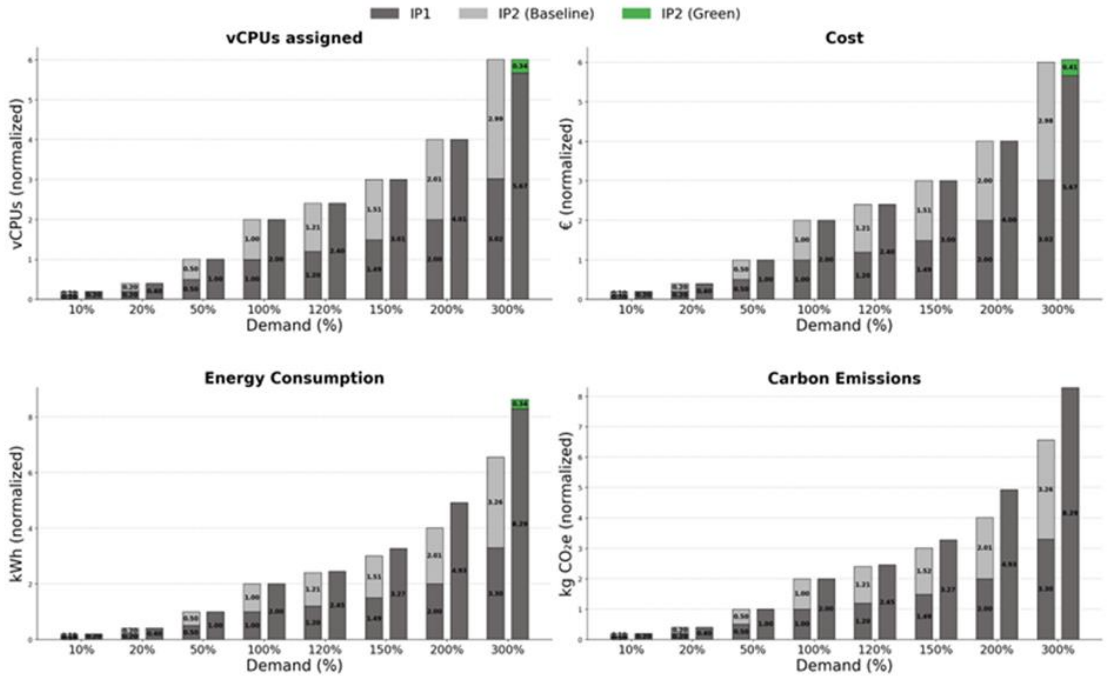

Figure 16: PO1. Laissez-faire vs baseline.

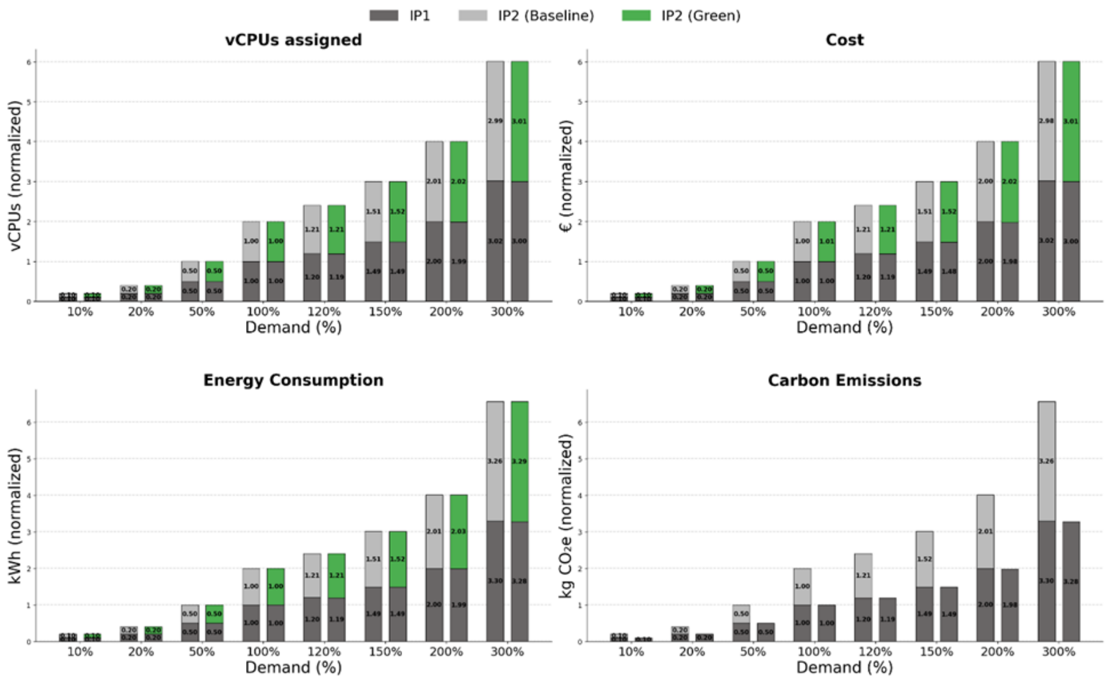

Figure 17: PO2. Subsidisation of Green Infrastructure vs. Baseline.

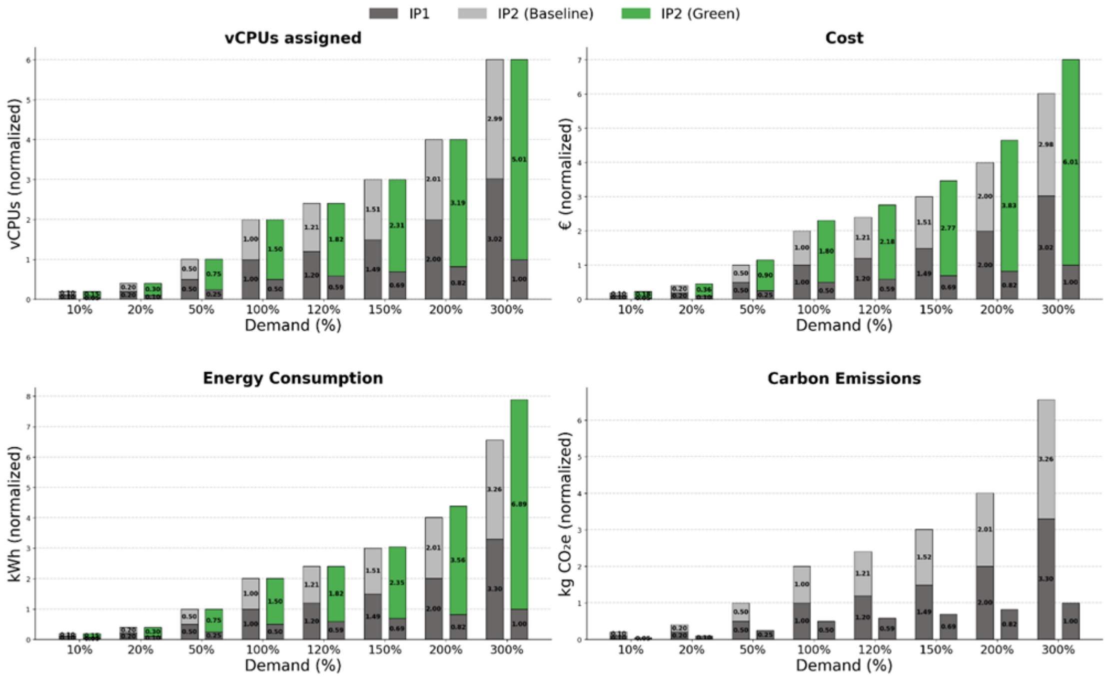

Figure 18: PO3. Introduction of DLAs vs. Baseline.

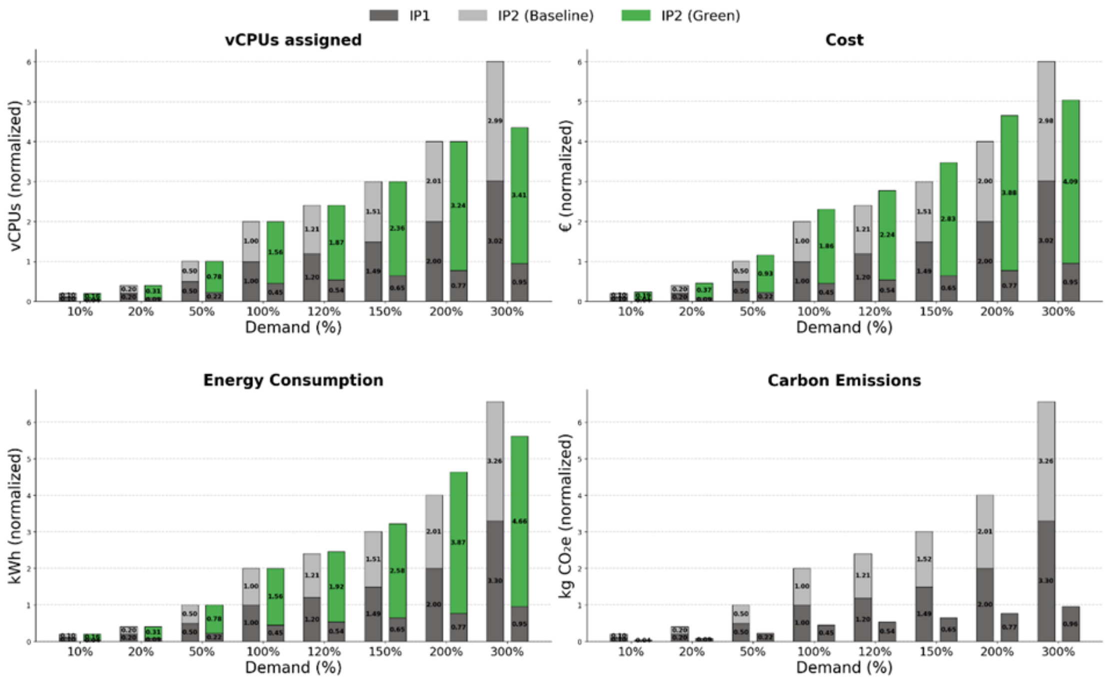

Figure 19: PO4. Tiered DLAs vs. Baseline.

Policy Option 3: Decarbonisation Level Agreements. As shown in Figure 18 the introduction of uniform DLAs is effective in achieving a significant reduction in carbon emissions, primarily by shifting demand towards greener infrastructure. However, this comes at the cost of higher system energy consumption and increased operational expenditure, particularly at high demand levels. These findings highlight that while regulatory constraints can successfully internalise sustainability objectives, they can also create economic distortions if not complemented by financial mechanisms to support stakeholders and maintain market efficiency.

Policy Option 4-Tiered DLAs for premium services- demonstrates that combining targeted regulatory constraints with market-based incentives for premium green services can yield substantial environmental benefits while maintaining economic viability. The differentiated approach aligns sustainability objectives with market realities and highlights the importance of capacity planning and investment to fully realise the potential of green infrastructure.

The results are shown in Figure 19. IP2, being the only provider capable of consistently meeting the emission requirement, takes on most of the workload across all demand levels. IP1 is relegated to a minimal supporting role, used only to satisfy residual demand not constrained by the emissions cap. Notably, at the highest demand level, the demand for green infrastructure and services grows beyond the capacity of IP2, which rejects a slice request, and the number of vCPUs drops compared to the baseline. However, this hypothetical situation is unlikely to happen in a real scenario, where NPPs would likely schedule a standard slice instead and renounce the price premium (or provide compensation for non-compliance with DLAs). Furthermore, sustained demand beyond green capacity would incentivise investment in green infrastructure by IPs to revert this shortage.

References

[A1] T.O. Atalay, D. Stojadinovic, A. Stavrou and H. Wang, H. "Scaling network slices with a 5g testbed: A resource consumption study", In 2022 IEEE Wireless Communications and Networking Conference (WCNC), pp. 2649–2653.

[A2] Comisión Nacional de los Mercados y la Competencia (CNMC), "Resolución de Determinación del Coste Medio Ponderado del Capital de Telefónica del Ejercicio 2024 (WACC/DTSA/002/24)", (2024)

[A3] European Commission, Body of European Regulators of Electronic Communications (BEREC), and Axon Partners Group, "Finalisation of the mobile cost model for roaming and the delegated act on a single EU-wide mobile voice call termination", 18 Dec. 2024 [Online]. Available: https://digital-strategy.ec.europa.eu/en/library/finalisation-mobile-cost-model-roaming-and-delegated-act-single-eu-wide-mobile-voice-call-0

[A4] A. Bellin, M. Centenaro and F. Granelli, "A preliminary study on the power consumption of virtualized edge 5g core networks" In 2023 IEEE 9th International Conference on Network Softwarization (NetSoft), pp. 420-425.

[A5] "Our World in Data: Carbon intensity of electricity" [Online].
Available: https://ourworldindata.org/grapher/carbon-intensity-electricity

[A6] Eurostat, "Development of electricity prices for household consumers 2008-2024", 2024.

[A7] T.O. Atalay, A. Famili, D. Stojadinovic and A. Stavrou, "Demystifying 5g traffic patterns with an indoor ran measurement campaign" In 2023 IEEE Global Communications Conference, pp. 1185-1190.

[A8] T.O. Atalay, D. Stojadinovic, A. Famili, A. Stavrou and H. Wang, "Network-slice-as-a-service deployment cost assessment in an end-to-end 5g testbed", In 2022 IEEE Global Communications Conference, pp. 2056-2061.

Annex B

Lean Canvas Responses from Consortium Partners

ATOS/EVIDEN

ATOS/EVIDEN has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 4.

Problem:

- Massive energy consumption in B5G/6G networks due to higher device density, higher transmission speeds, and intensive data processing: The deployment and operation of 5/6G networks require substantial energy resources, leading to high operational costs and significant environmental impact. As the demand for faster and more reliable connectivity grows, so does the energy consumption of these networks. This creates a pressing need for innovative solutions that can reduce energy usage without compromising performance. Problem: 6G networks, with their higher device density, higher transmission speeds, and intensive data processing, could consume much more energy than 5G networks. This is partly due to the need to implement technologies such as Massive MIMO, beamforming, and terahertz communications, which require higher energy consumption.
- Lack of information on the total energy used when running a specific service in a B5G/6G network. This means accounting for all devices and infrastructure elements involved, from the moment a user initiates the service until its termination. The challenge lies in the distributed nature of B5G/6G and the variety of technologies involved. To accurately assess the total end-to-end power consumption of a specific service in a 6G network requires comprehensive data. This includes a precise definition of the service, detailing its data requirements (bandwidth, latency, volume), its duration and the network components it uses. Equally important is a thorough understanding of the network topology, identifying the devices involved (user equipment, peripheral servers, core network elements), the data routing paths and the technologies used at each stage (MIMO, beamforming, etc.). In addition, it is essential to have detailed energy profiles of both the devices and the infrastructure, showing their consumption in different states (idle, transmitting, receiving, processing) and how it varies depending on factors such as data load and signal strength.
- Lack of mechanisms for dynamic network slice creation and management. Current solutions for dynamic network slices creation and management often involve manual or semi-automated slice creation, which is too slow and inflexible for the dynamic nature of B5G/6G services. There are significant obstacles to dynamic and efficient operation, including the difficulty of automating segment creation, scaling and management, as well as the complexity of resource orchestration and ensuring adequate isolation between segments. End-to-end orchestration of segments across multiple network domains, securing individual segments while maintaining overall network security, and achieving the scalability and elasticity required for a massive number of segments are also problematic. In addition, enabling inter-segment communication, establishing standardised interfaces for interoperability and implementing effective segment-specific monitoring and assurance mechanisms remain key challenges impeding the full potential of network segmentation in B5G. The challenge lies in automating the entire lifecycle of a slice, from creation and configuration to scaling, modification, and eventual termination, all in near real-time.

Solution:

- **Developing AI-based software solutions** for real-time orchestration and optimisation of network resources by dynamically managing power consumption. Adopt network functions virtualisation (NFV) to increase efficiency by improving scalability and reducing power consumption. In addition, adopt edge computing to minimise the energy costs of transporting data by processing and storing it closer to the source.
- **Combine several existing key techniques and new innovate mechanisms for modeling energy consumption in the different domains of the B5G/6G network.** A practical solution involves an approach that combines several key techniques. Network simulation software can model the B5G/6G network and simulate service usage, providing initial estimates of power consumption. Then, at the network level, real-time telemetry and monitoring of device and infrastructure energy usage provides crucial data for analysis and identification of energy hotspots. Based on all this information, AI models, using machine learning of the collected data, can refine these estimates and enable predictions for various service scenarios, ultimately aiding network optimisation. Extending this analysis to include device power consumption profiles and information from operators regarding the consumption of data centres and proprietary devices located in their facilities can help provide a more holistic view of end-to-end consumption.
- **Implement a multi-dimensional approach to enable automated B5G/6G slicing**. Possible solutions to the network fragmentation challenges in B5G/6G include a combination of advanced technologies such as AI-based orchestration that can automate segment lifecycle management and resource allocation. Adopt SDN and NFV for flexible and programmable segmentation. Also, integrating edge computing to extend segmentation capabilities to the network edge for latency-sensitive applications. On the other hand, intent-based networks also simplify segment management by focusing on high-level service requirements. Finally, advanced monitoring and analytics tools, leveraging machine learning, will enable real-time visibility into segment performance and quality of service assurance.

Unique Value Proposition: ATOS/EVIDEN can leverage its expertise to build smarter, more efficient and sustainable B5G/6G networks by developing AI-based solutions that optimise network performance, reduce energy consumption and minimise its carbon footprint. For customers, this not only means significant cost savings and increased network efficiency but also enhances their competitive advantage by differentiating their services and demonstrating their commitment to environmental responsibility.

Unfair Advantage: To build smart, efficient and sustainable 5G/6G networks that empower customers in various industries, deep technology expertise in various fields such as network architecture, software-defined networking (SDN), network functions virtualisation (NFV), edge computing, artificial intelligence (AI) and machine learning (ML) is crucial. This ATOS/EVIDEN expertise will translate into significant competence in faster development of innovative applications and more agile responses to market demands.

Customer Segments: The main segments are those that have a greater need for intelligent network management solutions for their own use, or to offer them to their customers, such as Mobile Network Operators (MNOs) or Edge Computing Providers, and on the other hand sectors with critical needs for intelligent and automated networks, as well as industries that generate a large carbon footprint, here we can include some Vertical industries such as Manufacturing, Healthcare, Automotive and Media & Entertainment.

Existing Alternatives: Traditional cloud computing often relies on over-provisioning resources and lacks dynamic resource allocation, leading to energy inefficiency. Non-optimized B5G/6G networks can also consume significant energy due to factors like inefficient power amplifiers and a lack of focus on renewable energy integration. Furthermore, current approaches often rely on manual intervention and lack proactive optimization strategies. These limitations highlight the need for more intelligent and sustainable approaches to cloud and network management

Key Metrics: Key metrics for smart, autonomous and sustainable B5G/6G networks will provide relevant information, among others, of the proportion of network operations powered by renewable energy, the level of automation of network tasks, the efficiency of resource utilisation, the ability of the network to self-heal from failures, the accuracy of autonomous decision-making and for the adaptability of the network to changing conditions.

High-Level Concept: The high-level concept "Smart, autonomous and sustainable B5G/6G networks" highlights the paradigm shifting towards a smart and sustainable management strategy. It focuses on the automation of intelligent resource allocation optimisation in cloud computing, coupled with the intelligent use of energy resources by integrating renewable energies in the optimisation of B5G/6G networks.
Channels: The channels through which ATOS will reach its customers are mainly its Client portfolio, Partnerships, International events and its social networks.

Early Adopters: ATOS has identified as early adopters mainly the highly polluting industrial sector, which for environmental reasons needs to make significant changes in their sustainability strategies by adopting solutions that allow them to be environmentally friendly and save on energy resources.

Cost Structure: The development of an optimised and energy-efficient solution for B5G/6G networks entails considerable costs, including costs for research and development, covering engineers and subject matter experts. Also, infrastructure costs, covering testbeds, peripheral computing devices and specialised equipment. Operational costs include electricity consumption for the operation of the infrastructure, and if necessary specific software, its software licences and maintenance. These costs will vary significantly depending on the scope of the solution to be implemented, the duration and the technologies used.

Revenue Structure: Revenues will come from licensing intellectual property (IP) related to AI/ML algorithms for network optimisation, energy management and self-healing to other network operators. Software solutions (e.g. orchestration platforms, AI/ML-based management tools) for sustainable 5G/6G networks. Also, offering consulting services to network operators on the design, implementation and optimisation of sustainable 5G/6G networks. Finally, with software-as-a-service (SaaS) offerings, providing subscription-based access to software platforms for network management, optimisation and energy management. This could include AI-based network orchestration tools, predictive maintenance and carbon footprint analysis.

Table 4: ATOS/EVIDEN Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• Massive energy consumption in B5G/6G networks due to higher device density, higher transmission speeds, and intensive data processing. • Lack of information on the total energy consumed when running a specific service in a B5G/6G network. • Lack of mechanisms for dynamic network slices creation and management.	• Developing AI-based software solutions for real-time orchestration and optimisation of network resources. • Combine existing key techniques and new innovate mechanisms for modelling energy consumption in the different domains of the B5G/6G network. • Implement a multi-dimensional approach to enable automated B5G/6G slicing	• Build smarter and more autonomous AI-powered B5G/6G networks that are sustainable and energy efficient, resulting in optimal infrastructure management and a substantial reduction of the carbon footprint.	• Technology expertise to build smarter, more efficient and sustainable 5G/6G networks for customers in multiple domains where the applicability of these solutions will help them become more competitive.	• Mobile Network Operators (MNOs) • Vertical industries (Manufacturing, Healthcare, Automotive, Media & Entertainment) • Edge Computing Providers
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Solutions for non-optimised 5G/6G networks with high energy consumption, based on over-provisioning and static resource allocation.	• Renewable Energy Usage (Carbon footprint reduction) • Resource Utilization Efficiency • Self-Healing Capabilities • Autonomous Decision-Making Accuracy • Adaptability to Changing Conditions	• Smart, autonomous and sustainable B5G/6G networks	• Client portfolio • Partnerships • Social media • International events	• Industrial sector (Highly polluting)

Cost Structure	Revenue Streams
• Research & Development (R&D) Engineers • Infrastructure of Testbeds and Labs • Energy costs & SW licences.	• Licensing of AI/ML Algorithms • Consulting and Professional Services • Software-as-a-Service (SaaS) offerings

TEI

TEI has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 5.

From 6Green Grant Agreement: "*The 6Green project envisions the 5/6G ecosystem as a sustainable, interconnected, greener, flexible end-to-end intercompute system, able to properly interface stakeholders by means of latest generation intent-based and cloud-native paradigms, and facilitating their interactions* *according to the aforementioned green economy business models and agreements. This will enable 5/6G vertical applications and* ***network slices to be dynamically, scalably, and autonomically placed in the edge-cloud continuum, instantiated, modified, dimensioned, migrated, and released in a coordinated fashion****, when and where really needed by end-users to minimize the induced impact at the infrastructure layer."*

Problem:

- **Dynamic, scalable, zero touch – green oriented Network Slice management:** The deployment and operation of 5/6G networks require at the infrastructural level, the ability to improve the legacy network slice management (mainly oriented to pure latency and bandwidth optimization) toward a more agile and power efficiency aware set of solutions.

Solution:

- **New Algorithms and Standard Protocols (e.g. BGP and PCEP) protocol extensions:** In the last two years of the 6GREEN development, the Ericsson Group that is taking part in this project, filed **two patents** specifically dedicated to:
- Extend the legacy algorithms (in a back-compatible way) in order to include new optimization criteria in addition to the legacy latency and bandwidth ones,
- Extend the standard protocols (e.g. BGP and PCEP) to allow a really dynamic and zero-touch network slice management. These extensions are in evaluation to be proposed to the SDO attention.

Unique Value Proposition: A 6G OSS decision process based on the native application of Ai/ML and the provided extended learning/Knowledge/prediction capabilities necessarily requires an higher level of dynamicity. The same requirement comes from the progressive network softwarization and disaggregation, therefore a new innovative solution has been conceived were the network slices doesn't need to be rebuild any time that whichever of the present static constraints are changed (limiting their dynamicity and reactivity) but are instantaneously completely adaptable on-the-fly among all the possible combinations advertised by the extended protocols that have been defined. This will provide an exceptional level of reactivity, dynamicity and automation to the AI/ML decision-based processes.

Unfair Advantage: The unfair advantage represented by the present solutions in this context is that they are widespread worldwide with a huge installed base and therefore any new innovative idea must necessarily be back-compatible, but this fact has been carefully considered and addressed.

Customer Segments: The primary customers for these solutions include telecom operators, vertical industries, infrastructure providers, and software developers. These stakeholders are increasingly seeking sustainable and efficient network solutions to meet regulatory requirements and corporate sustainability goals.

Existing Alternatives: Legacy OSS systems. Legacy Network Slice management subsystems.

Key Metrics: Success will be measured by key metrics such as the reduction in energy consumption, a decrease in the carbon footprint, and improved network efficiency.

High-Level Concept: The overarching concept is to create "Green 5/6G Networks for a Sustainable Future"

Channels: Being part of the evolved OSS solutions, that are part of the Ericsson Portfolio, it will be part of the new Ericsson tenders and consequent installations.

Early Adopters: The initial focus will be on environmentally conscious telecom operators and businesses that prioritize sustainability.

Cost Structure: The cost structure mainly includes expenses related to research and development, and production costs.

Revenue Structure: Ericsson Customers.

Table 5: TEI Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• Green oriented network slices (to be dynamically, scalably, and autonomically placed in the edge-cloud continuum)	• New innovative Implementations to overcome the legacy solutions merely oriented to latency and bandwidth constraints.	• Provide innovative, sustainable, and energy-efficient network slices leveraging on new algorithms and proper improvements of the current telco protocols (BGP and PCEP) to achieve a complete zero-touch solution.	• The current protocols and algorithms are widespread worldwide with a huge installed base and any improvement must necessarily be back compatible.	• Telecom operators • Vertical industries • Infrastructure providers • Software developers
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Traditional Network Slices management in traditional OSS systems.	• Reduction in energy consumption • Decrease in carbon footprint • Improved network efficiency	• "Green 5/6G Networks for a Sustainable Future."	• Being part of the evolved OSS solutions, that are part of the Ericsson Portfolio, it will be part of the new Ericsson tenders and consequent installations	• Environmentally conscious telecom operators and businesses

Cost Structure	Revenue Streams
• R&D expenses • Production costs • Marketing costs	• Revenue from Ericsson customers

ININ

ININ has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 6.

Problem:

- **Interruptions of energy supply (i.e., disaster scenario) to the critical infrastructure:** critical infrastructure is expected to operate 24/7, with no interruption. Although this is not achievable in practice, we want to reach as close as possible to this goal. Interruption of energy supply may cause unwanted situations, creating a need for an adequate response to the situation for the critical services to operate continuously. Timewise, the interruption of energy supply can be short or long, however, as it may cause unwanted situation in any case, such situations are named “disaster scenario”.
- **Providing timely response of the infrastructure to the disaster scenario:** in ideal case, the disaster scenario (interruption of energy supply) should be unnoticed by the customers, which requires mechanisms able to react promptly to minimize any harmful consequences for the customers.
- **Minimizing potential damage due to the energy supply interruptions and maximizing green energy utilization:** as there are various disaster scenarios possible (e.g., short-term, long-term, full energy supply outage, partial outage, etc.), the response should minimize impact experienced by the customers. Since the impact on the customers may not be prevented in every case, most critical parts of the infrastructure should be handled with the highest priority. As well, energy supplied, either in normal conditions or during the disaster scenario, should be as green as possible.

Solution:

- Implement Edge Agility to keep the most essential service working during disaster scenario and for efficient resource utilization: ability to move application components across cloud-continuum provides better reliability of the service as well as choosing more energy efficient resources or resources consuming more green energy. However, priority should be always given to the operability of the service.
- Introduce Green Elasticity to adapt computing resources usage to conditions of the disaster scenario and to efficiently utilize resources: through leveraging energy-efficient hardware acceleration, resource can be better utilized and adapted (scaling to zero for non-essential services) to temporary conditions of the disaster scenario or normal service usage.
- Develop Energy-aware Backpressure for real-time energy and carbon footprint monitoring: with the help of monitoring, and services profiling from an energy use perspective, further improvements of the solution and decisions will be possible to make.

Unique Value Proposition: An innovative, sustainable, extremely reliable and energy-efficient 5/6G network solution will be provided. The customer will benefit from real-time response to energy supply constraints, capitalizing on solution’s ability to adapt to energy supply constraints in challenging/critical environments.

Unfair Advantage: ININ’s past experiences and extensive hands-on expertise in ICT infrastructure design, development and operation, as well as critical services design and development experiences, its involvement in PPDR vertical and strong partnerships with key industry players allows for maximizing customers’ benefit.

Customer Segments: The primary customers for these solutions include critical infrastructure operators, ICT operators, and vertical industries. These customers are increasingly seeking reliable, sustainable and energy efficient solutions to meet requirements.

Existing Alternatives: Current alternatives include (traditional) cloud solutions, non-optimized 5G networks, and large redundant capabilities such as batteries. Although the development of such solutions leverages both reliability and energy efficiency, ININ’s approach goes even farther utilizing innovative solutions provided by 6Green.

Key Metrics: In technical terms, success of the solution provided will be evaluated through following metrics: network availability, energy-constraint conditions detection time, time to disable non-critical services and UEs, network latency and green energy utilization rate. These metrics will demonstrate the ability of the solution to address technical requirements.

High-Level Concept: The overarching concept is to create "Green and sustainable 5/6G Networks for critical operations." Vision promotes green energy usage and sustainability for critical infrastructure.
Channels: Market penetration is planned to be achieved through multiple channels, i.e., by test and trials campaigns, dissemination at fairs and other industry events, promotion campaigns on the web and social media, through partnerships and by direct sales.

Early Adopters: Among early adopters we see primarily technologically advanced critical infrastructure and ICT operators, as well as smaller vertical industries players and/or players in niche verticals.

Cost Structure: costs, required to develop and deploy the solution includes R&D costs, costs of infrastructure/technology required for the solution to work properly, then deployment and integration costs and operational costs. Besides, administrative and legal costs (e.g., to address potential GDPR and data confidentiality issues) and marketing/sales costs should be also considered.

Revenue Structure: Revenue to enable further development is expected to be collected by EU funding, i.e., to support the initial development, and then, when the solution is market ready, revenue is expected to come from providing and operating services, and from licensing fees.

Table 6: ININ Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• Interruptions of energy supply (i.e., disaster scenario) to the critical infrastructure. • Providing timely response of the infrastructure to the disaster scenario. • Minimizing potential damage due to the energy supply interruptions and maximizing green energy utilization.	• Implement Edge Agility to keep the most essential service working during disaster scenario and for efficient resource utilization. • Introduce Green Elasticity to adapt computing resources usage to conditions of the disaster scenario. • Develop Energy-aware Backpressure for real-time energy and carbon footprint monitoring.	• Provide innovative, sustainable, extremely reliable and energy-efficient 5/6G network solution providing real-time response for challenging environments affected by energy supply constraints.	• Extensive hands-on expertise in ICT infrastructure, critical services, PPDR vertical, and strong partnerships with key industry players.	• Critical infrastructure operators • ICT operators • Vertical industries
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Cloud solutions • Extensive redundant capabilities (e.g., batteries, fuel powered generators)	• Network and services availability • Energy-constraint conditions detection time • Time to disable non-critical services and UEs • Network latency • Green energy utilization rate	• "Green and sustainable 5/6G Networks for critical operations."	• Test and trials campaigns • Dissemination at fairs and other industry events • Web and social media promotion • Partnerships • Direct sales	• Technologically advanced critical infrastructure and ICT operators • Small scale and niche vertical industries players

Cost Structure	Revenue Streams
• R&D costs • Infrastructure/technology costs • Deployment and integration costs • Operational costs • Administrative and legal costs (e.g., to address potential GDPR and data confidentiality issues) • Marketing/sales costs	• EU funding to support the initial development • Revenue from providing reliable and energy efficient services • Revenue from integration of services • Licensing fees • Support services fees

ORO

ORO has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 7.

Problem:

- **High energy consumption in 5/6G networks:** The deployment and operation of 5/6G networks require substantial energy resources, leading to high operational costs and significant environmental impact. As the demand for faster and more reliable connectivity grows, so does the energy consumption of these networks. This creates a pressing need for innovative solutions that can reduce energy usage without compromising performance.
- **Increased carbon footprint from telecom operations:** Telecom operations contribute to a considerable carbon footprint due to the extensive use of energy-intensive infrastructure and equipment. The carbon emissions associated with powering data centers, network towers, and other telecom facilities are substantial, exacerbating the global issue of climate change. Addressing this problem is crucial for the telecom industry to align with global sustainability goals and reduce its environmental impact.
- **Need for sustainable and scalable network solutions:** The current network solutions are not adequately designed to meet the dual demands of sustainability and scalability. As the telecom industry evolves, there is an urgent need for network solutions that can scale efficiently while minimizing their environmental footprint. Developing sustainable network technologies is essential to ensure that the growth of the telecom sector does not come at the expense of the planet's health.

Solution:

- **Implement Edge Agility for efficient resource utilization:** Edge Agility involves dynamically managing and redistributing workloads across the edge-cloud continuum to optimize resource utilization. By intelligently shifting applications and services closer to the end-users only when needed, this approach minimizes energy consumption and reduces latency. This ensures that network resources are used efficiently, leading to significant energy savings and improved performance.
- **Introduce Green Elasticity for energy-aware hardware acceleration:** Green Elasticity focuses on leveraging energy-efficient hardware acceleration to enhance the performance of network functions and vertical applications. By utilizing low-power hardware accelerators, such as GPUs and programmable switches, this solution reduces processing latency and energy consumption. Additionally, it enables smart scaling of resources based on real-time demand, further optimizing energy usage and reducing the overall carbon footprint.
- **Develop Energy-aware Backpressure for real-time energy and carbon footprint monitoring:** Energy-aware Backpressure involves implementing cross-domain observability mechanisms and analytics to monitor and evaluate the energy consumption and carbon footprint of network operations in real-time. By collecting and processing energy usage data from various network components, this solution provides actionable insights to stakeholders. It enables them to make informed decisions to optimize energy efficiency and reduce carbon emissions, ensuring a more sustainable network infrastructure.

Unique Value Proposition: Orange aims to deliver innovative, sustainable, and energy-efficient 5/6G network solutions that not only reduce the carbon footprint but also lower operational costs. This approach positions Orange as a leader in providing eco-friendly telecom infrastructure, appealing to environmentally conscious stakeholders.

Unfair Advantage: Orange's extensive expertise in telecom infrastructure, combined with strong partnerships with key industry players, provides a significant competitive edge. This unique position allows

Orange to leverage its knowledge and relationships to drive the adoption of sustainable practices across the industry.

Customer Segments: The primary customers for these solutions include telecom operators, vertical industries, infrastructure providers, and software developers. These stakeholders are increasingly seeking sustainable and efficient network solutions to meet regulatory requirements and corporate sustainability goals.

Existing Alternatives: Current alternatives include traditional cloud computing and non-optimized 5G networks, which do not adequately address the energy consumption and carbon footprint issues. Orange's solutions offer a more sustainable and efficient approach, setting them apart from existing technologies.

Key Metrics: Success will be measured by key metrics such as the reduction in energy consumption, a decrease in the carbon footprint, and improved network efficiency. These metrics will demonstrate the tangible benefits of Orange's sustainable network solutions.

High-Level Concept: The overarching concept is to create "Green 5/6G Networks for a Sustainable Future." This vision encapsulates Orange's commitment to environmental responsibility and innovation in the telecom industry.

Channels: Orange will utilize direct sales, strategic partnerships, and digital platforms to reach its target customers. These channels will facilitate the adoption of sustainable network solutions and drive market penetration.

Early Adopters: The initial focus will be on environmentally conscious telecom operators and businesses that prioritize sustainability. These early adopters will serve as key advocates for Orange's green network solutions.

Cost Structure: The cost structure includes expenses related to research and development, infrastructure investments, and the implementation of energy-efficient technologies. These costs are necessary to develop and deploy cutting-edge sustainable solutions.

Revenue Structure: Revenue will be generated from offering sustainable network services, energy-efficient solutions, and licensing green technologies. This diversified revenue stream will support Orange's long-term growth and commitment to sustainability.

Table 7: ORO Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• High energy consumption in 5/6G networks. • Increased carbon footprint from telecom operations. • Need for sustainable and scalable network solutions	• Implement Edge Agility for efficient resource utilization. • Introduce Green Elasticity for energy-aware hardware acceleration. • Develop Energy-aware Backpressure for real-time energy and carbon footprint monitoring	• Provide innovative, sustainable, and energy-efficient 5/6G network solutions that significantly reduce carbon footprint and operational costs.	• Extensive expertise in telecom infrastructure and strong partnerships with key industry players	• Telecom operators • Vertical industries • Infrastructure providers • Software developers

Existing Alternatives	Key Metrics	High-Level Concept	Channels	Early Adopters
• Traditional cloud computing and non-optimized 5G networks	• Reduction in energy consumption • Decrease in carbon footprint • Improved network efficiency	• "Green 5/6G Networks for a Sustainable Future."	• Direct sales • Partnerships • Digital platforms	• Environmentally conscious telecom operators and businesses

Cost Structure	Revenue Streams
• R&D expenses • Infrastructure costs • Energy-efficient technology investments	• Revenue from sustainable network services • Energy-efficient solutions • Green technology licensing

SMILE

SMILE has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 8.

Problem:

- **Monitoring is usually made of information collected at a system level, but energy related information is either sparse or missing** most of the exposed metrics at a system level are designed at a bios level, this means the ability to expose new metrics to the userpace is limited by the hardware state. While the userspace system (e.g. Linux) gets frequent updates, the bios gets rare firmware upgrades. A solution is needed to provide through software means the build of metrics independently of the bios capabilities.
- **To cope with regulations, monitoring must provide information related to clusters or clusters of clusters, which can be complex to centralize in the long run:** monitoring always start at a system level, that is the one of a single physical or virtual operating system, while in modern infrastructures there is rarely a single operating system involved. Recent microservices oriented supervisors expect at least three worker nodes to ensure minimal operations and this can expand up to hundreds or thousands of nodes. Although the computing power made available is large, the monitoring cost tends to grow in a way where it is difficult for operators to store more than a few days of information.
- **Monitoring itself can use resources meant to be used at an operational level; in critical scenarios monitoring resources usage can conflict with domain needs:** in critical systems every single bit of bandwidth is expected, especially in modern systems, where components tend to have an elastic consumption of resources; at many points in time the overall executing node may find itself in a situation where there is no more resources to be shared amongst applicative components. Monitoring then, which is both critical, to detect for example anomalies, and useless, as it doesn't provide end users with a direct benefit, can appear as an extra pressure point over resources.

Solution:

- **Develop a monitoring solution that can infer energy related metrics from different system resources, to enable a seamless energy related monitoring experience over various types of servers or devices:** metrics are in many cases related to each other. Considering the energy metrics they directly relate to the usage of typical resources such as CPU, RAM, Disk. Observing and modeling the evolution of the usage for these metrics enables the possibility to infer the energy consumption even if not made available as a direct metric.

- **Provide methodology and tools to enable the transformation of raw metrics into higher level information, while supporting longer term storage:** system metrics themselves sometimes lack context, designing a tool to model higher level considerations through KPIs will help into understanding metrics for what they are from a domain perspective.
- **Conceive algorithms which may reduce the monitoring footprint over system resources by diminishing dynamically the collecting space of the information:** monitoring although rarely thought as a resource consuming component, still does have a footprint over the system resources. Implementing a scheduler on top of the scheduling may help in retrieving only the needed amount of information.

Unique Value Proposition: SMILE will propose its expertise to propose and implement an efficient Open-Source system to retrieve and expose energy and CO2 related information within a telecom network architecture.

Unfair Advantage: Such solution may only goes toward a better management of large scale and/or energy sensitive systems

Customer Segments: As the solution is generic, typical services providers customers.

Existing Alternatives: Only local, manual solutions could be considered, limiting their interest in real life or scale scenarios.

Key Metrics: Metrics we observed are oriented towards the energy usage and the resources cost of the monitoring.

High-Level Concept: The high-level concept "Energy related, long term, efficient monitoring" showcases the evolution of the classical monitoring, aimed at detecting anomalies in a short timeframe of observation, towards a more sustainable approach, including longer timeframe and energy related information.

Channels: The channels through which SMILE will reach its customers are mainly its position in the Open-Source community.

Early Adopters: SMILE expects early adopters to be researchers aiming to improve / benchmark systems in specific or extreme cases. Once this level of adoption is reached, we believe system engineers to take the lead in implementing our results.

Cost Structure: Typical of the software development, that is: manpower comprised of engineers, infrastructure setup and usage, which results into energy consumption.

Revenue Structure: We respect a strict "public money, open code" policy and therefore our results can only be monetized through Open-Source friendly business models. Customers may reach us at any time to gather our expertise on solutions that are otherwise publicly available and free to use.

Table 8: SMILE Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• Monitoring is usually made of information collected at a system level, but energy related information are either sparsed or missing.	• Develop a monitoring solution that can infer energy related metrics from different system resources, to enable a seamless energy related monitoring	• Propose an efficient Open-Source system to retrieve and expose energy and CO2 related information within a telecom network architecture	• Better management of large scale and/or energy sensitive systems	• Mobile Network Operators (MNOs) • Vertical industries (Manufacturing, Healthcare, Automotive, Media & Entertainment) • Edge Computing Providers

• To cope with regulations, monitoring must provide information related to clusters or clusters of clusters, which can be complex to centralize in the long run. • Monitoring itself can use resources meant to be used at an operational level; in critical scenarios monitoring resources usage can conflict with domain needs.	experience over various types of servers or devices. • Provide methodology and tools to enable the transformation of raw metrics into higher level information, while supporting longer term storage. • Conceive algorithms which may reduce the monitoring footprint over system resources by diminishing dynamically the collecting space of the information.			
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Manually, local, monitoring solutions	• Renewable Energy Usage (Carbon footprint reduction) • Resource Utilization Efficiency • Number of metrics by machines • Monitoring storage duration	• Energy related, long term, efficient monitoring	• Open-Source communities	• Researchers • System Engineers
Cost Structure			**Revenue Streams**	
• Research & Development (R&D) Engineers • Infrastructure of Testbeds and Labs • Energy costs			• Open Source based business model	

TNOR

TNOR has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 9.

Problem:

- **High energy consumption in 5/6G networks:** The deployment and operation of 5/6G networks require substantial energy resources, especially with the increasing number of devices connecting to the network and the use cases demanding for high performance/availability/reliability. There is the need to develop innovative solutions to enable tight proportionality between the network energy consumption and workloads.
- **Lack of awareness on the energy consumption/carbon footprint by customers and 5/6G stakeholders:** While it is the infrastructure that gets the energy bill, the workloads are induced by upper stakeholders (i.e., network platform providers and vertical application providers) and the end

users (i.e., businesses and consumers), who might mostly be unaware of their contribution to the carbon footprints of the network and digital services.
- **Need for a holistic solution for network sustainability:** There are inherent tradeoffs between power savings and performance, such that the infrastructure provider alone cannot blindly enforce sustainability frameworks without affecting other 5/6G stakeholders or the end users. A holistic approach is needed, involving the complete 5/6G ecosystem and ensuring energy observability at all levels towards a win-win solution.

Solution:
- **Implement Edge Agility for optimized workload distribution in the compute continuum:** Edge agility optimizes the workload distribution across the compute continuum, placing network functions and vertical applications only to where/when they are needed and smartly "scale-to-zero" where/when not needed. This will improve both the energy efficiency and performance of end-to-end services.
- **Implement Green Elasticity for exposing energy-aware platform capabilities:** Green Elasticity exposes platform capabilities such as software/hardware accelerators, offloading mechanisms and power management APIs to make all the 5/6G stakeholders jointly target energy efficient tradeoffs between compute and network resources that meet end-to-end latency and operating requirements.
- **Implement Energy-aware Backpressure for energy and carbon footprint observability:** Energy-aware backpressure enables monitoring of energy and carbon footprint at different granularities (i.e., slice, NF, vApp, pod, etc.), analytics for estimating past/future workloads and induced footprints, as well as exposes them to 6Green's internal optimization framework, and to the vertical stakeholders for informed decisions towards sustainability.

Unique Value Proposition: Telenor aims to provide innovative and energy-efficient 5/6G network solutions that involve all stakeholders in the 5/6G ecosystem, this is aligned with our sustainability ambitions towards delivering on our science-based targets in terms of both operations and value chain. This ensures that new technologies are developed with sustainability considerations in mind.

Unfair Advantage: As a leading technology-driven communication services provider with presence in the Nordics and Asia, Telenor has extensive expertise in telecom infrastructure and network platform, as well as strong partnerships with key players in both industry and research. This not only allows Telenor to bring in telecom knowledge and experience into 6Green, but also exploit the lessons learned from the project into sustainable practices within the telecom space.

Customer Segments: The primary customers for sustainable solutions include telecom operators, vertical industries, infrastructure providers and end users – both businesses and consumers. With sustainability on top of everyone's agenda, all 5/6G stakeholders including the end users have started to set (corporate) sustainability goals, which could potentially benefit from 6Green's key innovations.

Existing Alternatives: Current alternatives within Telenor include sleep modes and other optimizations on the radio access network (RAN) only, as well as offering green incentives for mobile phone circularity.

Key Metrics: Success will be measured by key metrics such as improved network energy efficiency, as well as Telenor's climate goals approved by the Science Based Targets Initiative (SBTi) for Scopes 1, 2 and 3.

High-Level Concept: For Telenor, the overarching concept is to create a "Clean and Green Telecom". This means that Telenor aims at enabling the digital shift to be green, safe and for all. Telenor has set concrete science-based targets to substantially reduce GHGs emissions of from its global operations. Telenor has also submitted a net-zero target to reach a 90% reduction across all scopes (Scopes 1, 2 and 3) by 2045.

Channels: Telenor will use direct sales, strategic partnerships and digital platforms to reach its target customers towards the adoption of sustainable network solutions and green business models in the telecom industry.

Early Adopters: The initial focus will be on environmentally conscious 5/6G stakeholders and end users, exploring how informed decisions on network/services sustainability could potentially lead to a win-win 5/6G ecosystem.

Cost Structure: The cost structure includes expenses related to research and innovation, infrastructure OPEX and software licenses/support, awareness campaign costs, as well as investments on energy-efficient technologies and power purchase agreements for clean energy. These costs are necessary to advocate and develop sustainable practices in the telecom industry.

Revenue Structure: Revenue will be generated from energy-efficient solutions and pricing initiatives based on energy savings, green incentives and use of clean energy.

Table 9: TNOR Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• High energy consumption in 5/6G networks • Lack of awareness on the energy consumption/carbon footprint by customers and 5/6G stakeholders • Need for a holistic solution for network sustainability	• Implement Edge Agility for optimized workload distribution in the compute continuum • Implement Green Elasticity for exposing energy-aware platform capabilities • Implement Energy-aware Backpressure for energy and carbon footprint observability	• Provide innovative and energy-efficient 5/6G network solutions that involve all stakeholders in the 5/6G ecosystem to achieve significant carbon footprint and operational costs reduction.	• Extensive expertise in telecom infrastructure and network platform • Strong partnerships with key industry and research players	• Telecom operators • Vertical industries • Infrastructure providers • End Users: Businesses and Consumers
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Sleep modes and other optimizations on the radio access network (RAN) • Green incentives for circularity.	• Improved network energy efficiency • Meet the Science-based targets (SBTi) for Scopes 1, 2 and 3	• "Clean and Green Telecom"	• Direct sales • Partnerships • Digital platforms	• Environmentally conscious 5/6G stakeholders and end users.

Cost Structure	Revenue Streams
• R&I expenses • Infrastructure and software costs • Energy-efficient technology and clean energy investments • Awareness campaign costs	• Energy-efficient solutions • Pricing initiatives

TID

TID has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 10.

Problem:

- **High energy consumption in 5/6G networks:** The deployment and operation of 5/6G networks require substantial energy resources, leading to high operational costs and significant environmental impact when this energy does not come from green sources.
- **Potential demand for new connections and elastic computing and connectivity resources**. There is an increasing demand for more, faster reliable and flexible connectivity and elastic computing resources in the cloud-edge continuum. This increases energy consumption of 5/6 networks and creates a pressing need for innovative solutions that can reduce energy usage without compromising performance.
- **Lack of awareness on energy consumption and carbon footprint**. Telecom operations contribute to a considerable carbon footprint due to the extensive use of energy-intensive infrastructure and equipment. Addressing this problem is crucial for the telecom industry to align with global sustainability goals and reduce its environmental impact. However, there is no systematic control of energy consumption or carbon emissions by telecom networks and associated computing nodes.

Solution:

- **Develop Energy-aware Backpressure for real-time energy and carbon footprint monitoring.** Energy-aware Backpressure involves implementing cross-domain observability mechanisms and analytics to monitor and evaluate the energy consumption and carbon footprint of network operations in real-time. This is a pivotal solution for implementing power consumption and carbon emission optimization techniques on top of telecom networks and potentially extensible to other industry verticals. By collecting and processing energy usage data from various network components, this solution provides actionable insights to stakeholders. It enables them to make informed decisions to optimize energy efficiency and reduce carbon emissions, ensuring a more sustainable network infrastructure.
- **Implement energy-aware Edge Agility to allow resource scheduling optimized for sustainability**. Edge Agility involves dynamically managing and redistributing workloads across the edge-cloud continuum to optimize resource utilization. By intelligently shifting applications and services closer to the end-users only when needed, this approach minimizes energy consumption and reduces latency. This approach must be extended to optimize carbon emissions, as well. This ensures that network resources are used efficiently, leading to significant energy savings and improved performance, and that resource scheduling favors green infrastructures and ensures minimal carbon footprint.
- **Introduce Green Elasticity for energy-aware hardware acceleration:** Green Elasticity focuses on leveraging energy-efficient hardware acceleration to enhance the performance of network functions and vertical applications. By utilizing low-power hardware accelerators, such as GPUs and programmable switches, this solution reduces processing latency and energy consumption. Additionally, it enables smart scaling of resources based on real-time demand, further optimizing energy usage and reducing the overall carbon footprint.

Unique Value Proposition: TID/Telefónica aims to deliver innovative, sustainable, and energy-efficient 5/6G network solutions and enable/promote economic incentives to involve all stakeholders in the 5/6G ecosystem in the effort of reducing energy consumption, carbon footprint and operational costs of telecom networks and digital services.

Unfair Advantage: TID/Telefónica has extensive expertise in planning, deploying and operating telecom infrastructure, and in designing open network APIs to involve service developers and customers in tailoring network to their needs. Combined with strong partnerships with key industry players, this expertise provides a significant competitive edge that TID/Telefónica brings to 6Green, and it provides a sound starting position to make the most out of the project in order to develop its unique value proposition.

Customer Segments: The primary customers for these solutions include telecom operators, vertical industries, and infrastructure providers. These stakeholders are increasingly seeking sustainable and efficient network solutions to meet regulatory requirements and corporate sustainability goals. An additional niche segment could be sectoral regulatory bodies (not necessarily telco for solutions targeting other verticals) interested in monitoring carbon footprint in their industries.

Existing Alternatives: Current alternatives include traditional cloud computing and non-optimized 5G networks, which generally do not properly address the energy consumption and carbon footprint issues. Moreover, some optimization mechanisms have been defined in the context of RAN to reduce energy consumption when the expected load is low, e.g., by switching on/off network resources. Solutions stemming from 6GREEN offer a more sustainable and efficient approach, dealing with carbon emissions and not only with energy consumption, which sets them apart from existing technologies.

Key Metrics: We are already measuring key metrics such as energy consumption, network resource utilization, and improved network efficiency. In addition, 6Green will pave the way to connect these metrics with the carbon footprint of telecom networks and digital services, enabling further optimizations of efficiency coming from deriving workloads to greener infrastructures which ultimately reduce our impact on the environment.

High-Level Concept: The vision is to create "Elastic Green 5/6G Networks for a Sustainable Future." This vision encapsulates commitment to environmental responsibility and innovation in the telecom industry.

Channels: TID/Telefónica will utilize direct sales, strategic partnerships, and digital platforms to reach its target customers. These channels will facilitate the adoption of sustainable network solutions and drive market penetration.

Early Adopters: The initial focus will be on environmentally conscious telecom operators and customers (residential & business) that prioritize sustainability. Among business customers, those belonging in industry verticals with high environmental footprint will more likely be adopting solutions that monitor energy consumption and carbon footprint for telecom/IT and their own industry.

Cost Structure: The cost structure includes expenses related to research and development, infrastructure investments, and the implementation of energy-efficient technologies. In addition, there will be additional costs to develop products and services especially for B2B segments, and commercial B2C and B2B expenses. These costs are necessary to develop and deploy cutting-edge sustainable solutions.

Revenue Structure: Revenue will be generated from a green premium for offering sustainable telecom services. In addition, ad hoc design and set up of energy-efficient and monitoring solutions can be commercialized for B2B customers. Finally, recurrent revenue can come from licensing green technologies for those solutions. This diversified revenue stream will support Telefónica/TID’s long-term growth and commitment to sustainability.

Table 10: TID Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• High energy consumption in 5/6G networks. • Potential demand for new connections and elastic computing and connectivity resources • Lack of awareness on energy consumption and carbon footprint	• Develop Energy-aware Backpressure for real-time energy and carbon footprint monitoring and prediction • Implement energy-aware Edge Agility to allow resource scheduling optimized for sustainability. • Introduce Green Elasticity for energy-aware hardware acceleration.	• Provide innovative, sustainable, and energy-efficient 5/6G network solutions and economic incentives to involve all stakeholders in the 5/6G ecosystem in reducing carbon footprint and operational costs.	• Extensive expertise in telecom infrastructure • Strong partnerships with key industry players	• Telecom operators • Vertical industries • Infrastructure providers • End users: businesses and consumers • Sectoral regulatory bodies
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Traditional cloud computing and non-optimized 5G networks • Limited RAN optimization to reduce energy consumption in low-load periods	• Energy consumption • Resource utilization • Network efficiency	• "Green Elastic 5/6G Networks for a Sustainable Future."	• Direct sales • Partnerships • Digital platforms	• Environmentally conscious stakeholders and customers • Industry vertical with high environmental footprint

Cost Structure	Revenue Streams
• R&D expenses • Infrastructure and software costs • Energy-efficient technology investments • Product development • Commercial costs	• Revenue premium from sustainable network services by environmentally-aware customers • Energy-efficient solutions • Real-time sustainability monitoring solutions • Green technology licensing

UBITECH

UBITECH has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 11.

Table 11: UBITECH Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• High Energy Consumption and Carbon Footprint in Vertical Application Deployments • Lack of Real-Time Monitoring and Adaptive Policy Enforcement • Inefficient Resource Allocation lacking optimised decisions	• Introduction of Green KPIs, Policies, and Automation for Optimized Energy Efficiency • Implementation of a Real-Time Monitoring Entity for Dynamic Policy Enforcement • Extension related 3GPP functions with efficient decisions for Intelligent Resource Allocation	• A holistic policy-based approach to energy-efficient vertical application deployment by integrating real-time monitoring, automated lifecycle management, and adaptive resource allocation within the edge-cloud continuum.	• Reuse of the mature MAESTRO framework providing runtime reconfiguration of deployed services while including the framework for the decision mechanisms. • Extensive expertise in 3GPP architecture for efficient integration	• Telecom operators • Vertical industries • Infrastructure providers • End Users: Businesses and Consumers
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Some similar solutions by large vendors, as well as project outcomes, BUT No automated orchestration solutions and micro-service management exist. Also limited policy management	• Time for service creation and modification/ update • Successful response and time required in response to monitored metrics and rules/policies		• Direct sales (existing and new business relations) • Fairs, exhibitions • Clustering	• Mobile Network Operators (as service provider over their infrastructure) • Private network owners (for management of services at local level)

Cost Structure	Revenue Streams
• R&D • Personnel • Maintenance • H/W infrastructure	• Licenses • Installation, maintenance services • Consulting services

UPM

UPM has elaborated on the Lean Canvas components as follows, which are then summarised in the template in Table 12.

Problem:

- **Limited integration of academia in real-world deployment of green telecom solutions.** The lack of direct collaboration with industry players in the research of 5G/6G networks and their deployment as real-world solutions hinders the added value of future research. This disconnect reduces the potential impact of cutting-edge research on the overall telecommunications sector.
- **Limited research on how to improve energy consumption and carbon footprint by technology design.** There is a need for deeper investigations into how emerging technologies— including new radio architectures —can significantly reduce power consumption and minimize environmental impact. Without a structured approach, progress toward truly green telecom infrastructures remains slow.
- **Lack of training in designing sustainable solutions for ICT students.** As the societal demand for sustainable ICT solutions grows, future engineers and researchers must be equipped with the skills necessary to design and implement sustainable networks. However, many ICT programs still lack dedicated courses or modules focusing on sustainability principles in telecommunications. This gap in education prevents graduates from developing the mindset and technical competencies required to contribute effectively to the industry's sustainability goals.

Solution:

- **Research on sustainable AI orchestration of network resources**, capable of dynamically managing and redistributing workloads across the edge-cloud continuum to optimize resource utilization. By intelligently shifting applications and services closer to the end-users only when needed, this approach minimizes energy consumption and reduces latency. This approach must be extended to optimize carbon emissions, as well. This will require developing real-time energy and carbon footprint monitoring capabilities on top of telecom networks.
- **Research on incentivization of green telecom networks and services**. Exposing sustainable KPIs does not necessarily mean that all the stakeholders make use of them and ensure their networks or services minimize energy consumption and carbon emissions. Additional research is needed regarding the economic incentives for stakeholders to minimize them, e.g., by adopting specific pricing schemes, penalizing excess consumption or emissions, etc.
- **Engagement in standardization and policy-making discussions**. Actively participating in standardization bodies and policy-making discussions ensures that academic research on sustainable 5G/6G technologies influences the development of industry regulations and best practices. By contributing to frameworks set by organizations such as the ITU, ETSI, and 3GPP, UPM can help shape policies that promote energy efficiency, lower carbon footprints, and encourage the adoption of green telecom solutions.
- **Integrate sustainability aspects in teaching curriculum of telecom** to raise the awareness of students and practitioners about these issues, and to spread the knowledge about related standards and solutions.

Unique Value Proposition: UPM brings together a unique combination of deep technical expertise in mobile networks and a strong understanding of the economic factors that drive technology adoption and broader use. By conducting advanced research on energy-efficient architectures, UPM can provide innovative solutions that balance technological performance with economic feasibility.

Unfair Advantage: UPM has extensive expertise in R&D&I on telecom networks and services. in developing network applications and services, and in developing techno-economic models for the ICT industry. Combined with strong partnerships with key industry players and other academic institutions, this expertise provides a significant competitive edge that UPM brings to 6Green, and that will be key to making the most out of the project in order to develop a sound value proposition.

Customer Segments:

- **Research: Institutions providing public funding to advance the State-of-the-Art (SotA).**
    - Public funding institutions, such as national research agencies and international programs like Horizon Europe, play a crucial role in supporting the development of next-generation sustainable telecom solutions. These organizations seek cutting-edge research that pushes the boundaries of mobile network efficiency, fosters innovation, and aligns with global sustainability goals. By securing funding from such institutions, academic research can contribute to the advancement of green 5G/6G technologies while ensuring long-term viability.
- **Transfer: Industry stakeholders adopting sustainable telecom solutions.**
    - Telecom operators: Network operators are key beneficiaries of sustainable mobile networks, as energy-efficient technologies help reduce operational costs and align with corporate sustainability initiatives. They seek innovative solutions that enhance network performance while minimizing environmental impact.
    - System developers: Companies developing telecom hardware and software require research-backed advancements in green technology to integrate into their products. Collaboration with academia provides them with access to novel energy-saving algorithms and architectures.
    - Vertical industries: Sectors such as smart cities, manufacturing, and healthcare increasingly rely on mobile networks for digital transformation. Sustainable connectivity solutions allow them to meet regulatory sustainability requirements while optimizing their operations.
    - Infrastructure providers: Vendors responsible for building and maintaining telecom infrastructure need sustainable hardware and energy-efficient designs to meet the growing demand for green mobile services.
    - Sectoral regulatory bodies: Policymakers and regulators require research-based insights to develop frameworks that encourage sustainable telecom practices. Academic contributions ensure that regulations are data-driven and aligned with the latest technological advancements.
- **Teaching: ICT students as future leaders in sustainable telecom.**
    - ICT students represent the next generation of engineers and researchers who will shape the future of telecommunications. Providing them with knowledge and training in energy-efficient mobile networks equips them with the necessary skills to design and implement sustainable solutions.

Existing Alternatives: Current alternatives include other research institutions and start-ups already working in the same field.

Key Metrics: We are already measuring key metrics that can break down to monitor the research and teaching activity about sustainability such as no papers on this topic or their citations, Master/Bachelor/PhD Thesis project and grants related to this topic, or the number of courses and subjects whose program includes issues about sustainability of networks and services.

High-Level Concept: The vision is to create "Elastic Green 5/6G Networks for a Sustainable Future." This vision encapsulates a commitment to environmental responsibility and innovation in the telecom industry.

Channels:

- **Participation in industry and academic conferences.** Engaging in key industry and academic conferences allows researchers to showcase advancements in sustainable 5G/6G technologies, exchange knowledge with experts, and strengthen collaboration with industry stakeholders. Events such as those organized by IEEE or ACM, or industry events, such as MWC, industry platforms to present findings, gain feedback, and foster partnerships that drive real-world implementation of energy-efficient mobile networks.
- **Research dissemination through academic publications and whitepapers.** Publishing research in high-impact journals, conference proceedings, and whitepapers ensures that findings on sustainable telecom solutions reach a broad audience, including researchers, industry professionals, and policymakers. This dissemination not only contributes to the body of knowledge on green mobile networks but also enhances the credibility and visibility of UPM within the telecommunications ecosystem.
- **Educational programs and training for students and professionals.** Offering specialized courses, workshops, and training programs on energy-efficient mobile networks helps equip both students and professionals with the necessary skills to design and implement sustainable telecom solutions. These programs bridge the knowledge gap between academia and industry, ensuring that the workforce is prepared to meet the growing demand for green ICT expertise.

Early Adopters: The initial focus will be on environmentally conscious telecom operators and customers (residential & business) that prioritize sustainability. Among business customers, those belonging to industry verticals with high environmental footprints will more likely be adopting solutions that monitor energy consumption and carbon footprint for telecom/IT and their own industry. Finally, motivated and environmentally conscious students will be those early adopting educational programs focused on green telecommunications.

Cost Structure: The cost structure includes expenses related to research and development, infrastructure and software investments and operational costs, and commercial costs to bring this to the market. These costs are necessary to develop and deploy cutting-edge research on the topic.

Revenue Structure: This expertise can be used to successfully apply for grants and continue to make cutting-edge research on the topic. Additional revenue will be generated from ad hoc design and the setting up of energy-efficient and monitoring solutions can be commercialized for B2B customers through projects with industry partners, or from licensing green technologies for those solutions. This diversified revenue stream will support UPM's long-term growth and commitment to sustainability.

Table 12: UPM Lean Canvas Template Response.

Problem	Solution	Unique Value Proposition	Unfair Advantage	Customer Segments
• **Limited integration of academia** in real-world deployment of green telecom solutions.	• Research on sustainable AI orchestration of network resources • Research on incentivization of green telecom networks and services	• Deliver cutting-edge research on energy-efficient mobile networks by leveraging know-how on **mobile networks** and **economic incentives.**	• Extensive expertise in telecom infrastructure • Expertise in software and systems development	• Research: - Institutions providing public funding to advance SotA • Transfer: - Telecom operators - System developers

• Limited research on how to improve energy consumption and carbon footprint by **technology design** • Lack of training in designing sustainable solutions for **ICT students**	• Engagement in standardization and policy-making discussions. • Integrate sustainability aspects in teaching curriculums.		• Expertise in regulations and techno-economic analysis of telecom networks and systems • Partnerships with key industry players and research institutions	- Vertical industries - Infrastructure providers - Sectoral regulatory bodies • Teaching: - ICT students
Existing Alternatives	**Key Metrics**	**High-Level Concept**	**Channels**	**Early Adopters**
• Other research institutions and startups	• Papers/citations • Master/Bachelor Thesis • PhD students • Grants and projects • Courses and subjects including issues about sustainability of networks and services	• "Green Elastic 5/6G Networks for a Sustainable Future.	• Participation in industry and academic conferences. • Research dissemination through academic publications and whitepapers. • Educational programs and training for students and professionals.	• Environmentally conscious stakeholders and customers • Industry verticals with high environmental footprint • Motivated and environmentally conscious students.

Cost Structure	Revenue Streams
• R&D expenses • Infrastructure and software investment and operational costs • Commercial costs	• Grants / funded projects • Energy-efficient solutions • Real-time sustainability monitoring solutions • Green technology licensing