Network Working Group
Internet-Draft
Intended status: Informational
Expires: 14 May 2026

C. Pignataro, Ed.
Blue Fern Consulting
A. Rezaki
Nokia
H. ElBakoury
Independent Consultant
S. Prabhu
Nokia
10 November 2025

Environmental Sustainability Terminology and Concepts
draft-pignataro-green-enviro-sust-terminology-03

Abstract

This document defines a set of sustainability-related terms and concepts to be used while describing and evaluating the negative and positive environmental sustainability impacts and implications of Internet technologies.

Status of This Memo

Copyright Notice

Table of Contents

1. Introduction

Over the past decade, there has been increased awareness of the environmental impact produced by the widespread adoption of the Internet and internetworking technologies. The impact of Internet technologies has been overwhelmingly positive over the past years (e.g., providing alternatives to travel, enabling remote and hybrid work, enabling technology-based endangered species conservation, etc.), and there is still room for improvement.

This document proposes some common terminology for discussing environmental sustainability impact of Internet technologies, and presents environmental sustainability-related concepts to network and protocol designers and implementors.

2. Definition of Terms

Given that the term 'considerations' is well known within the IETF community, it is fair to start by defining 'sustainability'. The 1983 UN Commission on Environment and Development had important influence on the current use of the term. The commission's 1987 report [UNGA42] defines it as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". This in turn involves balancing economic, social, and environmental factors.

This section defines sustainability-specific terms as they are used in the document, and as they pertain to environmental impacts. The goal is to provide a common lexicon for sustainability considerations among network equipment vendors, operators, designers, and architects.

Notwithstanding the most comprehensive set of definitions of relevant terms readers can find at [IPCC], this section contributes the application and exemplification of the terminology to the internetworking domain and field. The terms are alphabetically organized.

Appropriate technology:
Appropriate technology is a movement (and its manifestations) encompassing technological choice and application that is small-scale, affordable by locals, decentralized, labor intensive, energy efficient, environmentally sustainable, and locally autonomous. Though the original name for the concept now known as appropriate technology, "intermediate technology" is now often considered a subset of appropriate technology that focuses on technology that is more productive than "inefficient" traditional technologies, but less costly than the technology of industrialized societies. Globally impactful technology is to be adaptable to local contexts it is used in. Regarding internetworking, there could be linkages to centralization / decentralization challenges, as well as maintainability & deployability aspects. Considering the diversity of local contexts, from developed countries with remote/rural coverage/access issues, to developing countries with unstable electricity grids as well as literacy and technology usability/accessibility issues, internetworking technology needs to be designed, developed and operated according to these local requirements, also supporting small scale business models to make impact.

Biodiversity loss:
Biological diversity is a measure of the abundance and variety of life on earth. Biodiversity loss is the depletion of this diversity due to human activity, notably through the destruction of natural ecosystems and through the cascading effects of climate change, materials extraction, waste disposal and pollution, among other impacts, on the living world and species.

CO2e / CO2eq / CO2-eq:
Carbon dioxide equivalent, is the unit for measuring the climate change impact of non-CO2 gases as compared to CO2, which is selected as a benchmark.

Carbon awareness:

is being mindful of the carbon intensity of the electricity being used and prioritizing the use of low carbon intensity electricity in network set-up and operations. As carbon intensity is location and time dependent, carbon awareness requires dynamic monitoring and response, such as carbon aware routing and networking. This is a form of "demand shaping" which aims to match the use of energy with the supply of clean energy.

Carbon intensity (CI):
also referred to as emission intensity and emission factor, is a measure of the carbon-equivalent emission of consumed electricity, i.e., grams of carbon-equivalent per kilowatt-hour (gCO2e/kWh). When the supplied energy mix is purely from renewable sources such as sun and wind, carbon intensity is practically 0, when coal and gas-powered electricity generation gets in the mix, carbon intensity increases. Carbon intensity can vary instantaneously or predictably based on the time and location of electricity usage. Prioritizing electricity usage when carbon intensity is low is a target.

Carbon offset and credit:
is a reduction of GHGs from the atmosphere as compensation for GHGs produced elsewhere, with credits being generated and used accordingly. This reduction in GHG emissions can be an increase in carbon storage through land restauration, or an actual removal of GHG. For example, certified forestation projects that absorb carbon dioxide produce carbon credits that an airline can use to offset its GHG emissions by using (purchasing) these credits. There are accredited carbon trading mechanisms to facilitate this exchange. This is generally regarded as a non-scalable solution and activities such as the reduction of GHG emissions and the shifting of electrical energy production to renewables are a primary focus.

Circularity (circular economy):
is a model or system where material resources and products are kept in use for as long as possible through long life cycles, reuse, repair, refurbishing and recycling, thereby reducing material use, waste, and pollution as well as biodiversity and geodiversity loss. Keeping internetworking equipment in longer use through modularity, serviceability, upgradeability, and maintainability are strategies to improve circularity.

Climate change (climate emergency, global warming):
can be summarized as the increase in the global average temperatures and its destructive impact on life on Earth. The climate emergency refers to the ongoing and projected impacts of rising global temperatures and the narrow time window we have to

limit temperature increases to a threshold determined by the Paris Climate Agreement (2015) to avoid the permanent destabilization of Earth life-support systems.

Climate change adaptation:
are the measures we can take to adjust ourselves to the already happening and projected future adverse effects of climate change. This notably includes raising the resilience of internetworking solutions to higher operating temperatures and other impacts of climate change, as well as the use of internetworking technology to increase the resilience of societies and nature itself.

Climate change mitigation:
encompasses all measures to reduce the impact of climate change. More specifically, any measures that reduce the amount of GHGs in the atmosphere can be considered as climate change mitigation through reduced inflow of GHGs into the atmosphere (such as burning of fossil fuels) or increasing the impact of carbon sinks such as forests and oceans. Reducing the carbon footprint of internetworking and increasing its carbon handprint by helping other sectors to decarbonize are mitigation efforts.

CUE:
Carbon usage effectiveness [CUE] is a metric that helps determine the amount of greenhouse gas (GHG) emissions produced per unit of IT energy consumed within a data center. It provides an effective way to measure operational carbon footprint and thus the environmental impact of data center operations. The CUE is the ratio of the total CO2 emissions caused by total data center energy consumption, divided by the energy consumption of IT equipment. To calculate CUE when using electricity from the grid, carbon emissions can be based on published data. See also "PUE".

Demand Response:
is a strategy that dynamically adjusts electricity consumption in response to grid conditions, helping to reduce reliance on high-emission energy sources. Demand Response mechanisms optimize energy usage by shifting or reducing power demand during peak periods, improving grid stability, enhancing energy efficiency, and supporting sustainability goals.

Doughnut economics:
is a visual framework for sustainable development. It attempts to find a safe operational space within planetary boundaries and complementary (yet seemingly opposing) social boundaries, thereby meeting the needs of human societies without pushing earth environmental boundaries to their tipping points [Doughnut]. The significance of this model for interworking is that it

demonstrates how to conceptualize and position boundaries in our designs that are seemingly opposing, to create a balanced approach, for example between energy efficiency and performance or resiliency and materials efficiency. It is not one or the other, but to find a space where both can be achieved without crossing boundaries in respective domains.

Embodied emissions:
also referred to as embodied carbon and embedded carbon, refers to the amount of GHG emissions associated with upstream phases - raw material extraction, production, transportation (of materials and of product), and manufacturing-stages of a product’s lifecycle. Some initiatives also consider disposal.

Embodied energy:
refers to the total amount of energy consumed across all upstream stages of a product’s lifecycle, including raw material extraction, processing, manufacturing, and transportation of materials and components. Embodied energy does not account for the operational energy consumed during the use-phase of the product. In the context of ICT, this includes the energy used in producing semiconductors, assembling network equipment, and transporting devices to deployment locations. Understanding embodied energy is essential for assessing the full lifecycle sustainability of ICT systems and guiding circular design strategies.

Energy, power, and their measurement:
In physics, energy is defined as the capacity or ability to do work. For a system to provide an output, the quantitative property of energy is transferred to it. The energy measurement unit in the International System of Units (SI) is the joule (J). Power is energy used per second, measured in the International System of Units in watts (W), equivalent to the rate of one joule per second (J/s). In other words, energy is the integration of power over time. As such, Kilowatt-hour (kWh) is also a measure of energy, equivalent to 1 kW of power maintained for 1 hour, which is equal to 3.6 MJ (million joules).

Energy efficiency (EE):
increased energy efficiency can be summarized as doing the same task with less energy use, that is, providing a useful output/ impact with as little energy as possible, eliminating energy waste. Switching to more efficient power supplies and silicon or developing more efficient transmission or signal processing algorithms improves EE. Developing energy efficiency metrics for internetworking and associated measurement methodologies and conditions as well as consistently collecting this data over time

are essential to demonstrating EE improvements. An example of a common outcome-oriented metric is energy consumption per data volume or traffic unit, in Wh/B [Telefonica]; this particular metric has however also been criticized for being easy to misinterpret, falsely indicating that systems are energy proportional even when they are not (see "Energy proportionality".)

Energy equity:
Energy equity aims to minimize the negative impacts of energy systems and maximize the benefits for all energy users. Historically, these impacts and benefits haven’t been equitably distributed. Energy equity recognizes that disadvantaged communities have been historically marginalized and overburdened by pollution, underinvestment in clean energy infrastructure, and lack of access to energy efficient housing and transportation.

Energy proportionality:
is the correlation between energy used and the associated useful output. For internetworking this is generally interpreted as the proportionality of traffic or traffic throughput and energy used. This concept is broadly applicable to networking infrastructure, data center, and other communication architectures. It is not a given that there is a one-to-one correlation between traffic and energy use, notably due to the materially significant idle power use by devices, as well as the overall network capacity being allocated to serve at times of highest traffic utilization.

Energy savings / conservation (ES):
is the avoidance of energy use, by eliminating a task altogether, when possible. Shutting down unused ports on networking equipment is energy savings/conservation.

Footprint (environmental/ecological):
in general terms is the impact we have on the planet. It can be divided into subcategories such as carbon footprint, water footprint, land footprint, biodiversity footprint, etc. Related to the climate emergency, we are mostly focused on our carbon footprint, however, it has been shown that sub-categories of footprint are not entirely independent of each other. For example, our carbon footprint has a proven impact on the climate emergency through rising global temperatures, cascading significant impact on forest cover in warming areas since tree species adapted to certain climates vanish, thereby reducing biodiversity in that region, in-return impacting the carbon sink properties of the environment and exacerbating climate change. A holistic approach to our environmental footprint would therefore provide the best opportunity to create impact.

GHGs:
Greenhouse gases are types of gases that trap heat from the sun in earth’s atmosphere, thereby increasing average global temperatures and creating the climate emergency. Carbon dioxide (CO_2) is one of the most common (and referenced) greenhouse gases. Other GHGs include methane (CH_4), which is significantly more potent than CO_2, and sulfur hexafluoride (SF_6), an artificial electrical insulator with a warming effect tens of thousands of times greater than CO_2.

GHG Emissions Scopes:
According to the Greenhouse Gas (GHG) Protocol [GHG-Proto], Chapter 4, the emissions scopes are defined as below:

* Direct GHG emissions are emissions from sources that are owned or controlled by the company.

* Indirect GHG emissions are emissions that are a consequence of the activities of the company but occur at sources owned or controlled by another company.

The GHG protocol [GHG-Proto], Chapter 4, also includes the following descriptions of emissions scopes for accounting and reporting purposes:

* Scope 1 Emissions: Direct GHG emissions - Direct GHG emissions occur from sources that are owned or controlled by the company, for example, emissions from combustion in owned or controlled boilers, furnaces, vehicles, etc.; emissions from chemical production in owned or controlled process equipment.

* Scope 2 Emissions: Electricity indirect GHG emissions - Scope 2 accounts for GHG emissions from the generation of purchased electricity consumed by the company. Purchased electricity is defined as electricity that is purchased or otherwise brought into the organizational boundary of the company. Scope 2 emissions physically occur at the facility where electricity is generated.

* Companies shall separately account for and report on scopes 1 and 2 at a minimum.

* Scope 3 Emissions: Other indirect GHG emissions - Scope 3 is an optional reporting category that allows for the treatment of all other indirect emissions. Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company. Some examples of scope 3 activities are extraction and production of purchased materials; transportation of purchased fuels; and use of sold products and services.

In telecommunications networks, Scope 3 emissions include the use phase of the sold products in operations, and is currently the largest part by far, of the whole GHG emissions (Scopes 1, 2 and 3), depending on the carbon intensity of the energy supply in use.

GWP:
Global warming potential, is the potential impact of GHGs on climate change, measured in CO2e.

Geodiversity:
is the variety of the nonliving parts of nature, that is, the materials constituting Earth, including soils, water (rivers, lakes, oceans), minerals, landforms and the associated processes that form and change them. The materials used in the production of internetworking equipment as well as their manufacturing and operational processes themselves, have impact (footprint) on geodiversity. Materials efficiency as well as circularity improvements help mitigate this impact.

Green Software Engineering:
is a framework for designing, developing, and operating software with a focus on energy efficiency, minimal resource consumption, and sustainability principles. It aims to reduce the environmental impact of computing by optimizing algorithms, improving hardware utilization, minimizing unnecessary computations, and incorporating energy-aware development practices. Examples include efficient code execution, adaptive workload scaling, and leveraging renewable-powered cloud infrastructure.

Handprint (environmental/ecological):
is a concept developed in contrast to footprint, to quantify and demonstrate the positive environmental/ecological impact of technologies, products or organizations. Through a LCA (life cycle assessment) approach, the use of a technology or the products and services of an organization would have both a footprint and handprint usually denoted by the terms "X for sustainability" (handprint) and "Sustainable X" (footprint). What is important is that handprint impact does not compensate for

footprint impact. They are to be calculated and reported independently; footprint to be minimized as much as possible, and handprint maximized as much as possible, which are by definition different activities anyway. Otherwise, this might be construed as "greenwashing". A popular seesaw figure in common sustainability literature depicting handprint and footprint sitting on opposite ends of a seesaw, one going up while the other is going down is a misguided representation.

LCA (Life Cycle Assessment):
is a comprehensive methodology to measure the environmental impact of a product, service, or process over its complete lifecycle, from the extraction and procurement of materials, through design, manufacturing, distribution, deployment, operations (use), maintenance/repair, decommissioning, refurbishment/reuse, recycling and disposal (waste), considering the full upstream and downstream supply chains as well. It is an extremely complicated process and there are multiple methods used worldwide, which might not produce same/similar results. LCA covers full footprint aspects, not only covering carbon, but also materials and biodiversity. Many of the subtleties and nuances of the measurement of GHG and environmental impacts stem from the very important distinction between attributional and consequential models. Detailed definitions can be found at [UNEP-LCA].

LCA - Attributional Model:
Also referred to as Allocational models, start by allocating or attributing quantities (e.g., GHG emissions) to entities (e.g., a router, a building, a town), and performing comparisons between the measurements (or estimates) of the quantity by the entities.

LCA - Consequential Model:
Perform the measurement of the quantity by establishing a baseline scenario (e.g., before feature introduction) and a modified scenario (e.g., after the feature introduction).

Materials efficiency and reuse:
is the concept of using less primary and (more) recycled materials to provide the same output. A networking equipment that provides the same function with less aluminium used is more materials efficient. Reuse of materials in manufacturing, thereby reducing primary materials extraction is a cornerstone of circularity, reducing environmental footprint and promoting geodiversity.

Net-zero:
in general, is to bring down GHGs as close to zero as possible. It is generally recognized that it may not be possible to get GHGs to 0 in many contexts and the balance is said to be covered by

carbon offset. For example, many organizations and countries have net-zero targets by certain dates and typically what they mean is that they will reduce their GHGs by more than 90% and the remaining up to 10% will be offset.

Operational Emissions
refer to the greenhouse gas (GHG) emissions associated with the active use phase of a product or system. In the context of ICT systems, operational emissions primarily stem from electricity consumption required to power hardware such as servers, networking equipment, cooling systems, and user devices during their operation. These emissions are influenced by the energy efficiency of the systems, utilization patterns, and the carbon intensity of the electricity used, which can vary based on geographic location and time. Unlike embodied emissions, which are fixed at the point of manufacture and deployment, operational emissions are continuous and dynamic, and can be optimized through strategies such as energy-aware scheduling, carbon-aware routing, and demand response. Monitoring and reducing operational emissions is a key focus area in sustainable ICT practices.

PUE:
Power usage effectiveness, is a data centre energy efficiency metric. The PUE is defined by dividing the total amount of power entering a data center by the power used solely to run the IT equipment within it. PUE is expressed as a ratio, with the overall power usage effectiveneess improving as the quotient decreases towards one. See also "CUE".

Planetary boundaries:
is a concept that defines 9 environmental boundaries that, if not crossed, provides a safe space for humanity to live. This was developed and tracked by the Stockholm Resilience Centre [Planet-B]. Their latest report indicates that 6 out of the 9 boundaries have already been crossed. This translates to the increased risk of irreversible environmental change, the so-called tipping points. Climate change is one of these boundaries, represented as carbon dioxide concentration in the atmosphere (ppm by volume) and others are biodiversity loss, land use, fresh water, ocean acidification, chemical pollution, ozone depletion (one boundary that has been successfully mitigated), atmospheric aerosols and biogeochemical (nitrogen in the atmosphere and phosphorus in oceans).

Rebound effect:
is the reduction in the potential benefits of more efficient technologies and solutions to reduce resource use, due to the increased demand they might trigger as costs might decrease, in

return even increasing the overall resource use. This is known as Jevons paradox: efficiency leading to increased demand. In internetworking, this can manifest itself when more energy and resource efficient systems reduce the cost for infrastructure build and operations and when this is reflected to customers as reduced cost, customers respond by increased use of telecommunications services which pushes infrastructure build and operations upwards, thereby negating the projected gains from efficiency measures. Another descriptive source for this phenomenon can be found at [Frontiers].

Tipping points:
are critical environmental thresholds, which when crossed likely lead to irreversible state changes in climate systems that might push the overall earth system out of its stable state that supports life on Earth. For example, there are tipping points defined for the Antarctic and Greenland ice sheets disappearing, the Arctic sea-ice loss, Siberian permafrost loss or the dieback of the Amazon and Boreal forests. As planetary boundaries are crossed, the likelihood of the tipping points being reached also increases. When the tipping points are hit, notably simultaneously, the overall impact to the global Earth system might be catastrophic, as another stable state which no longer supports life could be reached.

UN SDGs:
United Nations Sustainable Development Goals are 17 global objectives that collectively define a framework for a sustainable global system where people and the planet collectively thrive and live in peace, prosperity and equity. They were adopted in 2015 and most of them have a target achievement date of 2030 [UN-SDG]. They are part of the so-called UN 2030 Agenda. The International Telecommunications Union (ITU) has published on how our technology could help meet the UN SDGs [ITU-ICT-SDG]. Notably, most UN SDGs provide guidance for the handprint impact of internetworking technologies, while some are also related to potential action for footprint reduction. The 17 SDGs are:

Goal 1	No poverty
Goal 2	Zero hunger
Goal 3	Good health and well-being
Goal 4	Quality education
Goal 5	Gender equality
Goal 6	Clean water and sanitation
Goal 7	Affordable and clean energy
Goal 8	Decent work and economic growth
Goal 9	Industry, innovation and infrastructure
Goal 10	Reduced inequalities

Goal 11	Sustainable cities and communities
Goal 12	Responsible consumption and production
Goal 13	Climate action
Goal 14	Life below water
Goal 15	Life on land
Goal 16	Peace, justice and strong institutions
Goal 17	Partnerships for the Goals

The SDG Academy [SDG-Acad] also provides useful information on the topic, as well as progress to date.

3. Environmental Sustainability Concepts

3.1. 'Sustainable X' versus 'X for Sustainability'

Every technology solution, system or process has sustainability impacts, as it uses energy and resources and operates in a given context to provide a [perceived] useful output. These impacts could be both negative and positive w.r.t sustainability outcomes. With a simplistic view, the negative impact is termed as footprint and the positive impact is handprint, as defined in the "Definition of Terms" section. Again, generally speaking, footprint considerations of a technology are grouped under "Sustainable X" and the handprint considerations are covered under "X for Sustainability".

Additionally, when sustainability impacts are considered, not only environmental but also societal and economic perspectives need to be taken into account, both for footprint and handprint domains. A systems perspective ensures that the interactions and feedback loops are not forgotten among different sub-areas of sustainability.

Another fundamental sustainability impact assessment requirement is to cover the complete impact of a product, service or process over its full lifetime. Life Cycle Assessment (LCA) starts from the raw materials extraction & acquisition phases, and continues with design, manufacturing, distribution, deployment, use, maintenance, decommissioning, refurbishment/reuse, and ends with end-of-life treatment (recycling & waste). It is imperative that we consider not only the design and build stages of our technologies but also its use and end-of-life phases. An equally essential way of ensuring a holistic perspective is the supply-chain dimension. When we consider the footprint impact of a technology we are building, we need to consider the full supply chain that the technology is part of, both upstream, what it inherits from the material acquisition, components and services used, to downstream for wherever the technology is used and then decommissioned. Further, this includes transportation of materials or products, and the carbon-friendliness of the means and routes chosen. What this implies is that we are responsible for the direct and indirect impacts of our activity, both on demand and supply directions.

Below, we cover the "Sustainable Internetworking" and "Internetworking for Sustainability" perspectives in more detail.

3.1.1. Sustainable Internetworking

Sustainable internetworking is about ensuring that the negative impacts of internetworking are minimized as much as possible.

In the environmental / ecological sustainability domain, the sub-areas to be considered are:

* Climate change,

* materials efficiency, circularity, preservation of geodiversity, and

* biodiversity preservation.

Climate change considerations in internetworking by and large translate to energy sourcing, consumption, savings and efficiency as this impacts the GHGs of the internetworking systems directly, when mostly non-renewable energy sources are used for the operations of the networks. When the carbon intensity of the energy supply used in operations decreases (more renewable energy in the supply mix), then the use phase GHGs also proportionally decrease. This might put the GHG emissions of the manufacturing and materials extraction and acquisition phases ahead of the use phase. These are called the embodied emissions.

However, energy is not the only aspect to consider: materials efficiency and circularity are key considerations to limit the resource use of our technologies, thereby reducing the scarcity of materials but also the destruction of many ecosystems during their extraction and manufacturing, polluting water and land with waste, which might also impact directly or indirectly the abundance and health of the species on the planet, namely biodiversity. While it is significantly more difficult to quantify and measure the impact of our technologies in these domains, the planetary boundaries framework provides helpful guidance.

For the societal and economic footprint of our technologies, we need to be mindful about the potential negative effects of our technologies w.r.t. the social boundaries, as depicted in the so-called doughnut economics model, that includes education, health, incomes, housing, gender equality, social equity, inclusiveness, justice and more. What we need to realize is that our technology has direct and indirect impacts in these aspects and the challenge is not only to meet environmental sustainability targets but social and economic ones as well. There are very practical considerations, for example: are there partial or total barriers to accessing the Internet or its services? what is the impact of biases in artificial intelligence (AI), as it pertains gender biases, when those AI models are used in job selection? More technology doesn’t always mean better outcomes for all and can we mitigate this impact? Admittedly, a quantitative approach to the societal and economical aspects is more challenging; thinking in terms of profit, people, and planet, as well as the Key Values (KV) / Key Value Indicators (KVIs) approach described in Section 3.2 bring some relief.

3.1.2. Internetworking for Sustainability

When it comes to the positive impact of internetworking in tackling the sustainability challenges faced, we are in the "internetworking for sustainability" realm. This is a very diverse topic covering innumerable industrial and societal verticals and use cases. Essentially, we are asking how our technology can help other sectors and users to decarbonize, and to reduce their own footprints and to increase their handprints in environmental, societal and economic dimensions. These are induced or enablement effects. Examples are how internetworking is being used in smart energy grids or smart cities, transport, health care, education, agriculture, manufacturing and other verticals. While efficiency gains are usually a basis, there are also other impacts through ubiquitous network coverage, sensing, affordability, ease of maintenance and operation, equity in access, to name a few.

Climate change mitigation and climate change adaptation, as defined in the "Definition of Terms" section, are particular focus areas where internetworking could help create more resilience in our societies and economies along with sustainability.

Essentially, handprint considerations are asking us to think about how our technology could be used to tackle sustainability challenges at first, and second, to generate feedback on how to create enablers and improvements in our technology for it to be more impactful. The usual Key Performance Indicators (KPIs) related to technical system parameters would be largely insufficient for this purpose. Supporting this effort, the Key Values (KV) and Key Value Indicators (KVIs) concepts have been developed, to be used in conjunction with use cases to develop impactful solutions. KV and KVIs are the subject of Section 3.2.

The following are some examples of internetworking for sustainability. This is not a comprehensive list; many more such examples can be found. Leveraging internetworking for sustainability usually involves special requirements, which are listed along with the examples.

Smart Grid:
The Smart Grid [RFC6272] generally refers to enhancements to traditional electrical grids that offer additional features such as two-way flows of electricity (e.g., accommodating solar panels, electrical batteries) and granular control of the grid (e.g., allowing to selectively turn off certain consumers such as Heating, Ventilation, and Air Conditioning (HVAC) units during certain times.) The Smart Grid aims to improve sustainability by facilitating concepts such as peak shaving (i.e., lowering peak usage to reduce the amount of excess generation of electricity that is not needed during non-peak periods), and encouraging residential homes and business to invest in renewable energy sources such as solar, for example offering credit for feeding surplus energy being generated back into the grid. For this to work, the Smart Grid requires support by networking technology that enables the required control loops as well as visibility into grid telemetry. This, in turn, requires the support of new requirements, including aspects of security (since a critical infrastructure is at stake), adherence to high precision service levels and ultra-low latency communication (e.g., to mitigate sudden spikes in voltage), and special provisions to ensure data privacy (given that data from private households, electrical vehicles, and personal devices is involved.)

Smart Cities:
Many applications for smart cities involve optimizations to make cities more sustainable. Examples include smart garbage disposals that reduce the number of truck rolls (and associated emissions) to collect garbage only when needed, and guidance systems for smart parking that reduce the amount of vehicle traffic used to find parking spots. These applications are enabled by networking. Again, special requirements need to be supported for networks to support those applications, such as the ability to deploy equipment in harsh urban environments, or monitoring for vandalism.

Smart Agriculture:
Smart agriculture involves minimizing usage of resources such as fertilizer and water in the production of agricultural output. This also helps minimize the area set aside for farming and reclaim land for other purposes including biodiversity. Similarly, networking is an enabler for environmental

sustainability. Special requirements for applications in this space include aspects such as the ability to support networking equipment without the need to run power lines (e.g., using battery or solar), and support for intermittent communications.

3.2. Key Values and Key Value Indicators

In the context of sustainability, key values are what matters to societies and to people when it comes to direct and indirect outcomes of the use of our technology. While KPIs help us to build, monitor and improve the design and implementation of our technologies, key values and their qualitative and quantitative indicators tell us about their usefulness and value to society and people. As we want our technology to help tackle the grand challenges of our planet, their likelihood of usefulness and impact is a paramount consideration. KVs and KVIs help set our bearings right and also demonstrate the impact we could create. The main idea is shifting from measuring performance to measuring value.

While key values could be universal, like for example the United Nations Sustainable Development Goals (UN SDGs) [UN-SDG], how they are measured, or perceived (KVIs) could be context dependent and use case specific. To give a simplified example, UN SDG 3, "good health and well-being" is a key value for any society and individual. Then, when we consider the use case of providing health care and wellness services in a remote, rural community which doesn’t have any hospitals or specialist doctors, a key value indicator could be how fast a patient could access health care services without having to travel out of town, or the successful medical interventions that could be carried out remotely. Then the next step is to identify which parts of our technology could help enable this and design our technology to create impact for the KVs as per KVIs. In this case, universal network coverage, capacity and features to integrate a multitude of sensors, low-latency and jitter communication services could all be enablers with their own design targets and KPIs defined. Subsequently, we would track the KVIs and the KPIs together for successful outcomes.

Admittedly, this might not be a straightforward task to carry out for each protocol design. Yet, such analyses could be included in design processes along with use case development, covering a group of technology design activities (protocols) together. There are ongoing efforts in mobile networking research to use KVs/KVIs efficiently [M6G-SOCIETAL-KV-KVI] [M6G-VALUE-PERF] [Hexa-X_D1.2].

While we find ourselves trying to optimize seemingly contradicting parameters or aspects such as reducing latency and jitter and increasing bandwidth and reach targets with sustainability parameters or aspects such as reduced energy consumption and increased energy efficiency, key values and key value indicators would help keep our eyes on the targets that matter for the end users and communities and societies. Considerations for such potential design trade-offs, which are at the heart of our engineering innovations, are the topic of the next section.

3.2.1. Key Value Enablers

Between the design and creation of a technology, and realization of the value generated by its deployment and use, there are a number of enablers and blockers of its usage. We generally refer to them as KV Enablers. These are the key factors that would scale and spread use cases or block their deployment.

Technical enablers are the features needed for the technical capabilities and feasibility of the use cases, like the network features being deployed to support the use case. Beyond the technical aspects, there are also criteria at the system level which determine the context in which the technology will be used as well as the actions of the use case stakeholders. These might affect the level of adaptation to a particular society or ecosystem, such as cost of connectivity and Internet service access, availability of services, security, and privacy. While technical enablers are in more direct control of protocol and network designers, system-level enablers might in second-order, indirect, or beyond control, depending on the actions of other stakeholders and the existing environment.

An important corollary is that KV enablers can be used to derive technological requirements, KPIs and advancements to maximize key value.

4. IANA Considerations

This document has no IANA actions.

5. Security Considerations

A descriptive and unambiguous definition of terms decreases misunderstandings, misinterpretations, and misalignment, in turn improving the security posture of a system.

6. Acknowledgements

This document is created greatly leveraging ideas and text from [I-D.cparsk-eimpact-sustainability-considerations], and consequently acknowledges all the many contributions that improved it.

7. Informative References

[CUE] Belady, C., Azevedo, D., Patterson, M., Pouchet, J., and R. Tipley, "Carbon Usage Effectiveness (CUE): A Green Grid Data Center Sustainability Metric", 2 December 2010, <https://www.thegreengrid.org/en/resources/library-and-tools/241-Carbon-Usage-Effectiveness-%28CUE%29%3A-A-Green-Grid-Data-Center-Sustainability-Metric>.

[Doughnut] Wikipedia, "Doughnut (economic model)", 13 October 2023, <https://en.wikipedia.org/wiki/Doughnut_(economic_model)>.

[Frontiers] Frontiers, "The Rebound Effect and the Jevons’ Paradox: Beyond the Conventional Wisdom", 2023, <https://www.frontiersin.org/research-topics/6598/the-rebound-effect-and-the-jevons-paradox-beyond-the-conventional-wisdom#overview>.

[GHG-Proto] "The Greenhouse Gas Protocol - A Corporate Accounting and Reporting Standard, revised version", Geneva: World Business Council for Sustainable Development, Washington, DC: World Resources Institute, 2004, <https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf>.

[Hexa-X_D1.2] "Expanded 6G vision, use cases and societal values - including aspects of sustainability, security and spectrum", Deliverable D1.2, 30 April 2021, <https://hexa-x.eu/wp-content/uploads/2021/05/Hexa-X_D1.2.pdf>.

[I-D.cparsk-eimpact-sustainability-considerations] Pignataro, C., Rezaki, A., Krishnan, S., ElBakoury, H., and A. Clemm, "Sustainability Considerations for Internetworking", Work in Progress, Internet-Draft, draft-cparsk-eimpact-sustainability-considerations-07, 24 January 2024, <https://datatracker.ietf.org/doc/html/draft-cparsk-eimpact-sustainability-considerations-07>.

[IPCC]   "Intergovernmental Panel on Climate Change (IPCC). (2022). Annex I: Glossary. In Global Warming of 1.5 degrees Celsius: IPCC Special Report on Impacts of Global Warming of 1.5 degrees Celsius above Pre-industrial Levels in Context of Strengthening Response to Climate Change, Sustainable Development, and Efforts to Eradicate Poverty (pp. 541-562)", Cambridge University Press, doi 10.1017/9781009157940.008, 2022, <https://www.ipcc.ch/sr15/chapter/glossary/>.

[ITU-ICT-SDG]
ITU, "Digital technologies to achieve the UN SDGs", 2023, <https://www.itu.int/en/mediacentre/backgrounders/Pages/icts-to-achieve-the-united-nations-sustainable-development-goals.aspx>.

[M6G-SOCIETAL-KV-KVI]
Wikstr旦m, G., Schuler Scott, A., Mesogiti, I., Stoica, R., Georgiev, G., Barmpounakis, S., Gavras, A., Demestichas, P., Hamon, M., Hallingby, H., and D. Lund, "What societal values will 6G address?", 17 May 2022, <https://doi.org/10.5281/zenodo.6557534>.

[M6G-VALUE-PERF]
Ziegler, V. and S. Yrjola, "6G Indicators of Value and Performance", 4 May 2020, <https://doi.org/10.1109/6GSUMMIT49458.2020.9083885>.

[Planet-B] Azote for Stockholm Resilience Centre, based on analysis in Richardson et al 2023, "Planetary boundaries", 2023, <https://www.stockholmresilience.org/research/planetary-boundaries.html>.

[RFC6272] Baker, F. and D. Meyer, "Internet Protocols for the Smart Grid", RFC 6272, DOI 10.17487/RFC6272, June 2011, <https://www.rfc-editor.org/info/rfc6272>.

[SDG-Acad] "SDG Academy", 2023, <https://sdgacademy.org>.

[Telefonica]
Telefonica, "Consolidated Annual Report 2021", 2021, <https://statics.telefonica.com/en/financial-reports/2021/Consolidated-Annual-Report/#i7111116644124bd299d124820baf28f7_394>.

[UN-SDG]   "Sustainable Development, the 17 Goals", 2023, <https://sdgs.un.org/goals>.

[UNEP-LCA] "Global guidance principles for life cycle assessment databases : a basis for greener processes and products", 2011, <https://www.lifecycleinitiative.org/library/global-guidance-principles-for-lca-databases-a-basis-for-greener-processes-and-products/>.

[UNGA42] UN, "Report of the World Commission on Environment and Development : "Our common future"", 4 August 1987, <http://digitallibrary.un.org/record/139811>.

Authors’ Addresses

Carlos Pignataro (editor)
Blue Fern Consulting
United States of America
Email: cpignata@gmail.com, carlos@bluefern.consulting

Ali Rezaki
Nokia
Germany
Email: ali.rezaki@nokia.com

Hesham ElBakoury
Independent Consultant
United States of America
Email: helbakoury@gmail.com

Shailesh Prabhu
Nokia
India
Email: shailesh.prabhu@nokia.com