Alliance for IoT
and Edge Computing
Innovation

IoT and Edge Computing Carbon Footprint Measurement Methodology

Release 3

AIOTI WG ICT for CO2 reduction methodologies

28 June 2024

Executive Summary

This Report is addressing the users of IoT and Edge Computing technologies and services to help them understand and make informed choices on how to assess the carbon footprint of solutions and services they use and to also measure how these methodologies support carbon footprint reduction of their use.

The Report is structured to present rules and regulations of the European Green Deal, the initiatives and standards, and existing methodologies of measuring ICT carbon footprint. The report also includes how those methodologies can be applied to IoT and Edge Computing, the description of the methodologies, selection criteria and how to measure benefits of using them in reducing carbon footprint by using IoT and Edge Computing technologies and services for several industrial domains. Furthermore, this report includes as well a method of calculating the avoided carbon emissions in an industrial sector/domain, when ICT is used as an enabling technology.

Release 2 of this report updated the equations that were introduced in version (Release 1.1) of the Report, which address the calculation of avoided carbon emissions in industrial sectors when ICT is applied by focusing on:

- a baseline (industrial) scenario that is supported by an ICT solution and a green enabled (industrial) scenario that apply an advanced ICT solution to reduce carbon emissions in the same industrial scenario,
- the impact that a closed loop recycling/allocation process has on these equations.

This version of the report (Release 3.0) includes:

- use case that applies the Network Carbon Index (NCI), specified in ITU-T L.1333,
- updated the equations including the impact of higher order effects including rebound effects,
- included a "simplified avoided carbon emissions equation", introduced in ITU-T (rev)L.1480,
- included example uses cases that apply the AIOTI equations defined in this report,
- included example use cases that apply the "simplified avoided emissions calculation".

The Report ends with conclusions and recommendations for practical use.

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1. Introduction

The goals of this Report are:

- To help users of IoT and Edge Computing technologies and services, to understand and make informed choices on how to assess the carbon footprint of solutions and services they use, and to as well to measure how these methodologies support carbon footprint reduction of their use

- To present initiatives and standards, existing methodologies of measuring ICT carbon footprint and how they can be applied to IoT and Edge Computing

- To present selection methodology criteria and how to measure benefits of using them in reducing carbon footprint when using IoT and Edge Computing technologies and services for several industrial domains

- To propose a method of calculating the carbon avoided emissions in an industrial sector/domain, when ICT is used as an enabling technology

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2. Regulation, Standards and Initiatives

2.1 EU Green Deal policies

This section gives an overview of EU Green Deal policies and regulations.

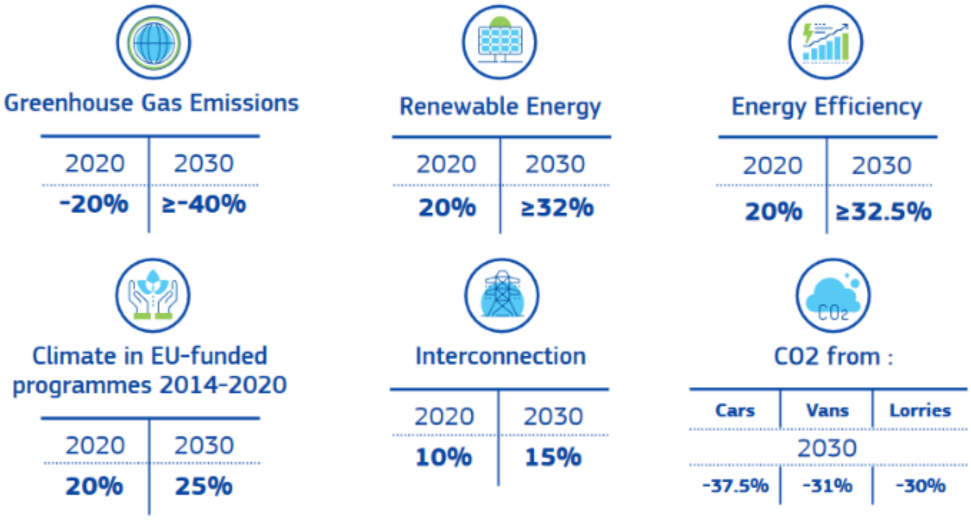
2.1.1 EU Green Deal

On 11 October 2019, the European Commission published the European Green Deal presenting a list of policy initiatives aimed at driving Europe to reach net-zero global warming emissions by 2050. The goal of the European Green Deal is to improve the well-being of people by making Europe climate-neutral and protecting Europe's natural habitat for the benefit of people, planet and economy. The European Green Deal targets that the EU needs to fulfil are (see Figure 2):

- reach climate neutrality by 2050;
- protect human life, animals and plants by cutting pollution;
- help become world leaders in clean products and technologies;
- help ensure a just and inclusive transition.

Some of the motivations behind the European Green Deal are:

- 93% of Europeans see climate change as a serious problem;
- 93% of Europeans have taken at least one action to tackle climate change;
- 79% agree that taking action on climate change will lead to innovation.



Greenhouse Gas Emissions

2020	2030
-20%	≥-40%

Renewable Energy

2020	2030
20%	≥32%

Energy Efficiency

2020	2030
20%	≥32.5%

Climate in EU-funded programmes 2014-2020

2020	2030
20%	25%

Interconnection

2020	2030
10%	15%

CO2 from :

Cars	Vans	Lorries
2030		
-37.5%	-31%	-30%

Figure 1: EU-Energy and Climate 2030 Targets 2018/2019

One of the key objectives of AIOTI should be to launch activities on realising (a subset of) the Europe's Green Deal objectives described below.

2.1.1.1 Climate neutral Europe

The EU aims to reach net-zero greenhouse gas emissions by 2050, an objective that will be endorsed in a "Climate Law" to be presented in March 2020. In particular, the reductions in the GHG (Greenhouse Gas) emissions compared to 1990 are:

- -20% in 2020 - 2023: EU member states update their national energy and climate plans to reflect the new climate ambition;
- -50 – 55% in 2030;
- Zero net emissions of greenhouse gases in 2050.

The proposed objectives to realise these targets are:

- Interconnect energy systems while integrating and increasing share of renewable energy sources into the grid;
- Promote and integrate innovative technologies and modern infrastructure;
- Boost energy efficiency and eco-design of products;
- Decarbonise the gas sector and promote smart integration across sectors;
- Empower consumers and help Member States to tackle energy poverty;
- Increase cross-border and regional cooperation to better share clean energy sources;
- Promote EU energy standards and technologies at global level;
- Promote support for citizen dialogues and support of energy communities.

2.1.1.2 Sustainable industry and Circular economy

In March 2020, a new circular economy action plan is launched as part of a broader EU industrial strategy that will include a sustainable product policy with "prescriptions on how we make things" in order to prioritise reducing and reusing materials before recycling them. Moreover, the minimum requirements are set to prevent environmentally harmful products from being placed on the EU market. False green claims will be tackled. The first efforts are targeted to focus first on resource intense sectors such as: textiles, construction, electronics and plastics.

In order to achieve the EU's climate and environmental goals requires a new industrial policy based on the circular economy. Some mentioned figures are:

- From 1970 to 2017, the annual global extraction of raw materials tripled, and it continues to grow;
- More than 90% of biodiversity loss and water stress come from resource extraction and processing;
- EU's industry accounts for 20% of the EU's emissions;
- Only 12% of the materials used by EU industry come from recycling.

Since digital technologies allow for the generation and processing of data required for new business models and complex circular supply chains, they are a key enabler for the circular economy's upscaling. Circularity is facilitated by features in IoT devices (e.g., end-to-end cybersecurity, privacy, interoperability, energy harvesting capabilities). End users, suppliers, manufacturers, and investors all benefit from a network of connected devices that deliver fast smart services and real-time valuable information.

Europe needs a digital sector that puts sustainability and green growth at its heart. In particular, digitalisation presents new opportunities for:

- monitoring of air and water pollution;
- monitoring and optimising how energy and natural resources are consumed.

2.1.1.3 Buildings' renovation and retrofitting

The reason of focusing on this objective is due to the fact that 40% of European's energy consumption is by buildings. The main focus will be to renovate buildings, to help people cut their energy bills and energy use.

The proposed objectives to accomplish better energy performance of buildings are:

- Prices of different energy sources should incentivize energy-efficient buildings;
- Design of buildings should be in line with the circular economy;
- Increased digitalization;
- More climate-proofing of buildings;
- Strict enforcement of rules on energy performance of buildings.
- Use/production of renewable energy, solar lights, energy saving devices, temperature control

2.1.1.4 Sustainable mobility

According to the European Green Deal, Europe must reduce emissions from transport further and faster. Transport accounts for a quarter of the European Union's greenhouse gas emissions and these continue to grow.

In [Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement | Nature Climate Change] it is shown the effect on the global CO_2 emissions of the forced confinement and almost complete reduction of transportation in 2020 due to COVID-19 pandemic, that altered patterns of energy demand around the world. Daily global CO_2 emissions decreased by –17% by early April 2020 compared with the mean 2019 levels, just under half from changes in surface transport. At their peak, emissions in individual countries decreased by –26% on average. As a suggested outcome, the government actions and economic incentives postcrisis will likely influence the global CO_2 emissions path for decades.

Therefore, the Green Deal seeks a 90% reduction in these emissions by 2050. Some of the objectives of realising the Sustainable mobility Green Deal targets are:

Go digital:

- Automated mobility and smart traffic management systems will make transport more efficient and cleaner;
- Smart applications and 'Mobility as a Service' solutions will be developed;
- Use different modes of transport:
  - more freight should be transported by rail or water;
  - the Single European Sky should significantly reduce aviation emissions at zero cost to consumers and companies.
- Boost supply of sustainable alternative transport fuels.

By 2025, about 1 million public recharging and refuelling stations will be needed for the 13 million zero- and low-emission vehicles expected on European roads.

Reduce pollution:

- The Green Deal will address emissions, urban congestion, and improve public transport, which can be realized by:
  - stricter standards on pollution by cars;
  - to reduce pollution in EU ports;
  - to improve air quality near airports.

2.1.1.5 R&D and innovation

It is considered that the Horizon Europe research and innovation program will also contribute to the Green Deal from 2021 to 2027. In particular, it is planned that 35% of the EU's research funding will be set aside for climate-friendly technologies under an agreement struck earlier this year. Moreover, a series of EU research "moon shots" will focus chiefly on environmental objectives.

2.1.2 Fit for 55 package

The European Green Deal, presented in the communication (COM(2019)640) of 11 December 2019, see Section 0 of this report, sets out a detailed vision to make Europe the first climate-neutral continent by 2050, safeguard biodiversity, establish a circular economy and eliminate pollution, while boosting the competitiveness of European industry and ensuring a just transition for the regions and workers affected.

With the announcement of the European Green Deal, the European Commission President Ursula von der Leyen pledged to put forward a comprehensive, responsible plan to increase the European Union's emissions reduction target for 2030. In particular. in her 17 September 2020 State of the Union address, von den Leyen proposed the reduction target to be set at 55%, alongside a revision of the EU's climate and energy legislation by June 2021, a target of spending 37% of the €750 billion NextGenerationEU recovery fund on Green Deal objectives, and the intention to raise 30% of the NextGenerationEU budget through green bonds.

The Commission adopted the communication '[Stepping up Europe's 2030 climate ambition]() - Investing in a climate-neutral future for the benefit of our people' (commonly known as the 2030 EU Climate target plan), on the same day. It also includes an updated 2030 emissions reduction target of net 55% compared to 1990 levels, from the current 40% emissions reduction target.

The communication builds on an extensive impact assessment and a public consultation during spring 2020. The analysis concludes that the current policy framework is insufficient. Without changes to the current policy framework and legislation, the European Commission communication projects only a 60% emissions reduction by 2050.

While the European Green deal communication referred to legislative processes and initiatives envisioned, the climate target plan gives some concrete examples of possible amendments.

The European Commission argues that delivering on the revised target with a coherent policy framework to support implementation across sectors would make European industry and businesses 'trailblazers'. This is expected to modernise the economy, delivering innovation and a competitive edge, while ensuring security and resilience of energy supply and health benefits. The new 2021-2027 Multiannual Financial Framework and NextGenerationEU provide an opportunity to transition and grow the economy simultaneously. According to the communication, climate action mainstreaming across other funds and programmes and ensuring a just transition through the Just Transition Mechanism is essential.

On 14 July 2021, the European Commission adopted a package of proposals to make the EU's climate, energy, land use, transport and taxation **policies fit for reducing net greenhouse gas emissions by at least 55% by 2030**, compared to 1990 levels. Achieving these emission reductions in the next decade is crucial to Europe becoming the world's first climate-neutral continent by 2050 and making the European Green Deal a reality. With these proposals, the Commission is presenting the legislative tools to **deliver on the targets agreed in the European Climate Law** and fundamentally transform our economy and society for a fair, green and prosperous future.

These proposals will enable the necessary acceleration of greenhouse gas emission reductions in the next decade.

They combine: application of emissions trading to new sectors and a tightening of the existing EU Emissions Trading System; increased use of renewable energy; greater energy efficiency; a faster roll-out of low emission transport modes and the infrastructure and fuels to support them; an alignment of taxation policies with the European Green Deal objectives; measures to prevent carbon leakage; and tools to preserve and grow our natural carbon sinks.

The updated EU-Energy and Climate Targets based on the Fit for 55 regulation are given in **Figure 2.**

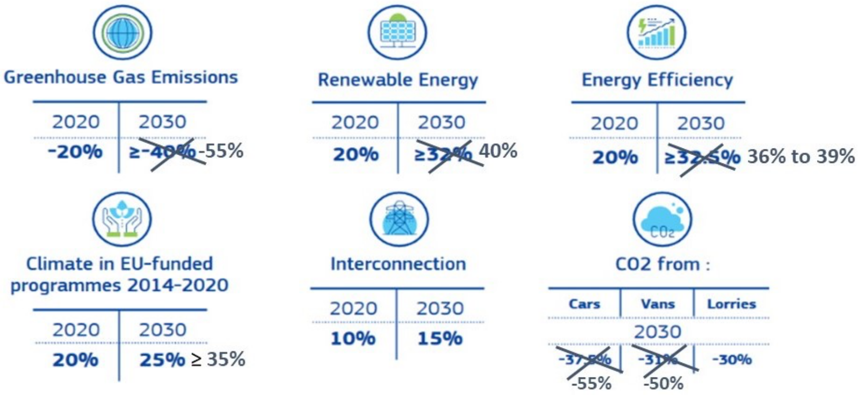


Figure 2: Updated EU-Energy and Climate Targets Fit for 55

The following initiatives were announced on 14 July 2021:

- Revision of the EU Emissions Trading System (ETS), including maritime, aviation and CORSIA as well as a proposal for ETS as own resource:

  The EU Emissions Trading System **(ETS) puts a price on carbon** and lowers the cap on emissions from certain economic sectors every year. It has successfully **brought down emissions from power generation and energy-intensive industries by 42.8%** in the past 16 years. On 14 July 2021, the Commission is proposing to lower the overall emission cap even further and increase its annual rate of reduction. The Commission is also proposing to phase out free emission allowances for aviation and align with the global Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and to include shipping emissions for the first time in the EU ETS. To address the lack of emissions reductions in road transport and buildings, a separate new emissions trading system is set up for fuel distribution for road transport and buildings. The Commission also proposes to increase the size of the Innovation and Modernisation Funds;

  To complement the substantial spending on climate in the EU budget, **Member States should spend the entirety of their emissions trading revenues on climate and energy-related projects**. A dedicated part of the revenues from the new system for road transport and buildings should **address the possible social impact on vulnerable households, micro-enterprises and transport users**.

- Carbon Border Adjustment Mechanism (CBAM) and a proposal for CBAM as own resource:

  The **new** Carbon Border Adjustment Mechanism **will put a carbon price on imports** of a targeted selection of products to ensure that ambitious climate action in Europe does not lead to 'carbon leakage'. This will **ensure that European emission reductions contribute to a global emissions decline**, instead of pushing carbon-intensive production outside Europe. It also aims to encourage industry outside the EU and our international partners to take steps in the same direction.

- Effort Sharing Regulation (ESR):

The Effort Sharing Regulation **assigns strengthened emissions reduction targets to each Member State** for buildings, road and domestic maritime transport, agriculture, waste and small industries. Recognising the different starting points and capacities of each Member State, these targets are based on their GDP per capita, with adjustments made to take cost efficiency into account.

- Revision of the Energy Tax Directive:

  The tax system for energy products must safeguard and improve the Single Market and support the green transition by setting the right incentives. A revision of the Energy Taxation Directive proposes to **align the taxation of energy products with EU energy and climate policies**, promoting clean technologies and removing outdated exemptions and reduced rates that currently encourage the use of fossil fuels. The new rules aim at reducing the harmful effects of energy tax competition, helping secure revenues for Member States from green taxes, which are less detrimental to growth than taxes on labour.

- Amendment to the Renewable Energy Directive to implement the ambition of the new 2030 climate target (RED):

- Amendment of the Energy Efficiency Directive to implement the ambition of the new 2030 climate target (EED):

- Reducing methane emissions in the energy sector

- Revision of the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (LULUCF):

Member States also share responsibility for removing carbon from the atmosphere, so the Regulation on Land Use, Forestry and Agriculture **sets an overall EU target for carbon removals** by natural sinks, equivalent to 310 million tons of CO2 emissions by 2030. National targets will require Member States to care for and expand their carbon sinks to meet this target. By 2035, the EU should aim to reach climate neutrality in the land use, forestry and agriculture sectors, including also agricultural non-CO2 emissions, such as those from fertiliser use and livestock. The **EU Forest Strategy** aims to improve the quality, quantity and resilience of EU forests. It supports foresters and the forest-based bioeconomy while keeping harvesting and biomass use sustainable, preserving biodiversity, and setting out **a plan to plant three billion trees** across Europe by 2030.

- Revision of the Directive on deployment of alternative fuels infrastructure:

- Revision of the Regulation setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles:

The following initiatives are announced for fourth quarter of 2021:

- Revision of the energy performance of Buildings Directive (EPBD);

- Revision of the Third Energy Package for gas (Directive 2009/73/EU and Regulation 715/2009/EU) to regulate competitive decarbonised gas markets.

These proposals are all connected and complementary. This balanced package and the revenues it generates are needed, to ensure a transition which makes Europe fair, green and competitive, sharing responsibility evenly across different sectors and Member States, and providing additional support where appropriate.

2.1.3 European Sustainability Product Initiative

Under the European Green Deal, the European Commission presented in March 2020 a New Circular Economy Action Plan, in which it announced a sustainable product policy legislative initiative to make products fit for a climate neutral, resource efficient and circular economy, reduce waste and ensure that the performance of frontrunners in sustainability progressively becomes the norm.

The Commission presented on 30 March 2022 a package of European Green Deal proposals to make sustainable products the norm in the EU, boost circular business models and empower consumers for the green transition.

As announced in the Circular Economy Action Plan, the Commission is proposing new rules to make almost all physical goods on the EU market more friendly to the environment, circular, and energy efficient throughout their whole lifecycle from the design phase through to daily use, repurposing and end-of-life.

The Commission also presented a new strategy to make textiles more durable, repairable, reusable and recyclable, to tackle fast fashion, textile waste and the destruction of unsold textiles, and ensure their production takes place in full respect of social rights.

A third proposal aims to boost the internal market for construction products and ensure that the regulatory framework in place is fit for making the built environment deliver on our sustainability and climate objectives.

Finally, the package includes a proposal on new rules to empower consumers in the green transition so that consumers are better informed about the environmental sustainability of products and better protected against greenwashing.

With those proposals, the Commission is presenting the tools to move to a truly circular economy in the EU: decoupled from energy- and resource dependencies, more resilient to external shocks and respectful of nature and people's health. The proposals build on the success of EU's existing Ecodesign rules, which have brought remarkable reductions in EU's energy consumption and significant savings to consumers. In 2021 alone, existing ecodesign requirements saved consumers €120 billion.

The rules have also led to a 10% lower annual energy consumption by the products in scope. By 2030, the new framework can lead to 132 mtoe of primary energy savings, which corresponds roughly to 150 bcm of natural gas, almost equivalent to EU's import of Russian gas.

Making sustainable products the norm

The proposal for a Regulation on Ecodesign for Sustainable Products addresses product design, which determines up to 80% of a product's lifecycle environmental impact. It sets new requirements to make products more durable, reliable, reusable, upgradable, reparable, easier to maintain, refurbish and recycle, and energy and resource efficient. In addition, product-specific information requirements will ensure consumers know the environmental impacts of their purchases. All regulated products will have Digital Product Passports. This will make it easier to repair or recycle products and facilitate tracking substances of concern along the supply chain. Labelling can be introduced as well. The proposal also contains measures to end the destruction of unsold consumer goods, as well as expand green public procurement and provide incentives for sustainable products.

The proposal extends the existing Ecodesign framework in two ways: first, to cover the broadest possible range of products; and second, to broaden the scope of the requirements with which products are to comply. Setting criteria not only for energy efficiency, but also for circularity and an overall reduction of the environmental and climate footprint of products will lead to more energy and resource independence and less pollution. It will strengthen the Single Market, avoiding diverging legislation in each Member State, and create economic opportunities for innovation and job creation, notably in remanufacturing, maintenance, recycling and repair. The proposal will set a framework and a process through which the Commission, working in close cooperation with all those concerned, will progressively set out requirements for each product or group of products.

Together with this proposal, the Commission has also adopted an Ecodesign and Energy Labelling Working Plan 2022-2024 to cover new energy-related products, update and increase the ambition for products that are already regulated, as a transitional measure until the new regulation enters into force. It notably addresses consumer electronics (smartphones, tablets, solar panels) - the fastest growing waste stream.

To support the deployment of sustainable products across the EU market, targeted sectoral initiatives were also proposed. The EU Strategy for Sustainable and Circular Textiles and the revision of the Construction Products Regulation will address two priority product groups with significant impacts.

Sustainable and circular textiles

European consumption of textiles has the fourth highest impact on the environment and climate change, after food, housing and mobility. It is also the third highest area of consumption for water and land use, and fifth highest for the use of primary raw materials.

The EU Strategy for Sustainable and Circular Textiles sets out the vision and concrete actions to ensure that by 2030 textile products placed on the EU market are long-lived and recyclable, made as much as possible of recycled fibres, free of hazardous substances and produced in respect of social rights and the environment. Consumers will benefit longer from high quality textiles, fast fashion should be out of fashion, and economically profitable re-use and repair services should be widely available. In a competitive, resilient and innovative textiles sector, producers have to take responsibility for their products along the value chain, including when they become waste. In this way, the circular textiles ecosystem will be thriving, and be driven by sufficient capacities for innovative fibre-to-fibre recycling, while the incineration and landfilling of textiles has to be reduced to the minimum.

The specific measures will include ecodesign requirements for textiles, clearer information, a Digital Product Passport and a mandatory EU extended producer responsibility scheme. It also foresees measures to tackle the unintentional release of microplastics from textiles, ensure the accuracy of green claims, and boost circular business models, including reuse and repair services. To address fast fashion, the Strategy also calls on companies to reduce the number of collections per year, take responsibility and act to minimise their carbon and environmental footprints, and on Member States to adopt favourable taxation measures for the reuse and repair sector. The Commission will promote the shift also with awareness-raising activities.

The Strategy also aims to provide support to and accompany the textiles ecosystem throughout its transformative journey. Therefore, the Commission is launching today the co-creation of a transition pathway for the textiles ecosystem. This is an essential collaborative tool to help the ecosystem to recover from negative impacts of the Covid-19 pandemic which have been affecting companies in their daily operations for the last two years. It will also strengthen their capacities to withstand both a fierce global competition and future shocks for their long-term survival. All the actors are encouraged to take active part in the co-creation process through their commitments on circularity and circular business models, actions to strengthen sustainable competitiveness, digitalisation and resilience, and identification of specific investments needed for the twin transition.

The construction products of tomorrow

The construction ecosystem represents almost 10% of EU value added, and employs around 25 million people in over 5 million firms. The construction products industry counts 430,000 companies in the EU, with a turnover of €800 billion. These are mainly small and medium-size enterprises. They are a key economic and social asset for local communities in European regions and cities.

Buildings are responsible for around 50% of resource extraction and consumption and more than 30% of the EU's total waste generated per year. In addition, buildings are responsible for 40% of EU's energy consumption and 36% of energy-related greenhouse gas emissions.

The revision of the Construction Products Regulation will strengthen and modernise the rules in place since 2011. It will create a harmonised framework to assess and communicate the environmental and climate performance of construction products. New product requirements will ensure that the design and manufacture of construction products is based on state of the art to make these more durable, repairable, recyclable, easier to re-manufacture.

It will also make it easier for standardisation bodies to do their work of creating common European standards. Together with enhanced market surveillance capacities and clearer rules for economic operators along the supply chain, this will help to remove obstacles to the free movement of the internal market. Finally, the revised Regulation will offer digital solutions to reduce administrative burdens, particularly on SMEs, including a construction products database and a Digital Products Passport.

2.1.4 Digital and Green Twin transition

The European Commission states that "Europe must leverage the potential of digital transformation, which is a key enabler for reaching the Green Deal objectives."

This idea is reinforced in the New Industrial Strategy for Europe, where it is underlined that the twin ecological and digital transitions will affect every part of our economy, society, and industry.

New green technologies are already here to help tackle the biggest challenge of our time: climate change. The European Commission has long promoted digital transformation to enhance economic competitiveness, while also recognising that digitisation can contribute to sustainability goals and enable the changes needed for a just green transition. The Commission's twin green and digital goals are seen to complement each other well.

The Fit for 55 packages will drive the transition to achieve the 2030 goal of reducing carbon emissions by 55%, and all sectors will play an important role in helping achieve this objective. Digital technology such as artificial intelligence, cloud computing, IoT can enable speed and scale in delivering the EU's decarbonisation goals. However, while ICT technologies can help most sectors of the economy to become greener, the ICT sector itself must accept its responsibility to meet high ecological standards.

2.1.5 Certification of carbon removals

The European Commission plans to put forward a regulatory framework proposal for the certification of carbon removals by the end of next year.

"A certification mechanism will provide more clarity on the quality of carbon removals, and ensure their environmental integrity. It will address the lack of standardisation of existing frameworks and contribute to a level playing field," the commission said today.

This is vital to ensuring the credibility of carbon removals, the commission said, which will be an "essential stepping stone" towards the bloc's legally binding target to reach carbon neutrality by 2050.

The commission plans to launch a call for evidence early next year and hold a conference in the first quarter of 2022 to increase understanding of and exchange on carbon removal accounting and certification. It will then propose an EU regulatory framework for the accounting and certification of carbon removals by the end of next year.

The commission also plans to establish an EU standard in monitoring, reporting and verifying emissions and carbon removals for both farms and forests, and captured, stored and transported CO2, as well as "regular exchanges with other jurisdictions" on the subject.

Compliance framework inclusion

The communication specifies that "any future policy choice (in the post-2030 legislative cycle) to allow carbon removals in EU compliance frameworks would need, as a necessary precondition, a sound and reliable definition of carbon removals providing guarantees in terms of environmental integrity".

This differs from a leaked draft of the communication, seen by Argus, which had simply stated that the legal framework would "define the type of carbon removals that could be accounted in the period after 2030 to neutralize emissions in EU compliance frameworks".

A group of environmental non-governmental organisations warned earlier this month in response to the leak that carbon removal offsets should be kept separate from the EU emissions trading system and other existing policy frameworks to avoid undermining climate ambition.

Environmental group Greenpeace said today that the plan "risks becoming an excuse for big polluters to stall their own climate action", arguing that industries could buy removals as carbon offsets rather than reducing their emissions. "Carbon removals can add to cuts, but we can't let polluters use removals to pretend they're reaching climate targets."

Industrial carbon removals

Alongside various proposals for "carbon farming" relating to land use, the communication puts forward a number of "aspirational objectives" for industrial carbon removals.

This includes aims to report and account by its fossil, biogenic or atmospheric origin any tonne of CO2 captured, transported, used and stored by industries by 2028, have at least 20pc of the carbon used in chemical and plastic products come from sustainable non-fossil sources by 2030, and remove 5mn t/yr CO2 from the atmosphere and store it permanently through frontrunner projects by 2030.

2.2 Initiatives and Standards

More and more companies are now facing the need to address Green digital transformation as to formalize green transformation efforts and integrate them into their business strategy, improve communication and increase transparency. Expectations for consistent, comparable and transparent information on climate and other environmental, technical, social and corporate governance (ESG) information are growing steadily - driven by investor pressure, stakeholder pressure and, increasingly, regulatory as standardization action.

Technologies such as 5G/6G, IoT and AI are opening a wide range of new opportunities by accelerating the speed of digitalization across multiple industries. Those new opportunities have to be conducted to a rapid pace of innovation to achieve the goals of the EU Green Deal.

A substantial portfolio of European and International entities is today involved in sustainability matters, working and cooperating in the development of strategies, recommendations and standards. This section gives an overview about those activities.

First of all, the issue Sustainability is manyfold. Initially based on Life Cycle Assessment from a general point of view, this issue is today diversified and divided in environmental issues (circular economy), in carbon footprint measurement methods of products, of services, of Verticals, in energy savings´ technical and assessment methods. Those are the relevant topics we address in this paper.

We can distinguish three key types of entities: regulations (see chapter 2.1), industrial driven Initiatives as NGMN, GSMA, GeSi, GRI, ZVEI, AIOTI, among others and standardisation bodies as ITU-T, ETSI, ISO, IEC and 3GPP.

2.2.1 NGMN

The NGMN Alliance (Next Generation Mobile Networks Alliance) [1] is an open forum founded by key-leading mobile network operators. Its goal is to ensure that next generation network infrastructure, service platforms and devices will meet the requirements of operators and, ultimately, will satisfy end user demand and expectations.

NGMN seeks to incorporate the views of all interested stakeholders in the telecommunications industry and is open to three categories of participants (NGMN Partners): Mobile network operators (Members), vendors, software companies and many other leading industry players (Contributors), and research institutes contributing substantially to mid- to long-term innovation (Advisors).

The NGMN work programme is a collaborative work programme in which all NGMN Partners (Mobile Network Operators, Vendors/Manufacturers and Research/Academia) contribute to agreed project objectives and deliverables.

One of its work programmes is the Green Future Network (GFN) which scope to build sustainable & environmentally conscious solutions. Its latest whitepaper "Metering for sustainable networks" recommends to deploy metering at the network and technical sites to check the energy performance of equipment in real time condition. Standardized metering shall be defined with generic unified architecture for data collection and are part of this document [1].

[1] https://www.ngmn.org/publications.html

2.2.2 GSMA

The GSMA is a global organisation unifying the mobile ecosystem to discover, develop and deliver innovation foundational to positive business environments and societal change. The GSMA supports the mobile industry's commitment to addressing the United Nations Sustainable Development Goals (SDGs), an initiative that aims to eradicate poverty, protect the planet, and ensure the prosperity of humanity as part of the 2030 sustainable development agenda. The GSMA contributes to all 17 SDGs through work carried out by GSMA Mobile for Development, driving innovation in digital technology to reduce inequalities and the industry taskforces to drive Climate Action and Sustainability. The GSMA has developed a Sustainability Assessment Framework to better understand the landscape of operator efforts in social and environmental sustainability [2]. Moreover, GSMA organizes yearly the Mobile World Congress at different places in the world.

[2] https://www.gsma.com/betterfuture/resources/strategy-paper-for-circular-economy-network-equipment

2.2.3 GeSi

The Global Enabling Sustainability Initiative (GeSI) is comprised of diverse and international members and partnerships, representing around 40 of the world's leading ICT companies, 12 global business and multiple international organisations. Its focus relies on achieving integrated social and environmental sustainability through ICT with reports, the SMART series. The latest report [3] aims to extend the previous analysis to 2030 and to look at ICT-enabled sustainability from a holistic point of view.

[3] https://www.gesi.org/research/smarter2030-ict-solutions-for-21st-century-challenges

2.2.4 GRI

The Global Reporting Initiative (GRI) is an independent, international organization that helps businesses and other organizations take responsibility for their impacts, by providing them with the global common language to communicate those impacts. GRI provides also widely used standards for sustainability reporting – the GRI Standards. The GRI Standards enable any organization – large or small, private or public – to understand and report on their impacts on the economy, environment and people in a comparable and credible way, thereby increasing transparency on their contribution to sustainable development.

2.2.5 AIOTI

The Alliance for IoT and Edge Computing Innovation (AIOTI) also works on sustainability related topics within WG Standardisation, WG ICT for CO2 Reduction Methodologies [4], and vertical WGs. The work and effort of the initiatives support substantially the work of the standardization bodies.

[4] https://aioti.eu/wp-content/uploads/2022/01/AIOTI-IG-Digital-for-Green-Vision-R1-Final.pdf

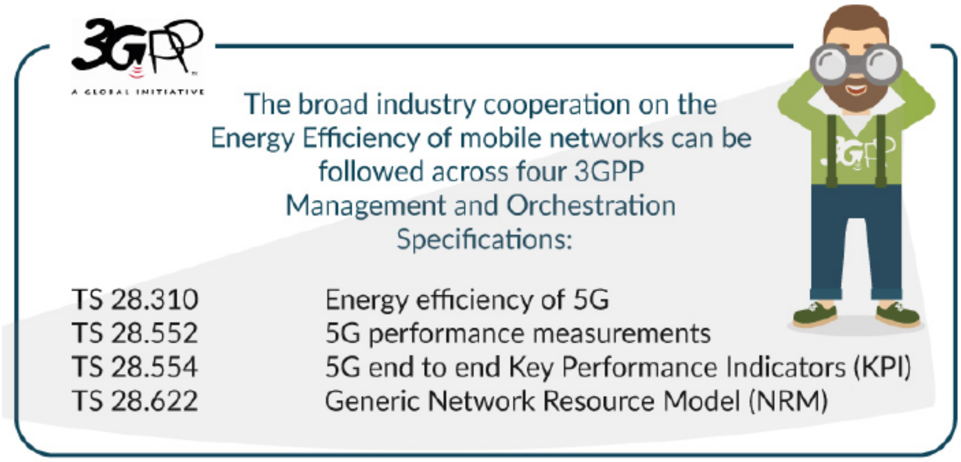
2.2.6 ZVEI

ZVEI is a German industrial association that represents the interests of a high-tech sector. The basis of the association's work is the exchange of experience and views between the members about current technical, economic, legal and socio-political topics in the field of the electrical industry. It supports market-related international standardisation work. Sustainability is of course a high relevant subject for the association. Some Position papers are the outcomes: for example, Green Deal – Fit for 55 package. In this position paper, the ZVEI analyses and evaluates six proposals from the EU's Fit for 55 package.

2.2.7 3GPP

The 3rd Generation Partnership Project (3GPP) is responsible for the standardization of mobile networks, including for ex. 4G LTE and 5G NR (New Radio). 3GPP unites seven telecommunications standard development organizations (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC), known as “Organizational Partners” and provides their members with a stable environment to produce Technical Reports and Technical Specifications that define 3GPP technologies.

Energy efficiency in mobile networks is a very important aspect in 3GPP standards. 3GPP put a significant effort to reduce the energy needed to carry a certain load for ex. by designing a lean signalling for 5G NR. In the last years 3GPP introduced and outworked energy savings methods and designs for UEs in release 16 with update in Release 17. Moreover, the definition of Energy Efficiency, KPIs and methods to measure them were studied in Release 17. The matter of energy saving in the Radio Access Network (RAN) part is a focus of Release 18, that just has started in May 2022. Planned work items for example are to include sleep modes for base stations when not transmitting and power amplifier improvements to boost efficiency when they are. The today available outcomes on Energy Efficiency in 5G is reported in following TS (Technical Specifications) [5]



The broad industry cooperation on the Energy Efficiency of mobile networks can be followed across four 3GPP Management and Orchestration Specifications:

TS 28.310	Energy efficiency of 5G
TS 28.552	5G performance measurements
TS 28.554	5G end to end Key Performance Indicators (KPI)
TS 28.622	Generic Network Resource Model (NRM)

Figure 3: 3GPP technical specifications on energy efficiency and energy saving matters

This effort is a part of the industry-wide activity on 5G, spanning an eco-system that also includes energy efficiency related output from GSMA, NGMN, ETSI and ITU-T.

[5] https://www.3gpp.org/technologies/keywords-acronyms/2159-ee_5g

2.2.8 ITU-T and ETSI

The Study Groups of ITU's Telecommunication Standardization Sector (ITU-T) assemble experts from around the world to develop international standards known as ITU-T Recommendations which act as defining elements in the global infrastructure of information and communication technologies (ICTs). Sustainability is one of its 5 strategic goals in its strategic plan 2020-2023 [11].

ITU-T Study Group 5 (SG5) is responsible for studies on methodologies for evaluating ICT effects on climate change and publishing guidelines for using ICTs in an eco-friendly way. Under its environmental mandate SG5 is also responsible for studying design methodologies to reduce ICTs and e-waste's adverse environmental effects, for example, through recycling of ICT facilities and equipment.

ETSI is one of the three European Standards Organization (ESO- CEN, CENELEC, ETSI). ETSI is supporting European regulations and legislation through the creation of Harmonised European Standards. The Energy Engineering Technical Committee (TC EE) develops standards for reducing the eco-environmental impact of Information and Communications Technologies (ICT) equipment. This includes:

- the Life Cycle Assessment (LCA) of ICT goods, networks and services
- methods to assess the energy efficiency of wireless access networks and equipment, core networks and wireline access equipment including Efficiency metrics/KPI definition for equipment and network
- network standby mode for household and office equipment
- Circular economy standard for ICT solutions
- Power feeding solutions based on higher DC voltage to reduce losses on the distribution cabling and innovative efficient storage solution

TC EE is also responsible for defining the environmental and infrastructural aspects for all telecommunication equipment and its environment, including equipment installed in subscriber premises. Wherever possible this will be achieved by referencing existing international standards.

TC EE and **ITU-T SG5** are working together to develop technically aligned standards on energy efficiency, power feeding solution, circular economy and network efficiency KPI and eco-design requirement for ICT, with the aim to build an international eco-environmental standardization. The list of related standards is in [12].

Here some relevant examples:

ES 203 228 (ITU-T L.1331) defines metrics and methods for assessing and measuring energy efficiency in operational networks. It is based on the measurement of performance of small networks, for feasibility and simplicity purposes.

ES 202 706 defines metrics and measurement method for energy efficiency of wireless access network equipment

ES 202 336-12 Monitoring and control interface for infrastructure equipment (power, cooling and building environment systems used in telecommunication networks); Part 12: ICT equipment power, energy and environmental parameters monitoring information model

Besides this technical committee an Industry Specification Group (ISG) on Operational energy Efficiency for Users (OEU) addresses sustainability issues – minimizing power consumption as GHG emissions on ICT sides and networks. In brief their work focuses on:

- the measurement of energy consumption by IT servers, storage units, broadband fixed access and mobile access, with a view to developing global KPIs
- the management of the end of life of ICT equipment
- the definition of global KPI modelling for green smart cities

The list of related standards is in [13].

[11] https://www.itu.int/en/council/planning/Pages/default.aspx

[12] https://www.etsi.org/committee/1395-ee

[13] https://www.etsi.org/committee/1429-oeu

2.2.9 ISO

ISO standards are developed by many technical committees with experts from many national standards organizations. Currently, ISO has 250 technical committees, 510 subcommittees, and near to 2500 working groups.

The ISO Standards cover a large range of activities: quality management (ISO 9000 family), environmental management (ISO 14000 family [13]), health and safety (ISO 45001), energy management (ISO 50001), food safety (ISO 22000), IT security (ISO/IEC 27001).

ISO/IEC 15459-6:2014 specifies a unique string of characters for the identification of groupings of products, product packages, transport units and items. The character string is intended to be represented in a linear bar code symbol and two-dimensional symbol or other automatic identification and data capture (AIDC) media attached to the entity to meet management needs and/or regulatory needs (e.g. customs clearance). To address these needs, different types of identifiers are recognized in the various parts of ISO/IEC 15459, which allows different requirements to be met by the unique identifiers associated within the context of the specific parts of ISO/IEC 15459.

In the following table the activities related to environmental management is listed:

Table 1: ISO and environmental management

SUBCOMMITTEE ↓	SUBCOMMITTEE TITLE	PUBLISHED STANDARDS	STANDARDS UNDER DEVELOPMENT
ISO/TC 207/SC 1	Environmental management systems	10	1
ISO/TC 207/SC 2	Environmental auditing and related environmental investigations	2	3
ISO/TC 207/SC 3	Environmental labelling	8	1
ISO/TC 207/SC 4	Environmental performance evaluation	7	3
ISO/TC 207/SC 5	Life cycle assessment	15	4
ISO/TC 207/SC 7	Greenhouse gas management and related activities	13	6

Source: https://www.iso.org/committee/54808/x/catalogue/p/1/u/0/w/0/d/0

The work done by the SC5 (Life cycle assessment) and SC7 (GHG management) are the most relevant part for the purpose of this document.

- ISO 14040 defines the principles and frameworks to conduct a correct Life Cycle Assessment.
- ISO 14044 specifies the requirements and guidelines for a correctly conducted Life Cycle Assessment (LCA)
- ISO 14060 family

The content of the relevant ISO standards is described in more details in chapter 3.1.4.

[13] https://www.iso.org/iso-14001-environmental-management.html

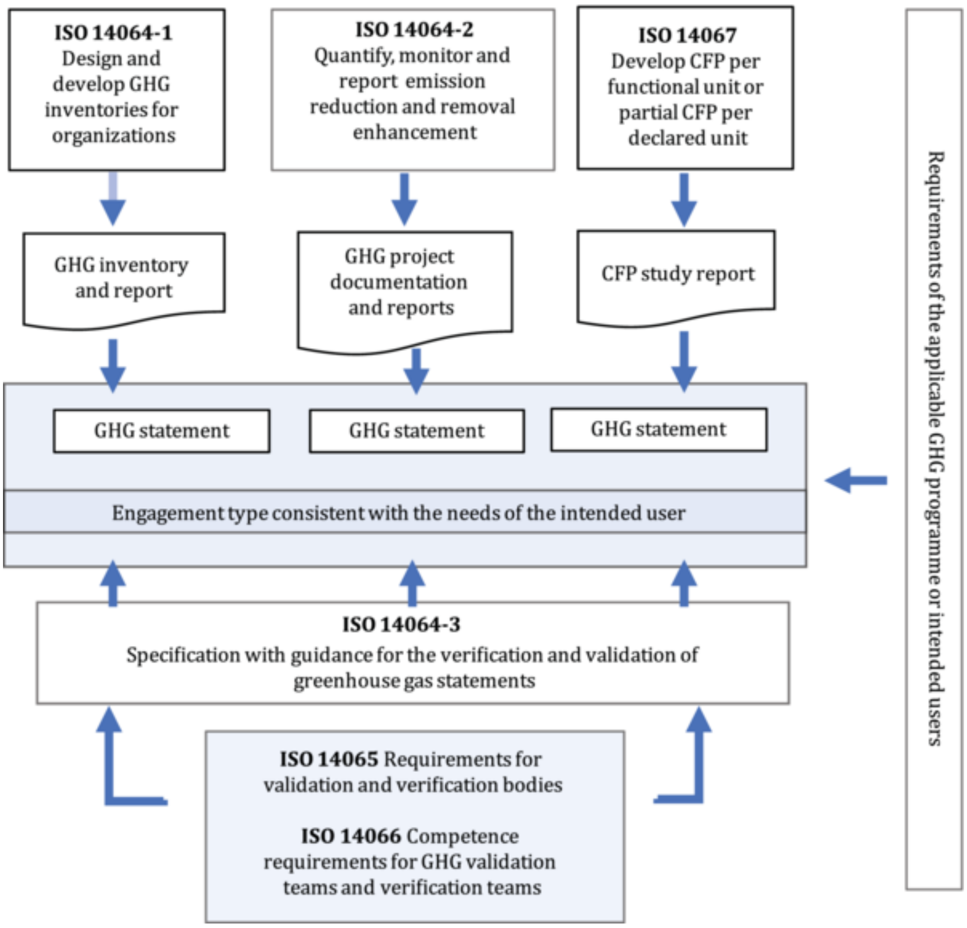


Figure 4: ISO 14060 family standards

Source: https://bluecarbonprojects.org/faq-items/iso-14060-family/#

2.2.10 The International Electrotechnical Commission (IEC)

The International Electronical Commission (IEC) is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies. It covers a wide range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, solar energy, nanotechnology among others. IEC works closely with the ISO (there are several ISO/IEC standards as for ex. 27001 or 17000 series) and with the ITU.

In their spectrum towards moving towards a more sustainable world in their work, an advisory committee on energy efficiency was created to help coordinating activities between different IEC TCs that contribute to this area. Following the list of the TCs involved so far:

IEC TC 2: Rotating machinery

IEC TC 9: Electrical equipment and systems for railways

IEC TC 14: Power transformers

IEC TC 22: Power electronic systems and equipment

IEC TC 23: Electrical accessories

IEC TC 27: Industrial electro heating and electromagnetic processing

IEC TC 64: Electrical installations and protection against electric shock

IEC TC 66: Safety of measuring, control and laboratory equipment

IEC TC 85: Measuring equipment for electrical and electromagnetic quantities

IEC TC 121: Switchgear and control gear and their assemblies for low voltage

To complete this chapter on standardization bodies, it is worth to mention that the World Standards Cooperation (WSC) was established in 2001 by the ITU, the ISO and the IEC in order to strengthen and advance the voluntary consensus-based international standards systems as to provide transparency of those three international standards development organizations.

Technical coordination mechanisms among IEC, ISO and ITU were agreed in order to resolve problems at earliest stage, optimize communication between the organizations and avoid duplication of work.

2.2.11 GS1

Under ISO/IEC 15459 (mentioned under the ISO part) GS1 is a global not for profit standardisation body specialised in product data identification, data capturing and data sharing. According to the same ISO standards, GS1 is an issuing agency for consumer goods, retail products and medical devices.

Over the years, GS1 standards have enabled identification for locations, assets, machines and others to support the development of supply chains automation and increased transparency. GS1 covers more than 25 sectors and has National member organisations in more than 110 countries.

GS1 standards are open and global and the majority of GS1 standards are ISO standards; the full list is available here.

GS1 recently published its positioning and the proposed data architecture for the implementation of the EU digital product passport available here.

GS1 worked with W3C to show the importance of interoperability under different perspectives and recently published a joint position on the semantics needs for the circular economy available here.

GS1 and W3C, together with other partners and under the coordination of the French CEA have been instrumental in developing a successful architecture for the CIRPASS Digital Product Passport, awarded EU funding under the Digital Europe Program.

Regarding the topic of this report focussing on carbon footprint methodologies, GS1 standards don’t directly cover this area but allow the data exchange, once the methodology chosen, of the results of the calculation in a global and open standardised way. In this way, CO2 emissions data attributes could be included in a data modelling and exchanged in data carriers in an interoperable way, B2B and B2C.

3. Existing methods on measuring Carbon Footprint

This chapter is providing description of the existing methods of measuring Carbon Footprint.

3.1 Generic Methods of measuring Carbon Footprint

The methodologies of measuring Carbon Footprint described in Analysis of Existing Environmental Footprint Methodologies for Products and Organizations: Recommendations, Rationale, and Alignment (European Commission Joint Research Centre, Institute for Environment and Sustainability H08 Sustainability Assessment Unit) are:

3.1.1 Product Environmental Footprint

- **ISO 14044: Environmental Management: Life Cycle Assessment:** this standard specifies requirements and provides guidelines for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, relationship between the LCA phases, and conditions for use of value choices and optional elements.

- **ISO 14067: Carbon Footprint of Product**: This document specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product (CFP), in a manner consistent with International Standards on life cycle assessment (LCA) (ISO 14040 and ISO 14044).

- **International Reference Life Cycle Data System (ILCD)**: is an initiative developed by JRC and DG ENV since 2005, with the aim to provide guidance and standards for greater consistency and quality assurance in applying LCA.

- **GHG protocol:** The GHG Protocol establishes comprehensive global standardized frameworks to measure and manage greenhouse gas (GHG) emissions from private and public sector operations, value chains and mitigation actions. The GHG Protocol is the most widely used carbon measurement methodology and is used by the Science Based Targets initiative, the most prominent GHG target setting methodology. The GHG Protocol has developed a specific GHG Protocol Product Standard to advise on how to measure product-related emissions in a way that is aligned with the GHG Protocol.

- **PAS 2050:** PAS 2050 a publicly available specification enables companies to measure the environmental impact of their activities, products and services and measure their lifecycle GHG emissions.

- **Ecological footprint:** The ecological footprint is a method promoted by the Global Footprint Network to measure human demand on natural capital, i.e. the quantity of nature it takes to support people or an economy.

- **BPX 30-323:** BPX30-323 is a repository of good practices prepared under the french law called which establishes the prospect of regulatory communication of environmental information relating to products.

3.1.2 Corporate Environmental Footprint

- **ISO 14064:** this standard specifies principles and requirements at the organization level for the quantification and reporting of greenhouse gas (GHG) emissions and removals. It includes requirements for the design, development, management, reporting and verification of an organization's GHG inventory.

- **Global Reporting Initiative (GRI)**: The Global Reporting Initiative is an international independent standards organization that helps businesses, governments and other organizations understand and communicate their impacts on issues such as climate change, human rights and corruption.

- **CDP Water Disclosure Project**: CDP's work with water security motivates companies to disclose and reduce their environmental impacts by using the power of investors and customers. The data CDP collects helps influential decision makers to reduce risk, capitalize on opportunities and drive action towards a more sustainable world.

- **GHG protocol: Corporate Standard**: The GHG Protocol Corporate Accounting and Reporting Standard provides requirements and guidance for companies and other organizations preparing a corporate-level GHG emissions inventory. The standard covers the accounting and reporting of seven greenhouse gases covered by the Kyoto Protocol – carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PCFs), sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3). It was updated in 2015 with the Scope 2 Guidance, which allows companies to credibly measure and report emissions from purchased or acquired electricity, steam, heat, and cooling.

- **ILCD**: The ICLD is an initiative developed by JRC and DG ENV since 2005, with the aim to provide guidance and standards for greater consistency and quality assurance in applying LCA. It is relevant to both product and corporate carbon footprinting.

- **Defra 'Guidance on how to measure and report your greenhouse gas emissions':** This is a UK Government document that explains how to measure greenhouse gas (GHG) emissions and set targets to reduce them. It is intended for all sizes of business and for public and voluntary sector organisations.

- **Defra Guidance on Environmental Key performance Indicators – Reporting Guidelines for UK Business:** These Guidelines seek to help companies report their environmental impacts in a meaningful and cost-effective way.

- **Bilan Carbone**: Bilan Carbone establishes a standard of excellence in GHG accounting; this tool is designed to compile an exhaustive inventory of GHG emitted by an organization, an event or a project. Bilan Carbone is also an environmental management tool, serving as a guide and supporting resource for organizations as they develop their climate and energy transition action. Note that Bilan Carbone is the french accounting methodology, compliant with ISO 14064.

Some more details on key Methods of measuring Carbon Footprint are provided below.

3.1.3 Science-Based Targets

Use of SBTs, see e.g.: Science-Based Target Setting Manual Version 4.1 | April 2020, Science Based Targets:

"SBTs represent a more robust approach for companies to manage their emissions over the long haul. SBTs are grounded in an objective scientific evaluation of what is needed for global GHG emissions reduction determined by relevant carbon budgets, rather than what is achievable by any one company. They offer a firm foundation for companies' long-term climate change strategies, boosting their competitive advantage in the transition to the low-carbon economy."

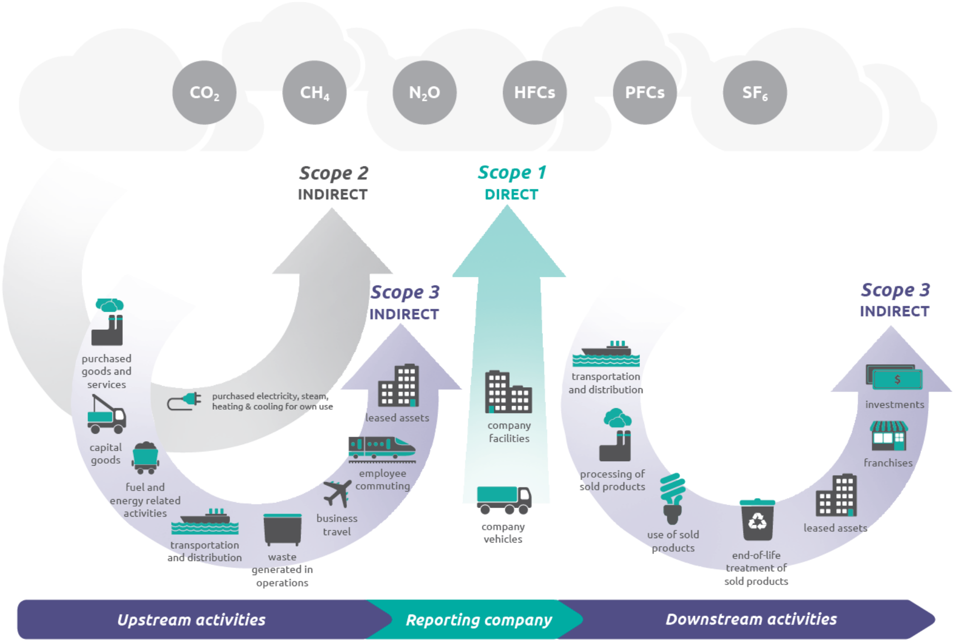


Figure 5: Overview of GHG Protocol scopes and emissions across the value chain, Source: GHG Protocol

Greenhouse gas emissions are categorized into three groups or 'Scopes' by the most widely used international accounting tool, the Greenhouse Gas (GHG) Protocol. Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain.

Companies should develop complete scope 3 inventories, at least using a screening approach and preferably using more detailed inventory methods, especially when scope 3 emissions are significant. If a company's scope 3 emissions account for at least 40% of total scope 1, 2 and 3 emissions), a scope 3 target should be set.

The Science-Based Target Setting Manual describes three methods and each has applicability to multiple sectors, and each has applicability to multiple sectors:

- **Absolute Emissions Contraction**: is a method for setting absolute targets that uses contraction of absolute emissions. Through this approach, all companies reduce their absolute emissions at the same rate, irrespective of initial emissions performance.

- **Sectoral Decarbonization Approach (SDA)**: is a method for setting physical intensity targets that uses convergence of emissions intensity. An intensity target is defined by a reduction in emissions relative to a specific business metric, such as production output of the company (e.g., tone CO2e per tone product produced). The SDA assumes global convergence of key sectors' emissions intensity by 2060.

  Currently, the SDA method provides sector-specific pathways for the following homogenous and energy intensive sectors:

  Available in the Science-Based Target Setting Tool:

  - Power Generation, Iron & Steel, Aluminum, Cement, Pulp & Paper, Services/commercial buildings

  Available in the SDA Transport Tool:

  - Passenger and Freight Transport

- **Economic Intensity Contraction**: Greenhouse Gas Emissions per Value Added (GEVA) is a method for setting economic intensity targets using the contraction of economic intensity. Targets set using the GEVA method are formulated by an intensity reduction of tCO2e/$ value added.

3.1.4 Green House Gas Protocol, used in the context of SBTs

When scope 3 emissions are significant, companies should develop a complete scope 3 inventory, which is critical for identifying emissions hotspots, reduction opportunities, and areas of risk up and down the value chain. The GHG Protocol Corporate Value Chain (Scope 3) Accounting and Reporting Standard (WRI & WBCSD, 2011), together with the Scope 3 Calculation Guidance, provide detailed guidance on how to complete a scope 3 inventory.

3.1.5 Publicly Available Specification (PAS), standardized by British Standards Institution

The PAS 2050 was introduced in 2008 (revised in 2011) with the aim of providing a consistent internationally applicable method for quantifying product carbon footprints.

The Publicly Available Specification (PAS) 2050 - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services was developed by the British Standards Institution in 2008. PAS 2050 is the first consensus-based and internationally applicable standard on product carbon footprint that has been used as the basis for the development of other standards internationally. The 2011 revision to PAS 2050 was developed through extensive consultation with international stakeholders, and in particular, through significant engagement with the wide PAS 2050 user community.

The key differences between PAS 2050 and the GHG Protocol Corporate Value Chain (Scope 3) are briefly described in QUANTIFYING THE GREENHOUSE GAS EMISSIONS OF PRODUCTS PAS 2050 & the GHG Protocol Product Standard.

The PAS 2060 carbon neutrality was introduced by BSI in 2010 and updated in 2014, having as goal to help organizations demonstrate the carbon neutrality of a specific product, entity, or activity. It underpins reliable, credible claims that the subject of such a claim can indeed be considered carbon neutral.

The PAS 2060 standard specifies a four-stage process to demonstrate carbon neutrality. This involves:

- Assessment of GHG emissions based on accurate measurement data
- Reduction of emissions through a target-driven carbon management plan
- Offsetting of excess emissions, often by purchasing carbon credits
- Documentation and verification through qualifying explanatory statements and public disclosure.
- Supporting the energy revolution towards net zero

3.1.6 ISO 14067

In this context, ISO produces documents that support the transformation of scientific knowledge into tools that will help address climate change. GHG initiatives on mitigation rely on the quantification, monitoring, reporting and verification of GHG emissions and/or removals.

In particular, the ISO 14060 family focuses on providing clarity and consistency for quantifying, monitoring, reporting and validating or verifying GHG emissions and removals to support sustainable development through a low-carbon economy. It also benefits organizations, project proponents and stakeholders worldwide by providing clarity and consistency on quantifying, monitoring, reporting, and validating or verifying GHG emissions and removals. Below a short overview of these ISO 14060 documents:

- ISO 14064-1 details principles and requirements for designing, developing, managing and reporting organization-level GHG inventories.
- ISO 14064-2 details principles and requirements for determining baselines and for the monitoring, quantifying and reporting of project emissions.
- ISO 14064-3 details requirements for verifying GHG statements related to GHG inventories, GHG projects, and carbon footprints of products.
- ISO 14065 defines requirements for bodies that validate and verify GHG statements.
- ISO 14066 specifies competence requirements for validation teams and verification teams.
- ISO/TR 14069 assists users in the application of ISO 14064-1, providing guidelines and examples for improving transparency in the quantification of emissions and their reporting. It does not provide additional guidance to ISO 14064-1.

The key ISO specification focusing on carbon footprint of products is ISO 14067:2018 (Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification). This specification has been prepared by the Technical Committee ISO/TC 207, *Environmental management*, Subcommittee SC 7, *Greenhouse gas management and related activities.*

ISO 14067:2018 specifies principles, requirements and guidelines for the quantification and reporting of the carbon footprint of a product (CFP), in a manner consistent with International Standards on life cycle assessment (LCA) (ISO 14040 and ISO 14044). Requirements and guidelines for the quantification of a partial CFP are also specified.

3.1.7 Port Environmental Review System (PERS)

The Port Environmental Review System (PERS) incorporates the main general requirements of recognised environmental management standards (e.g. ISO 14001), as well as also taking into account the specificities of ports. PERS builds upon the policy recommendations of the European Sea Ports Organisation (ESPO) and gives ports clear objectives to aim for. Its implementation is independently reviewed by LRQA Nederland B.V. A PERS certification is valid for a period of 2 years.

3.1.8 Organisation Environmental Footprint (OEF) method

The Organisation Environmental Footprint (OEF) is a Life Cycle Assessment (LCA) based method to quantify the environmental impacts of organisations: this includes companies, public administrative entities and other bodies. The OEF method builds on existing approaches and international standards. OEF information is produced for the overarching purpose of seeking to reduce the environmental impacts of organisations taking into account supply chain activities (from extraction of raw materials, through production and use, to final waste management). This purpose is achieved through the provision of detailed requirements for modelling the environmental impacts of the flows of materials and energy, and the emissions and waste streams associated with the product portfolio of an organisation, throughout its life cycle. The OEF is complementary to other assessments and instruments, such as site-specific environmental impact assessments or chemical risk assessments.

At organisational level, the importance of the environmental impacts occurring in the supply chain is increasingly recognised. Standards and methods were created, such as the GHG Protocol Corporate Standard and its sectoral guidance or Global Reporting Initiative indicators. At EU level, the EMAS Sectoral Reference Documents include guidance on indirect impacts, highlighting also the use of LCA-methods for evaluation of the respective product portfolio (PP).

The rules provided in the OEF method enable to conduct OEF studies that are more reproducible, comparable and verifiable, compared to existing alternative approaches. However, comparability is an option only if the results are based on the same Organisation Environmental Footprint Sector Rules (OEFSR) and if the performance is normalized against a reference system (e.g. yearly turnover with reference to the product portfolio).

The requirements included in the OEF method may be applied in three possible situations:

(1) For OEF studies of organisations which do not fall within the scope of a valid OEFSR;

(2) For OEF studies of organisations which fall within the scope of a valid OEFSR. The requirements in this OEF method shall be used in addition to the requirements listed in the applicable OEFSR;

(3) For developing an OEFSR.

More information could be found in the European Commission Joint Research Center technical report "Suggestions for updating the Organisation Environmental Footprint (OEF) method".

3.1.9 Product Environmental Footprint (PEF) method

The Product Environmental Footprint (PEF) is a life cycle assessment (LCA) based method to quantify the environmental impacts of products (goods or services). It builds on existing approaches and international standards. The overarching purpose of PEF information is to enable to reduce the environmental impacts of goods and services taking into account supply chain activities (from extraction of raw materials, through production and use and to final waste management). This purpose is achieved through the provision of detailed requirements for modelling the environmental impacts of the flows of material/energy and the emissions and waste streams associated with a product throughout its life cycle.

The rules provided in the PEF method enable to conduct PEF studies that are more reproducible, comparable and verifiable, compared to existing alternative approaches. However, comparability is only possible if the results are based on the same Product Environmental Footprint Category Rules (PEFCR).

The requirements included in the PEF method may be applied in three possible situations:

(1) For PEF studies of products which do not fall within the scope of a valid PEFCR;

(2) For PEF studies of products which fall within the scope of a valid PEFCR. The requirements in this PEF method shall be used in addition to the requirements listed in the applicable PEFCR;

(3) For developing a PEFCR.

More information could be found in the European Commission Joint Research Center technical report "Suggestions for updating the Product Environmental Footprint (PEF) method".

4. Methodology to measure IoT and Edge Computing Carbon Footprint

This section provides possible IoT and edge computing business driven scenarios, examples and best cases that can be applied to address the IoT and edge computing high level challenges and objectives.

4.1 ICT Methods of measuring Carbon Footprint

4.1.1 Guidance for ICT companies setting science based targets mobile networks operators, fixed networks operators and data centers operator mobile networks operators, fixed networks operators and data centers operators

The most known ICT method of measuring carbon footprint is the GUIDANCE FOR ICT COMPANIES SETTING SCIENCE BASED TARGETS MOBILE NETWORKS OPERATORS, FIXED NETWORKS OPERATORS AND DATA CENTRES OPERATOR, published in a joint activity by GeSi, ITU-T, GSMA and SBTi in 2019.

The goal of this document is to support information and communication technology (ICTs) companies in setting science based targets for greenhouse gases (GHGs) according to a set of new decarbonisation pathways, described in detail in Recommendation ITU-T L.1470 'GHG emissions trajectories for the ICT sector compatible with the UNFCCC Paris Agreement'1 and aligned to the IPCC Special Report on 1.5°C and developed to be used as a sectoral target-setting approach by the Science Based Targets Initiative (SBTi).

This method provides guidelines for an ICT company for:

- Setting an ICT company sub-sector target for scope 1 and 2 emissions
- Setting a target for scope 3 emissions

4.1.2 ITU-T L.1400-series of Recommendations

ITU-T SG5 has developed several Recommendations of interest to such assessments. This includes the ITU-T L.1400-series of Recommendations, in particular:

- Recommendation ITU-T L.1410: Methodology for environmental life cycle assessments of information and communication technology goods, networks and services
- Recommendation ITU-T L.1420: Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations
- Recommendation ITU-T L.1440: Methodology for environmental impact assessment of information and communication technologies at city level
- Recommendation ITU-T L.1450: Methodologies for the assessment of the environmental impact of the information and communication technology sector

- Recommendation ITU-T L.1470 specification provides detailed trajectories of greenhouse gas (GHG) emissions for the global information and communication technology (ICT) sector and sub-sectors that are quantified for the year 2015 and estimated for 2020, 2025 and 2030. Moreover, it establishes a long-term ambition for 2050. The trajectories, the long-term ambition and the 2015 baseline have been derived in accordance with ITU-T L.1450 and through complementary methods in support of the 1.5C objective described in [b-IPCC 1.5] and in support of the Science-based Targets (SBT) initiative.

- Recommendation ITU-T L.1480 on "Enabling the Net Zero transition: Assessing how the use of ICT solutions impacts GHG emissions of other sectors" was published in December 2022. Currently, a joint activity has been started, where ITU-T SG5, ETSI TC EE and AIOTI are participating on revising the ITU-T L.1480 specification. The revised ITU-T L.1480 specification is expected to be published by end of 2024.

Moreover, this portfolio of assessment standards establishes impacts of ICT at three different levels:

- The first order effects: Direct environmental effects associated with physical existence, i.e., the raw materials acquisition, production, use and end-of-life treatment stages, and generic processes supporting those including such as use of energy use and transportations.

- The second order effects: The indirect impact created by the use and application of ICT, which includes changes of environmental load due to the use of ICT that could be positive or negative.

- The higher order effects: The indirect effects (including but not limited to rebound effects) other than first and second order effects occurring through changes in consumption patterns, lifestyles and value systems.

Of the above-mentioned Recommendations, ITU-T L.1450 would be of particular interest as it derives the methodology for deriving the ICT footprint at a sector level on a national, regional or global scale. ITU-T L.1450 also provides the methodological basis for ITU-T L.1470.

Moreover, ITU-T L.1480 provides a methodology for assessing how the use of ICT solutions impacts GHG emissions of other sectors. The methodology provides guidance on the assessment of the use of ICT solutions covering the *net* second order effect (i.e., the resulting second order effect after accounting for the emissions due to the first order effects of the ICT solution), and the higher order effects such as rebound.

By providing a structured methodological approach, it aims to improve the consistency, transparency and comprehensiveness of assessments of how the use of ICT solutions impact GHG emissions over time.

4.1.3 ITU: Carbon Data Intensity for network energy performance monitoring: (A.1) TD2141-R1

The International Telecommunication Union (ITU) is a specialised agency of the United Nations responsible for many matters related to information and communication technologies. ITU Study Group 5 is responsible for systems and networks for fixed, mobile, radio determination, amateur and amateur-satellite services. This study group has been focussing on carbon metrics for telecommunication networks. A new work item is started by ITU SG5, i.e., ITU T L.1333 (ex L.NCIe): carbon data intensity for network energy performance monitoring, focusing on the definition of the Network Carbon Index (NCI).

4.1.4 ETSI GS OEU 020: Operational energy Efficiency for Users (OEU); Carbon equivalent Intensity measurement; Operational infrastructures; Global KPIs; Global KPIs for ICT Sites

The European Telecommunications Standards Institute (ETSI) is an independent, not-for-profit, standardisation organisation in the field of information and communications. ETSI supports the development and testing of global technical standards for ICT-enabled systems, applications and services. In 2020 ETSI published a Global Key Performance Indicator (Global KPI) seeking to support the measurement of carbon intensity and energy efficiency of ICT sites including, but not limited to, data centres and operator sites.

The KPIs proposed in this document seek to support ICT facility operators to measure and monitor the carbon intensity and energy efficiency of a single site or a group of sites. The document addresses the equivalent carbon of following objectives defined in ETSI EN 305 200-2-1 for data centres, ETSI EN 305 200-2-2 for fixed networks and ETSI EN 305 200-2-3 for mobile networks using four objective KPIs:

- Greenhouse gas emissions
- Effectiveness of energy generation over greenhouse gas emissions
- Avoided greenhouse gas emission
- Reused greenhouse gas emission

As this KPI addresses a range of facilities they are not seeking to measure the carbon intensity of a single process against a particular output metric, but rather to measure the carbon footprint of the sites. It is not clear that the approach used by ETSI is compatible with the approach required for the Science Based Targets initiative methodology, which relies on the Greenhouse Gas Protocol as a means of measuring a companies' carbon emissions.

4.1.5 ETSI ES 203 228: Mobile network data energy efficiency

In 2017 ETSI also published a standard for measuring the energy efficiency of mobile networks. It should be noted that energy efficiency measures are related to, but distinct from carbon intensity measures. The standard they present deals with the definition of metrics and methods to measure energy efficiency performance of Mobile Radio Access Networks. They define mobile network energy efficiency as the ratio between the volume of data sent over the network over a set period of time and the energy consumption of the mobile network equipment during the same time.

4.1.6 Deutsche Telekom: Carbon intensity ESG KPI

Deutsche Telekom have developed a series of KPIs to measure their performance on climate change. Overall, they calculate their CO2 emissions across the Group in line with the market-based method of the Greenhouse Gas (GHG) protocol. To inform and guide their progress they have also developed the following KPIs:

- PUE (power usage effectiveness) metric serves as one indicator for enhancing the energy efficiency in our data centres. They determine this metric using the method recommended by The Green Grid Association, where PUE = Total Facility Power / IT Equipment Power.
- Energy Intensity and Carbon Intensity KPIs: These reflect DT's energy consumption and CO2 emissions in relation to the volume of data transmitted, thus demonstrating how their network's energy and emissions efficiency has developed in practice.

- Energy Intensity KPI = Energy consumption (millions of kWh) / IP data volume (millions of terabytes)
- Carbon intensity KPI = Emissions (millions of kg of CO2e) / IP data volume (millions of terabytes

4.1.7 BT carbon intensity

British Telecom (BT) have showcased their progress in reducing emissions by highlighting the reduction in the carbon intensity of their operations. In 2021 they highlighted that they had reduced the carbon emissions intensity of their operations by 57%. In their Digital Impact and Sustainability Report 2021 report (p24) they noted that this measure included their Scope 1 and 2 greenhouse gases per unit of gross value added calculated as EBITDA adjusted (before specific items) plus employee costs.

4.1.8 TIM carbon intensity

TIM also measures carbon intensity by using an indicator that establishes a relationship between the company's direct and indirect operational CO2 emissions (Scope 1 and Scope 2), measured in kg and generated by Company's activities, with the service offered to the customers (Tbits transmitted). The factors taken into consideration are the amount of data and voice traffic of the fixed/mobile network and direct emissions produced by using fossil fuels for heating, vehicles and self-production of electrical energy together with indirect emissions due to purchase and consumption of electrical energy from the grid.

4.1.9 Network Carbon Intensity

Another document that describes ICT Methods of measuring Carbon Footprint applied by mobile operators, is the Green Future Networks: Sustainability Challenges and Initiatives in Mobile Networks, published by NGMN in July 2021.

The key KPI mentioned in this document is the Carbon Intensity that shows the CO^2 emissions in proportion to the transmitted data volumes in Tera Bytes. It takes into account the total CO2 emissions for all energy sources such as gas, fuel, and grid electricity. The data volume is composed of the total transmitted IP data volume including VoIP, Internet, and IP-TV.

$$\text{Carbon Intensity (kg/Tera Bytes)} = \frac{Carbon\ dioxide\ equivalent}{IP\ data\ volume\ transmitted}$$

Another definition, similar to the one that is mentioned above is provided in: The Path to Net Zero for ICT Requires Technology Innovation:

$$\text{Network Carbon Intensity (kg CO2e/Tera Bytes)} = \frac{Total\ Carbon\ Emission}{Total\ Data\ Volume}$$

Where, the Network Carbon Intensity is defined as the ratio of the carbon quantity emitted by all equipment due to electricity consumption of a systematized network facility within a long period of normal operation (preferably one year) to the total amount of data volume handled by the facility in the same period.

4.1.10 Perspectives on ICT electricity use in 2030

A prediction study is presented in [https://pisrt.org/psr-press/journals/easl-vol-3-issue-2-2020/new-perspectives-on-internet-electricity-use-in-2030/] whose objective is to estimate the global electric power use in 2030 associated with computing and communication - the Information and Communication Technology (ICT) infrastructure - consisting of the use stage of end-user consumer devices, network infrastructure and data centres as well as the production of hardware for all.

There are conflicting messages regarding the path to a power consumption under control. Depending on scope, in 2020 ICT stands for up to 7% of the total global electricity use. Researchers have used different ways to measure, different ways to model and have also used different kind of statistics.

Truthfully it is challenging to make accurate predictions of global ICT electric power use as it is problematic to account for unknown unknowns. Most researchers agree that the data traffic - no matter how it is defined - will increase exponentially for several years as it has been doing the last decade. The disagreement concerns how fast and how large the ICT related power use will become in around 2030. Probably there is a parallel to linear or exponential thinking of how fast some entity will increase. Further discussions concern whether the anticipated extra electricity use by ICT really is a concern if the additional power can drive the corresponding share of sustainable electric power in specific grids used by the ICT infrastructure. There is not much expectation that future consumer ICT infrastructure can actually slow its overall electricity use until 2030. With the current knowledge, there are more circumstances pointing towards rising - 1-2 PWh - power consumption of ICT than slowing or flattening.

4.1.10.1 The Overall Methodological Approach

Overall methodological approach presented here consists of the following steps to setting of the modelling framework leading to total electricity used per year:

- Consumer devices production and use: A framework is set up that includes the kind of consumer devices to be included, the units of these consumer devices produced each year from 2010 to 2030, their lifetimes, their production electricity per unit, their average annual electricity usage, and the annual electricity efficiency improvements to be achieved year by year in production and use.

- Fixed access networks (FAN) use: FAN consists of Fixed access wired and Fixed access Wi-Fi. A framework is set up based on the expected annual growth of fixed access wired data traffic and fixed access Wi-Fi data traffic between 2010 and 2030 and the improvements of electricity efficiency to be expected year by year from 2010 to 2030, and assumed known values for the 2010–2012 electricity of the defined FAN scope. The same framework is applied to both fixed access types.

- Wireless access networks (WAN) use: A framework is set up based on the annual growth of voice traffic; the growth of mobile data traffic; electricity used per traffic unit for each of voice; second-generation (2G) wireless telephone technology data, third generation (3G) data, fourth generation (4G) data and fifth generation (5G) data; share of the before mentioned technologies of the total wireless traffic year by year from 2010 until 2030; and improvements of electricity efficiencies to be achieved year by year.

- Data centres use: A framework is set up based on expected annual growth of global data centre Internet Protocol (IP) traffic between 2010 and 2030, electricity used per traffic unit, and improvements of electricity efficiencies to be achieved year by year.

- Networks and Data centre production: The estimation is based on the share of the use-stage electricity of the life cycle electricity of networks and data centres. The production electricity is correlated fully to the use-stage electricity.
- Global electricity: The estimation is based on a known starting value for 2010 and an annual growth rate for non-CT electricity. CT electricity (ECT) grows according to the present investigation.
- Renewable electricity: The estimation is based on known starting value for 2010 and an annual growth rate.
- GHG intensity of the global electricity mix: The estimation is based on a combination of GHG intensities of (annually changing) shares of non-renewable and renewable electricity.
- GHG global emissions: The estimation is based on a 2010 starting value of 46 Gigatons and a 2% annual growth rate until 2030, for non-CT GHG emissions. CT electricity GHG emissions grow according to the present investigation.

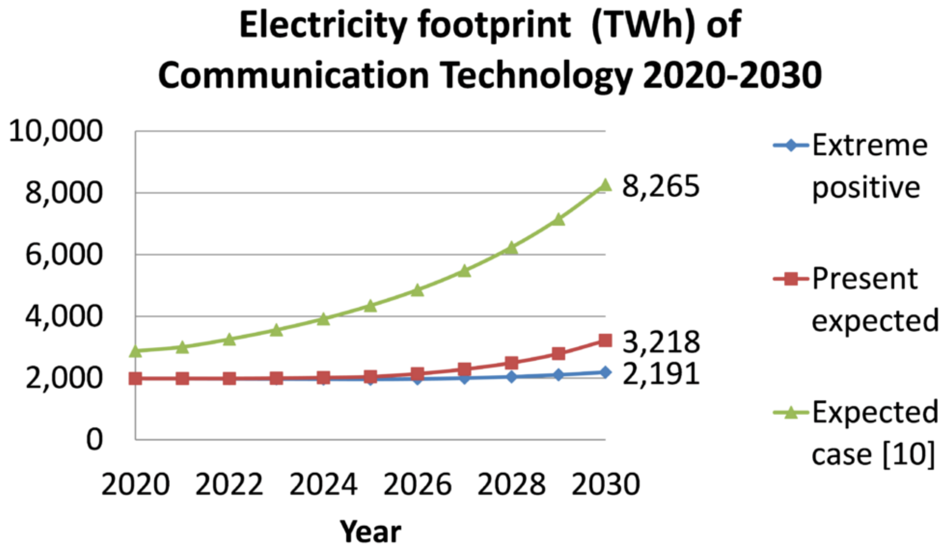


Figure 6: **Trends for ICT electric power use 2020 to 2030, Source**

It is very difficult to fathom the circumstances under which the electric power use of communication and computing (the ICT infrastructure) cannot rise considerably until 2030. According to the authors of the prediction study, the total TWh will develop along an average of the best and expected scenario with a strong leaning to the best case.

4.1.10.2 Calculating Digital Emissions - design a carbon calculation tool

Calculating greenhouse gas emissions from digital products and services requires taking into account embodied energy and materials used to manufacture the product or service, as well as the energy used to host the product across servers, cloud containers, and content delivery networks, especially taking into account the entire product's life cycle. Furthermore, determining the energy needs of end-users interacting with a product or service across devices over time is challenging.

Digital products and services have many components across multiple (often closed) systems, each of which have their own energy and resource requirements, and a blanket one-size-fits-all solution is elusive.

Wholegrain Digital and Mightybytes, collaborated with Medina Works, EcoPing, and the Green Web Foundation to define new open standards for estimating carbon emissions from digital products and services to help anyone interested in designing digital carbon calculation tools— like Website Carbon, Ecograder, or Ecoping.Earth, for instance— with a methodology that provides consistent results.

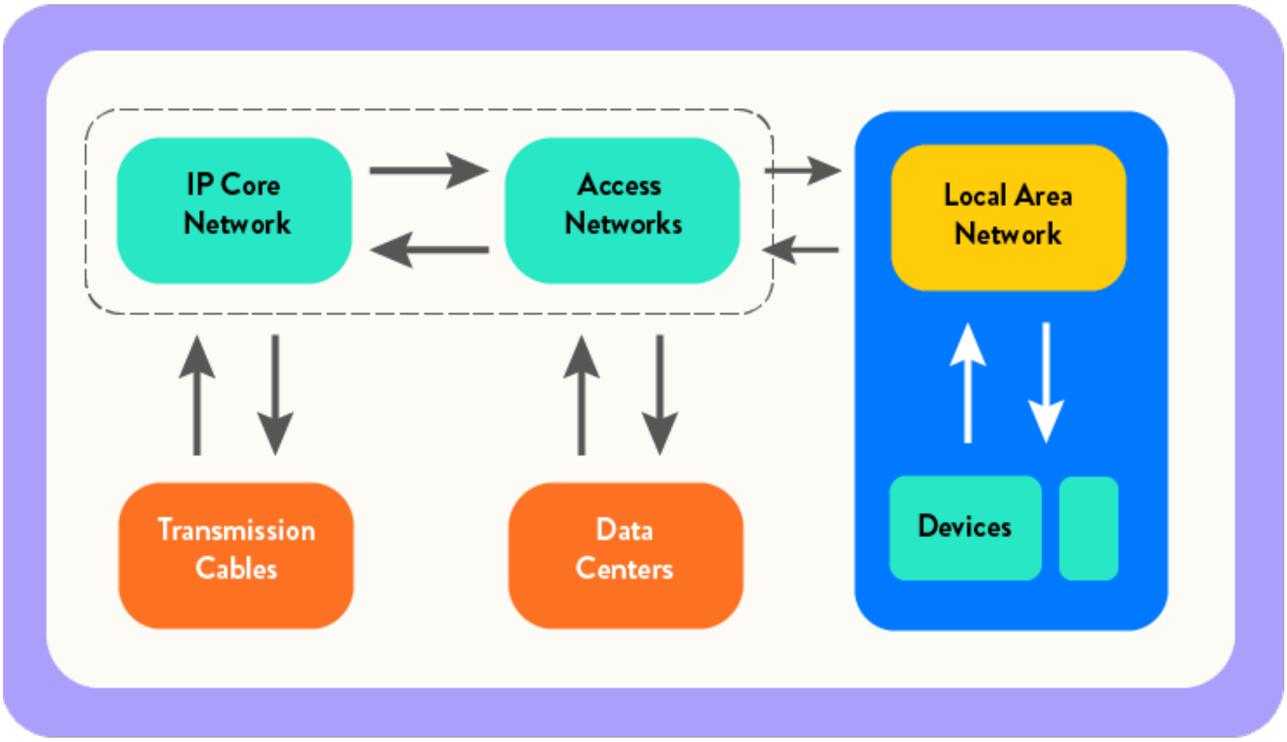


Figure 7: An illustration showing a network system diagram with devices (in teal, bottom right) on a Local Area Network (in yellow, top right) connecting (shown by arrows) to IP and Access Networks (in teal, top left),Source

The challenges in precisely calculating digital emissions calculations are found at network system borders. With overly narrow boundaries, a realistic depiction of energy utilization is difficult. Broad system boundaries, on the other hand, introduce more complicated variables into the equation, particularly when closed network components such as LANs and end-user devices are incorporated. The higher the probable margin of error, the wider the system's boundaries are.

In the provided approach of https://sustainablewebdesign.org/calculating-digital-emissions/, authors used the broadest system boundaries possible to reflect a full carbon footprint, dividing the impact for each sub-system to provide further information. To acquire a balanced assessment of the present data, authors also cross-referenced a number of research (see 'References' below).

System Segments

The system segments and percentages used are based on Anders Andrae’s study, referenced in §4.1.9, that can be found in the raw data sheet that accompanies the study:

- Consumer device use: end users interacting with a product or service. This accounts for an estimated 52% of the system. Returning visitors are assumed to be 25%, loading 2% of data.
- Network use: data transferred across the network. This accounts for an estimated 14% of the system.

- Data centre use: energy required to house and serve data. This accounts for an estimated 15% of the system.

- Hardware production: embodied energy used in the creation of embedded chips, use of data centres, use of networks, and the use of consumer communication devices. This accounts for an estimated 19% of the system.

Balancing the Numbers

Published approaches can have narrow system boundaries with greater energy estimates, while others can have broader system boundaries with lower energy estimates, according to the literature.

This posed a significant challenge:

- in case of overestimation, organizations can get caught in the trap of thinking they're doing more than they actually are. This can become especially challenging when PR teams get involved.

- On the other hand, underestimating energy use could lead an organization to the conclusion that the effort is not worth an organization's time because it is not impactful enough.

Numbers from the Andrae study, when cross-referenced with [*Investigating the Inconsistencies Among the Energy and Energy Intensity Estimates of the Internet, Swiss Federal Office of Energy SFOE, June 2021*], showed similar (though slightly higher) results. As of April 2022, carbon intensity figures were updated to match those from [https://ember-climate.org/data/data-explorer/], which provides more recent figures.

4.1.10.3 Calculating Digital Emissions: The Formulas

This methodology is a standardized approach and does not account for all variables of any digital product or service. As an open methodology, this may be adapted to incorporate factors relevant to a specific product or service.

The Key Metric

The selected primary metric for calculating the carbon footprint is kWh/GB, because this metric is easy to measure for most web services and is the unit of measurement used in the bulk of studies on the subject.

Energy Consumption

Data for calculating energy usage was collected from the Andrae study's raw data for the "Expected 2020 scenario."

Carbon Intensity

The default figure used for carbon intensity is the global average carbon intensity of electricity (442g/kWh), which is pulled from the CO^2 intensity dataset for "World" of [https://ember-climate.org/data/data-explorer/].
This can be replaced by numbers for the specific country or state when this is known,

Data Centre Energy

Data flow "inside data centres" and "between data centres," according to the approach, are sub-processes of the work required to run online services for end users. The figures are based on data flow to end users.

Specific Data Points

Used data points to define the calculations are detailed below:

- Annual Internet Energy: 1988 TWh
- Annual End User Traffic: 2444 EB
- Annual Internet Energy / Annual End User Traffic = 0.81 TWh/EB or 0.81 kWh/GB
- Carbon factor (global grid): 442 g/kWh
- Carbon factor (renewable energy source): 50 g/kWh

Emissions Calculation Formulas

Using the above data, the provided formulas are:

Energy per visit in kWh (E):

E = [Data Transfer per Visit (new visitors) in GB x 0.81 kWh/GB x 0.75] + [Data Transfer per Visit (returning visitors) in GB x 0.81 kWh/GB x 0.25 x 0.02]

Emissions per visit in grams CO^2e (C):

C = E x 442 g/kWh (or alternative/region-specific carbon factor)

Annual energy in kWh (AE):

AE = E x Monthly Visitors x 12

Annual emissions in grams CO2e (AC):

AC = C x Monthly Visitors x 12

Annual Segment Energy:

Consumer device energy = AE x 0.52

Network energy = AE x 0.14

Data centre energy = AE x 0.15

Production energy = AE x 0.19

Annual Segment Emissions:

Consumer device emissions = AC x 0.52

Network emissions = AC x 0.14

Data centre emission = AC x 0.15

Production emission = AC x 0.19

Guidance for Using this Methodology

For their own reporting reasons, the technique models the emissions from a system attributable to an organization. It is made to work with well-known standards such as the GHG Protocol Corporate Standard, to enable a company to model the environmental impact of digital services, usually as part of its Scope 3, or supply chain emissions. If greater accuracy data is available for each of the four main sections—consumer device network and data centre usage, and embodied carbon involved with building the hardware—the model is also built to permit substituting some average estimates.

References:

- New Perspectives on Internet Electricity Use in 2030, Anders S.G. Andrae, June 2020.
- Investigating the Inconsistencies Among the Energy and Energy Intensity Estimates of the Internet, Swiss Federal Office of Energy SFOE, June 2021.
- The Overlooked Environmental Footprint of Increasing Internet Use, Renee Obringer, Benjamin Rachunok, Debora Maia-Silva, Maryam Arbabzadeh, Roshanak Nateghi, Kaveh Madani, April 2021.

4.1.11 Green IoT and Edge AI as Key Technological Enablers for a Sustainable Digital Transition towards a Smart Circular Economy: An Industry 5.0 Use Case

Internet of Things (IoT) can help to pave the way to the circular economy and to a more sustainable world by enabling the digitalization of many operations and processes, such as water distribution, preventive maintenance, or smart manufacturing. Paradoxically, IoT technologies and paradigms such as edge computing, although they have a huge potential for the digital transition towards sustainability, they are not yet contributing to the sustainable development of the IoT sector itself. In fact, such a sector has a significant carbon footprint due to the use of scarce raw materials and its energy consumption in manufacturing, operating, and recycling processes. To tackle these issues, the Green IoT (G-IoT) paradigm has emerged as a research area to reduce such carbon footprint; however, its sustainable vision collides directly with the advent of Edge Artificial Intelligence (Edge AI), which imposes the consumption of additional energy. This article deals with this problem by exploring the different aspects that impact the design and development of Edge-AI G-IoT systems. Moreover, it presents a practical Industry 5.0 use case that illustrates the different concepts analysed throughout the article. Specifically, the proposed scenario consists in an Industry 5.0 smart workshop that looks for improving operator safety and operation tracking. Such an application case makes use of a mist computing architecture composed of AI-enabled IoT nodes. After describing the application case, it is evaluated its energy consumption and it is analysed the impact on the carbon footprint that it may have on different countries. Overall, this article provides guidelines that will help future developers to face the challenges that will arise when creating the next generation of Edge-AI G-IoT systems.

Reference: Use case Industry, https://www.mdpi.com/1424-8220/21/17/5745

4.1.12 24-7 Carbon Free Metrics

Beyond the methodologies developed previously a new privately led initiative was initiated through last COP26 to agree on more ambitious metrics related to the assessment of scope 2 emissions and the assessment of carbon intensity and emission related to the energy consumed by any distributed energy resources assets. While previous approaches account for average carbon intensity for the electricity consumed, this new approach aims at linking emission calculations with the origin of the electricity produced in real-time through the energy system.

The initiative is currently supported by a large number organisation piloting the approach in their own domain:

Figure 8: 24-7 Carbon Metrics supporters

The methodology considered aims at working collectively across sectors to drive the electricity system towards full decarbonization. The initiative targets to have all electricity stakeholders in the electricity ecosystem from utilities to end users through corporate purchases of clean electricity working in a same direction maximising usage of Renewable electricity every hour of the day considering the specific energy mix of any grid area that energy resources are connected with.

Key principles have been defined to guide these 24-7 metrics which have started to be used in the data centre sector as a starting point:

1. Time based matching of Distributed Energy Resource consumptions: the metrics is a significant step versus historical renewable certification which only accounts for annual electricity consumption versus renewable generation values. With 24/7 carbon free energy metrics, calculations take into account when the electricity is generated, considering the carbon footprint of electricity consumption varies hourly depending on the mix of electricity generation sources operating in a particular hour. The objective of this metric is to encourage energy consumers to ensure that each hourly consumptions are fully matched by carbon free electricity generation. Focusing on hourly measurements helps connect consumer sustainability goals to the physical reality of local energy systems;

2. Local procurement: while 100% renewable energy achievement is based on global renewable energy procurements, using 24-7 carbon free energy metrics is considering equipment consumption in view of the specific constraints of the every local electricity systems that assets are connected with. For large IoT systems deployed across various regions and locations, the emissions and carbon intensity to be considered should consider local grid carbon intensity which Grid Operators will soon be mandated to publish as part of the new Renewable Energy Directive. Focusing on local energy system constraints is the only way to drive electricity related emissions through the consumer prospective and commitment towards NetZero objectives;
3. Technology neutrality: using 24-7 carbon free energy metrics allows to consider all carbon free energy technologies as defined through the European taxonomy in view of their real impact in enabling decarbonization of local energy systems. As existing sources like hydro and nuclear power make significant carbon free contributions to grids, these should also be considered as part of the metrics calculation;
4. Additionality: it is important to consider 24-7 Carbon free consumptions as further incentive to deploy new clean renewable through 24-7 guaranteed renewable Power Purchase Agreements. The plan is to accompany this methods with contracts enabling new renewable projects to be developed. As clean energy market matures, these contracts can consider in repowering existing generation facilities, extending the life of clean energy assets as well as new renewable production plant investments. Additional criteria and due diligence should be put in place to ensure all procurements ultimately serves the objective of energy system decarbonation;
5. Local grid carbon intensities are central to associated calculations : the ultimate goal of the metrics is to accelerate the decarbonation of the electricity system through “a demand pool” from consumers and their associated consumption assets. The amount of Carbon free electricity in the electricity mix of local grids are therefore included in the calculation methodology. The approach aims at increasing the amount of clean energy imported from the grid through local procurements.

Two main metrics are considered as part of this methodology:

1. A Carbon Free energy score measuring the degree to which each hour of electricity consumption of an asset connected with a given local grid is matched with carbon free energy. The carbon free energy is calculated considering the carbon free electricity bilaterally contracted as well as the carbon free electricity obtained from local grids
2. A second metrics consisting in avoided emission (tCO2 e) measure the carbon emission impact of procurement decisions and is used to help prioritizing procurement activated across geographies given the distribution of consuming energy assets.

As an example, the enclosed diagram represents the annual Carbon clock used by Google for its data centre in Lenoir North Carolina during 2019

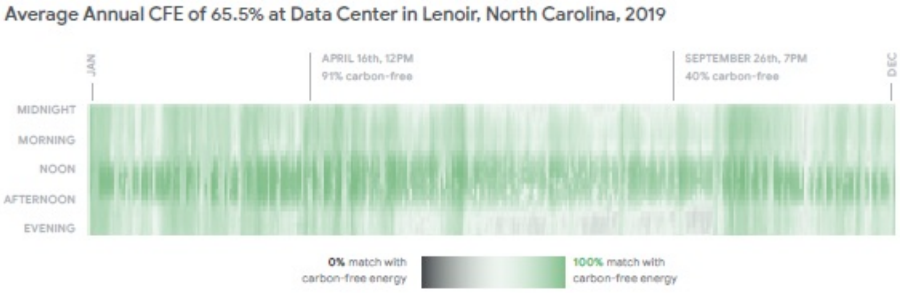


Figure 9: Annual carbon clock used by Google for its data centre in Lenoir North Carolina during 2019

As an example in energy domain, the 24-7 carbon free metrics methodology is particularly fit for purpose for evaluating the carbon emission and the carbon free energy scope of any consumption site connected to the energy system. Google and Microsoft are excellent examples of such deployment in their data centre making use of data aggregated through electricityMap.org.

Moving forward the next Renewable energy directive will further facilitate such deployment through the obligation put on local distribution grid operator to provide real-time information on the carbon intensity of their local electricity system while favouring renewable Power purchase agreements to accelerate deployment of wind and solar assets. These approaches will naturally complement efforts to improve the flexibility in the consumption of these sites, where we should expect smart consumption and local storage will be combined to dynamically adjust to changing electricity prices and carbon intensity.

In the Edge/IoT and cloud computing space particularly where every hardware component is self-metered, networked and controllable, first initiatives have been piloted to adjust the hardware computing intensity with external energy conditions whose best practices need to be expanded as part of the new Digital chapter for energy.

5. Methodology to measure Carbon Footprint of Industrial domains (smart networks, smart cities/buildings, connected mobility, precision farming, smart manufacturing)

This section presents recommendations for a methodology to measure the carbon footprint in key industrial domains. All of the approaches for measuring the carbon handprint of sectors that the IoT and Edge computing can support require the measurement of the reduction in the carbon footprint of these industries to act as a baseline against which to assess the potential benefits that IoT and Edge Computing solutions can offer. As described in Section 3 there is large range of methodologies for measuring carbon footprints. It is expected that there will be complex to select one or methodology from the existing methods of measuring the carbon footprint. A more realistic approach is to derive a list with selection criteria that can be used in order to select one or more existing methodologies.

5.1 Selection criteria for methodologies on measuring carbon footprint

This section provides a list with generic multi-industrial sector criteria on selecting one or more existing methodologies on measuring carbon footprint.

- Recommended to use one of the standardised methods, prioritising international/global standardised methods
- Depending on whether SBTi targets need to be covered?

  If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3
- Depending on the use case and the applied industrial domain
- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)
- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation
- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint

5.2 Electricity

The production, transport and use of energy makes up almost three quarters of global GHG emissions, with 31.9% of total Greenhouse Gas (GHG) emissions attributed to electricity, representing one of the greatest opportunity areas for climate tech. Rapid scaling of low-carbon energy is critical to curbing emissions and keeping the world on track to meet the Paris Agreement goals. Year-on-year unit costs of renewables have continued to fall, while energy efficiency has increased, driven by learning curves and economies of scale. Overall early stage innovation investment has been lower compared to other challenge areas, reflecting the relative maturity of wind and solar, which have transitioned to debt, project and other forms of financing. Investment in early stage energy-related innovation cover a range of innovation priorities, including alternative fuels, grid management tech, low GHG extraction, renewable energy generation, energy storage, high efficiency electronics and smart management, nuclear generation and waste heat capture/conversion/storage. Investment data from venture capital and private equity in the energy transition is shown in **Figure 10**.

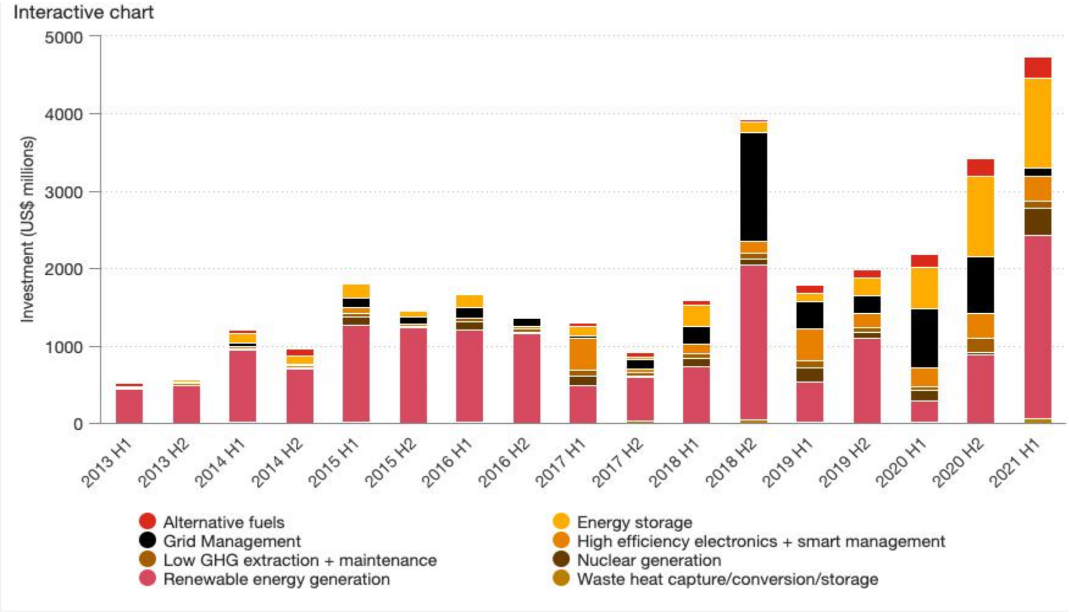


Figure 10: Early stage investment in the energy sector over time, Source: State of Climate Tech 2021

5.2.1 Electricity: Selection criteria for methodologies on measuring carbon footprint

- Recommended to use one of the standardised methods, prioritising international/global standardised methods

- Depending on whether SBTi targets need to be covered?

    If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3

- Depending on the carbon footprint requirements that the electricity use case impose on the devices/entities that enable the realisation of this use case, such as:

    Real time versus non-real time performance requirements imposed by the electricity use case

    C2B versus B2B market where the electricity use case is deployed

    Critical versus non-critical environment where the electricity use case is deployed

    Number of renewable sources integrated in the electricity use case

    Type of electricity grid, such as e2e smart grid versus neighbouring power grid versus home power grid

- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)

- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation

- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint

5.3 Mobility and transport

Transport is one of the fastest growing sources of emissions globally, having increased by 71% since 1990, accounting for 16.2% of global emissions. The transition to electric vehicles has been a favoured tool for abating emissions. In addition, developments in green hydrogen in terms of synthetic fuels for transport are expected to be a key driver of the future hydrogen economy. Business-as-usual continued growth in passenger and freight activity could outweigh all mitigation efforts unless transport emissions can be strongly decoupled from GDP growth. Electrifying transport systems remains a vital part of the net zero transition. Investment data from venture capital and private equity in the mobility and transport transition is shown in **Figure 11**.

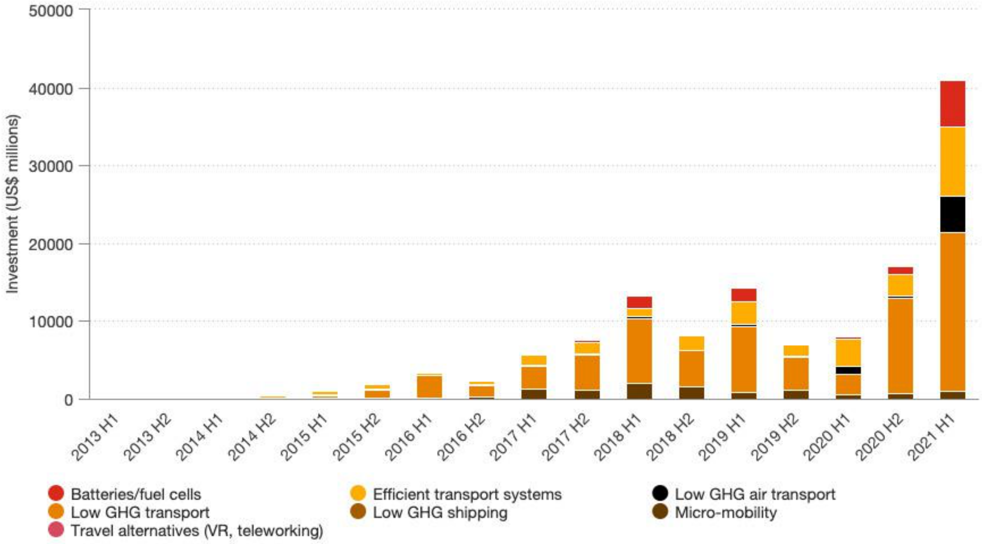


Figure 11: **Investment in the mobility and transport sector over time, Source: State of Climate Tech 2021**

5.3.1 Mobility and transport: Selection criteria for methodologies on measuring carbon footprint

- Recommended to use one of the standardised methods, prioritising international/global standardised methods
- Depending on whether SBTi targets need to be covered?

    If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3

- Depending on the carbon footprint requirements that the mobility and transport use case impose on the devices/entities that enable the realisation of this use case, such as:

    Real time versus non-real time performance requirements imposed by the mobility and transport use case

    C2B versus B2B market where the mobility and transport use case is deployed

    Critical versus non-critical environment where the mobility and transport use case is deployed

    Number of renewable sources integrated in the mobility and transport use case

    Type of mobility and transport domain-type-infrastructure, such as road, rail, air, maritime, or a combination of these

    Type of the vehicle (electric or non-electric)

- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)
- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation
- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint

5.4 Food, Forestry and Biodiversity

Agriculture, forestry and land-use systems are responsible for 18.4% of global GHG emissions, with the largest contribution coming from agriculture and land use activities. Financial investment in plant-based meat and dairy alternatives is growing, driven by consumer demand and media coverage. The next generation of solutions is expected to focus on lab-grown meat, insect proteins and genetic editing. Further attention is required to reduce food loss and waste and create more sustainable packaging solutions, which could also extend the shelf life of produce. These issues are critical, with food loss and waste making up approximately a quarter of food system GHG emissions. Investment data from venture capital and private equity in the food, forestry and biodiversity transition is shown in **Figure *12***

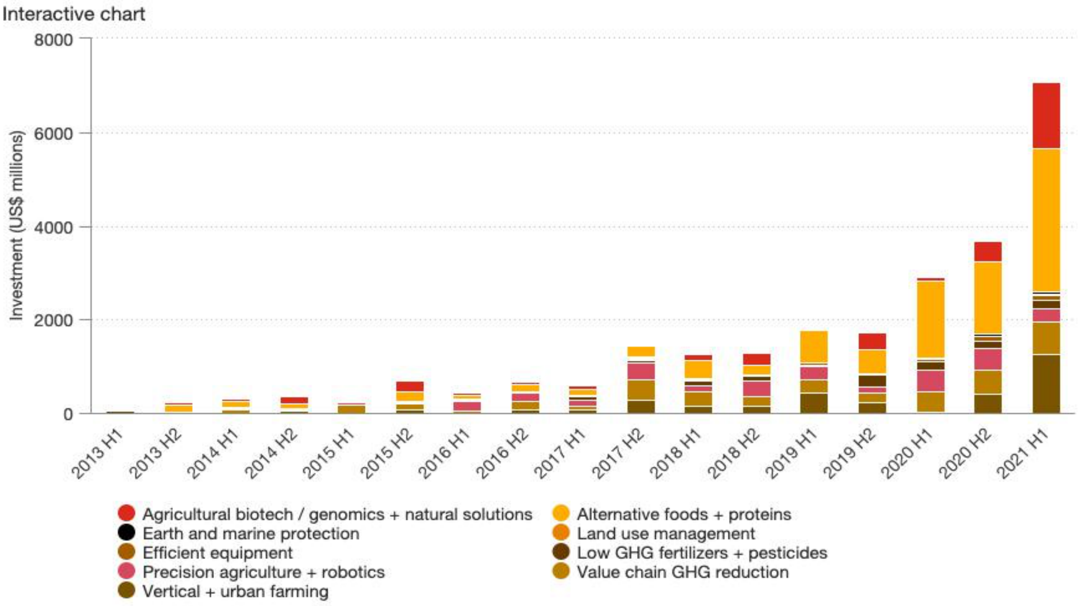


Figure 12: Investment in the food, agriculture and land use sector over time, Source: State of Climate Tech 2021

5.4.1 Food, Forestry and Biodiversity: Selection criteria for methodologies on measuring carbon footprint

- Recommended to use one of the standardised methods, prioritising international/global standardised methods

- Depending on whether SBTi targets need to be covered?

    If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3

- Depending on the carbon footprint requirements that the food, forestry and biodiversity use case impose on the devices/entities that enable the realisation of this use case, such as:

    Real time versus non-real time performance requirements imposed by the food, forestry and biodiversity use case

    C2B versus B2B market where the food, forestry and biodiversity use case is deployed

    Critical versus non-critical environment where the food, forestry and biodiversity use case is deployed

    Number of renewable sources integrated in the food, forestry and biodiversity use case

    Type of food, forestry and biodiversity domain-type-infrastructure, such as food, forestry and biodiversity or a combination of these

- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)

- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation

- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint

5.5 Industry and manufacturing

Global industry and manufacturing is responsible for 29.4% of GHG emissions and is one of the most difficult challenge areas to abate due to the need to retrofit, upgrade and replace existing equipment and transform the associated supply chains. Emissions result from energy used in manufacturing and industrial processes and the production of materials; they are also generated directly by industrial processes themselves (such as CO2 emitted during a chemical reaction). Therefore, an absolute reduction in emissions from industry and manufacturing will require deployment of a broad set of mitigation options, including more efficient use of resources, more efficient processes and improved energy efficiency. Investment data from venture capital and private equity in the industrial manufacturing transition is shown in **Figure *13***.

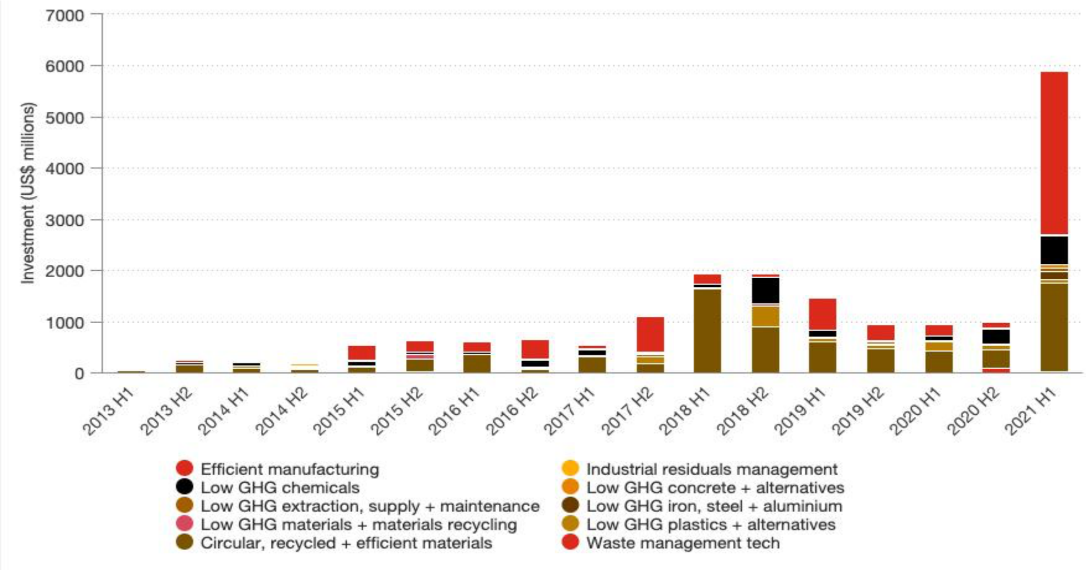


Figure 13: Investment in the industrial manufacturing sector over time, Source: State of Climate Tech 2021

5.5.1 Industry and manufacturing: Selection criteria for methodologies on measuring carbon footprint

- Recommended to use one of the standardised methods, prioritising international/global standardised methods
- Depending on whether SBTi targets need to be covered?

    If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3

- Depending on the carbon footprint requirements that the industry and manufacturing use case impose on the devices/entities that enable the realisation of this use case, such as:

    Real time versus non-real time performance requirements imposed by the Industry and manufacturing use case

    C2B versus B2B market where industry and manufacturing use case is deployed

    Critical versus non-critical environment where the industry and manufacturing use case is deployed

    Number of renewable sources integrated in the industry and manufacturing use case

    Type of Industry and manufacturing domain-type-infrastructure, such as shop/factory floor versus office floor, single factory versus multiple factories

- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)
- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation
- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint

5.6 Building environment

Buildings and construction are responsible for 20.7% of GHG emissions. Operational emissions account for nearly two-thirds of this, while the remainder comes from embodied carbon emissions, or the ‘upfront’ carbon that is associated with materials and construction processes.

To eliminate the carbon footprint of the building environment, both buildings and materials must become more efficient, smarter and cheaper. Small-scale efficiencies, such as improvements in heating, lighting or appliances, will also play an important role.

Given the breadth of the building environment’s impact, more pivotal solutions will also be needed: for example, building-level electricity and thermal storage, innovative construction methods and transformative circularity, or sensor-led smart building management. Investment data from venture capital and private equity in the building environment transition is shown in **Figure *14***.

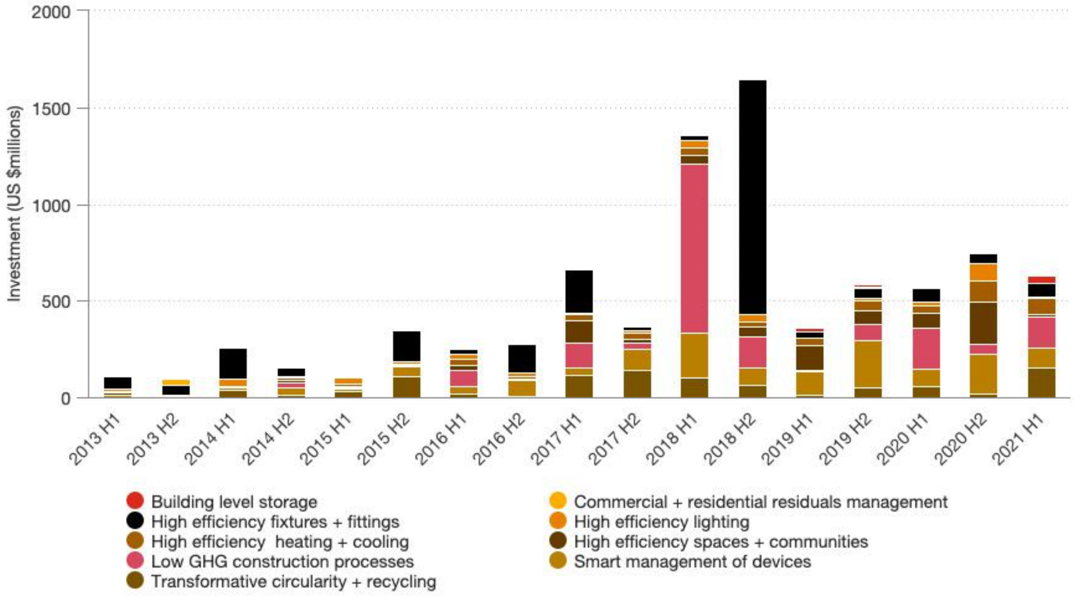


Figure 14: Investment in the Building Environment over time, Source: State of Climate Tech 2021

5.6.1 Building environment: Selection criteria for methodologies on measuring carbon footprint

- Recommended to use one of the standardised methods, prioritising international/global standardised methods
- Depending on whether SBTi targets need to be covered?

  If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3

- Depending on the carbon footprint requirements that building use case impose on the devices/entities that enable the realisation of this use case, such as:

  Real time versus non-real time performance requirements imposed by the building use case

  C2B versus B2B market where building use case is deployed

  Critical versus non-critical environment where the building use case is deployed

  Number of renewable sources integrated in the building use case

  Type of building domain-type-infrastructure, such as a house (standalone building) versus a flat (unit or townhouse or apartment), versus a factory building

- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)
- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation
- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint

5.7 Carbon removals (sinks)

Carbon removal refers to processes for absorbing CO2 out of the atmosphere, with methods ranging from planting trees to building industrial carbon-absorption machinery. Processes for removing carbon from the atmosphere include:

- Bioenergy with carbon capture and storage (BECCS): atmospheric CO2 is absorbed by plants and trees as they grow, and then the plant material (biomass) is burned to produce bioenergy. The CO2 released in the production of bioenergy is captured before it reaches the atmosphere and stored in geological formations deep underground on very long time scales. Since the plants absorb CO2 as they grow and the process does not emit CO2, the overall effect can be to reduce atmospheric CO2.

- Afforestation (planting new trees) and reforestation (replanting trees where they previously existed) are also considered forms of CDR because they enhance natural CO2 'sinks'.

- Chemical capture: Another technique uses chemical processes to capture CO2 from the air and store it away on very long time scales. In a process known as direct air carbon capture and storage (DACCS), CO2 is extracted directly from the air and stored in geological formations deep underground. Air is drawn into the DACCS system using an industrial scale fan. Liquid DACS systems pass the air through a chemical solution which removes the CO2 and returns the rest of the air back into the atmosphere. Solid DACS systems captures CO2 on the surface of a filter covered in a chemical agent, where it then forms a compound. The new compound is heated, releasing the CO2 to be captured and separating it from the chemical agent, which can then be recycled. The captured CO2 can then be compressed under very high pressure and pumped via pipelines into deep geological formations. This permanent storage process is known as 'sequestration'. There are 15 DACS plants currently in operation worldwide – Climeworks operates three in Switzerland, Iceland and Italy. Together, these small-scale plants capture approximately 9,000 tonnes of CO2 per annum. The first large-scale plant, currently being developed in the Permian Basin, Texas, is expected to capture 1,000,000 tonnes (one megaton) per annum when it becomes operational in 2025.

In addition to carbon removal initiatives, technologies are being developed to capture emissions from energy intensive installations before they are emitted into the atmosphere. These are referred to Carbon Capture, Utilisation and Storage (CCUS) technologies. CCUS technologies are not referred to as being carbon 'sinks' as they do not absorb carbon from the atmosphere, but rather they stop it from being emitted. It involves the capture of CO2 from large point sources, including power generation or industrial facilities that use fossil fuels. If not being used on-site, the captured CO2 is compressed and transported by pipeline, ship, rail or truck to be used in a range of applications or injected into deep geological formations (including depleted oil and gas reservoirs or saline formations) which trap the CO2 for permanent storage.

5.7.1 Carbon removals (sinks): Selection criteria for methodologies on measuring carbon footprint

- Recommended to use one of the standardised methods, prioritising international/global standardised methods

- Depending on whether SBTi targets need to be covered?

    If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3

- Depending on the carbon footprint requirements that carbon removals (sinks) use case impose on the devices/entities that enable the realisation of this use case, such as:

    Real time versus non-real time performance requirements imposed by the building use case

    C2B versus B2B market where carbon removals (sinks) use case is deployed

    Critical versus non-critical environment where the building use case is deployed

    Number of renewable sources integrated in the carbon removals (sinks) use case

    Type of carbon removals (sinks) domain-type-infrastructure, such as a carbon removal versus carbon sinks

- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)

- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation

- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint

6. Methodology to measure benefit of IoT and Edge Computing for Carbon Footprint reduction in industrial domains

6.1 Selection criteria for methodologies on measuring the benefit of IoT and Edge Computing for Carbon Footprint reduction in industrial domains

This section provides a list with generic multi-industrial sector criteria on selecting one or more existing methodologies on measuring the benefit of IoT and Edge Computing for Carbon Footprint reduction in industrial domains.

- Recommended to use one of the standardised methods, prioritising international/global standardised methods
- Depending on the IoT and Edge Computing Infrastructure to be used to reduce the carbon footprint
- Depending on whether there is a requirement to measure in addition to carbon footprint as well the electrical energy footprint
- Depending on whether SBTi targets need to be covered?

  If yes, depends on covering SBTi Scope1 and/or SBTi Scope 2 and/or SBTi Scope 3
- Depending on the use case and the applied industrial domain
- What is the goal of measurement (e.g. for the operational purposes, lifecycle, production etc.)
- Depending on whether the methodology needs to provide the necessary requirements imposed by the SPI/Product Passport regulation

6.2 Existing studies and case studies on measuring ICT benefits in industrial domains

6.2.1 Studies on potential energy savings due to the use of ICT by domains

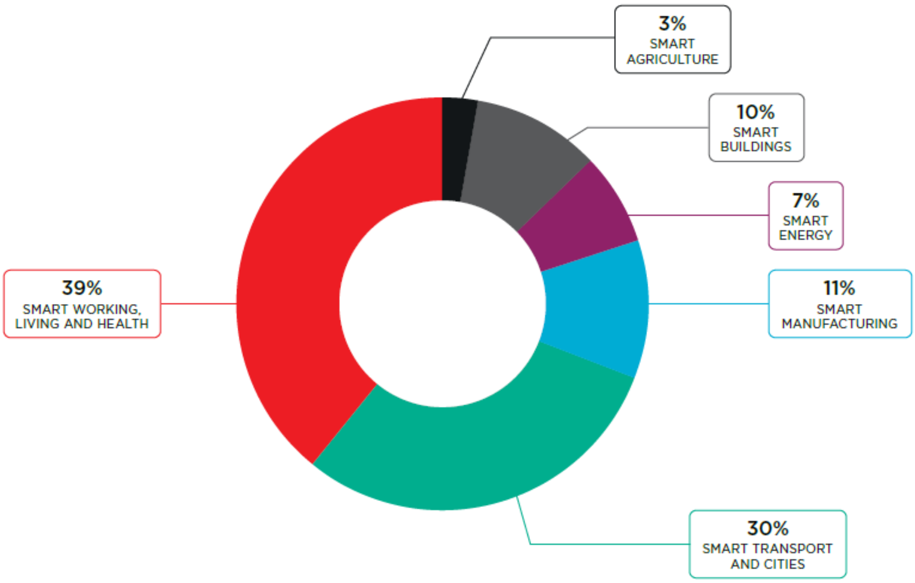


Figure 15: Potential impact of ICT technologies on energy savings by domains

Source: GSMA – The enablement effect – enabled avoided carbon emissions by category in 2018

The relevant factors for potential avoided carbon emission reduction using ICT technologies are among others, see **Figure *15***:

Saving in buildings: smart metering and building management systems to reduce gas and energy consumption (lighting, cooling or heating) and encourage behaviour changes.

Saving in transport and logistics: through mobile communication technology – telematics improves route optimisation and reduces fuel consumption.

Savings in production, manufacturing, farming: the use of mobile communication technology and IoT systems for storage, inventory and process management increase the efficiency of all processes as also reduces the energy needed for lighting or/and cooling or watering.

6.2.2 Case studies

In the following some case studies show the real potential of using ICT in their business.

6.2.2.1 Case Study smart buildings

GSMA (2019). “Take Things Further” Smart Energy Case Study Internet of Things. [online] GSMA.

Source: https://www.gsma.com/iot/wp-content/uploads/2019/09/Beyond-Connectivity-Telefonica-Smart-Energy-case-study.pdf

6.2.2.2 Case Study health

GSMA (2015). Mobile Policy Case Studies Policy in Practice. [online] pp.9–13.

Source: https://www.gsma.com/publicpolicy/wp-content/uploads/2016/09/GSMA2015_Report_MobilePolicyCaseStudies_English.pdf

Nhsconfed.org. (2017). NHS Statistics, Facts and Figures

Source: https://www.nhsconfed.org/resources/key-statistics-on-the-nhs

BT (2012). NHS N3 Network Case Study

Source: https://business.bt.com/solutions/resources/nhs-n3-infrastructure/

GeSI Smarter 2030 Health

Source: https://smarter2030.gesi.org/#health

6.2.2.3 Case Study smart transport

Telia Company (2018). Telia Company in Co-Operation to Lower Emissions from Transports.

Source: https://www.teliacompany.com/en/news/news-articles/2018/telia-company-in-co-operation-to-lower-emissions-from-transports/

E-Ferry (Geographical Islands FlexibiliTy – GIFT Project)

Source: http://www.gift-h2020.eu/

6.2.2.4 Case Study smart parking

China Mobile Smart Parking – Internet of Things Case Study

Source: https://www.gsma.com/iot/wp-content/uploads/2018/03/iot_china_mobile_parking_04_18.pdf

Smart Parking and Sensors in the Age of IoT - Semiconductor Digest

Source: https://www.semiconductor-digest.com/2019/07/01/smart-parking-and-sensors-in-the-age-of-iot/

6.2.2.5 Case Study smart agriculture

Latest from the Connected Mangroves reforestation project

Source: https://www.ericsson.com/en/blog/2019/10/latest-connected-mangroves-reforestation-project

Smart and Ericsson Launch First Internet of Things Project in Pampanga, Philippines - Out of Town Blog

Source: https://outoftownblog.com/smart-and-ericsson-launch-first-internet-of-things-project-in-pampanga-philippines/

AT&T IoT for Good Case Study: Asparagus Has a Lower Water Footprint Thanks to Devine Organics, WaterBit and AT&T

Source: https://www.business.att.com/content/dam/attbusiness/reports/iot-for-good-waterbit-and-devine-organics-case-study.pdf

6.2.2.6 Case Study smart cities

The Bike Sharing Phenomenon and Impact

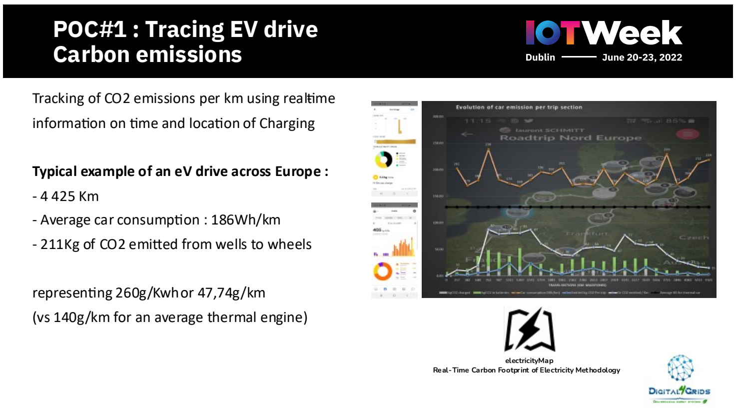
Source: https://www.ellenmacarthurfoundation.org/case-studies/bike-sharing-in-china

6.2.2.7 Case Study Electric Vehicles using 24-7 carbon free methodology

The measurement of carbon emission is to be defined according to the origin of the fuel used for transportation, being oil for ICE engine, electricity for Electrical Vehicle or Biofuels for other fuel cell transportation systems.

It therefore requires considering carbon intensity from wells to wheels taking into consideration the vehicle consumption efficiency as well as the origin and the quality of the fuel and so track carbon intensity across the value chain. In the case of electricity, the metrics define through the 24-7 carbon free methodologies offer the opportunity to properly consider the charging carbon intensity in view of the location of charging and the period of charging in the day (and the associated grid electricity mix).

The following example shows the impact of such carbon footprint analysis in the case of an EV circulating across several European countries.



POC#1 : Tracing EV drive Carbon emissions

Tracking of CO2 emissions per km using realtime information on time and location of Charging

Typical example of an eV drive across Europe :

- 4 425 Km
- Average car consumption : 186Wh/km
- 211Kg of CO2 emitted from wells to wheels

representing 260g/Kwh or 47,74g/km
(vs 140g/km for an average thermal engine)

Figure 16: Tracing EV drive carbon emissions, Source: Digital4Grids

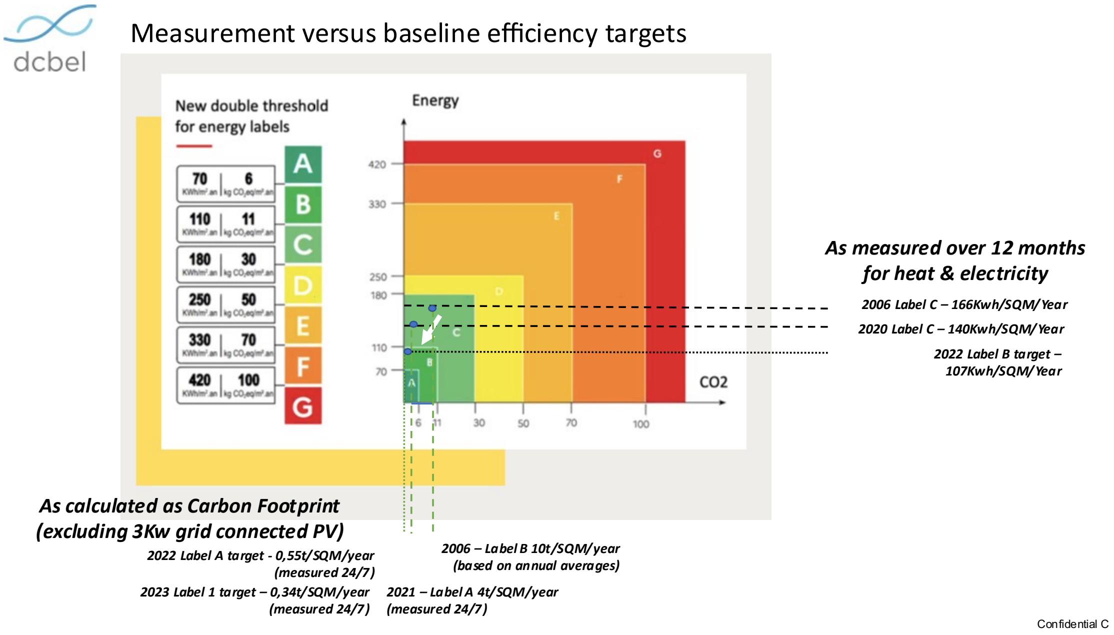
6.2.2.8 Case Study calculation of carbon footprint of residential home in France, Source: dcbel

The application of Building energy efficiency metrics to building currently revisited as part of the new Energy Performance Building directive which is targeting to accelerate the integration of rooftop Photovoltaics as a default option in all new building between 2025 and 2030. It furthermore reconsiders the various metrics considered for building performance between Energy Performance certificates for new buildings – considering to expand it to more measurement based metrics – to new NetZero Building metrics and Building Passports providing data on the evolution of Building energy and carbon footprint performance.

While current methodologies do not completely define metrics for carbon footprint as such, first trials have been made prototyping such measurements and illustrating the importance to link building submetering (for all technical lots including the digital/IT scope) with the Grid carbon intensity and the local renewables provided in the building as well as through the neighbouring energy communities.

Once again, the 24-7 carbon free energy metrics appears to be a very relevant set of metrics to properly assess carbon footprint evolutions through building passport, typically expanding traditional carbon footprint assessments which have historically focused on scope 1 and 3 (hence complementing scope 2).

The following diagram, see **Figure *17*** is an example of such metrics used for a residential home in France equipped with local PV. To note that the method can easily be expanded in that case to the home consumption and transportation scope if the user as an EV charging through its home.



As measured over 12 months for heat & electricity

2006 Label C – 166Kwh/SQM/Year

2020 Label C – 140Kwh/SQM/Year

2022 Label B target – 107Kwh/SQM/Year

As calculated as Carbon Footprint (excluding 3Kw grid connected PV)

2022 Label A target - 0,55t/SQM/year (measured 24/7)

2023 Label 1 target – 0,34t/SQM/year (measured 24/7)

2006 – Label B 10t/SQM/year (based on annual averages)

2021 – Label A 4t/SQM/year (measured 24/7)

Figure 17: Calculation of carbon footprint of residential home in France, Source: dcbel

As for other use cases the advantages of using 24-7 carbon free calculations are the following:

1. It defines a new accounting methodology and set of tools to monitor asset carbon footprints and monitor local renewables produced around the building as well as renewables sourced locally through a Citizen Energy community or a guaranteed 24-7 renewable Power Purchase agreement. The calculation on the basis of energy inflow/outflow submetering (replacing annual average baselines) and can be expanded to all technical equipment through the buildings (included embedded edge Iot or local cloud computing°
2. It offers a more consistent and intuitive approach correlated with energy physics: hourly calculations linked with real energy measurements across site submeters and taking into account real-time estimations of the carbon footprint of the electricity delivered through the Pan European energy system
3. It allows undisputed and comparable carbon footprint measurements for scope 2 emissions considering all Grid and on-site/community connected energy resources
4. It connects with new generation carbon analytics allowing to drill down per building submetering usage, as showed hereafter as an example.

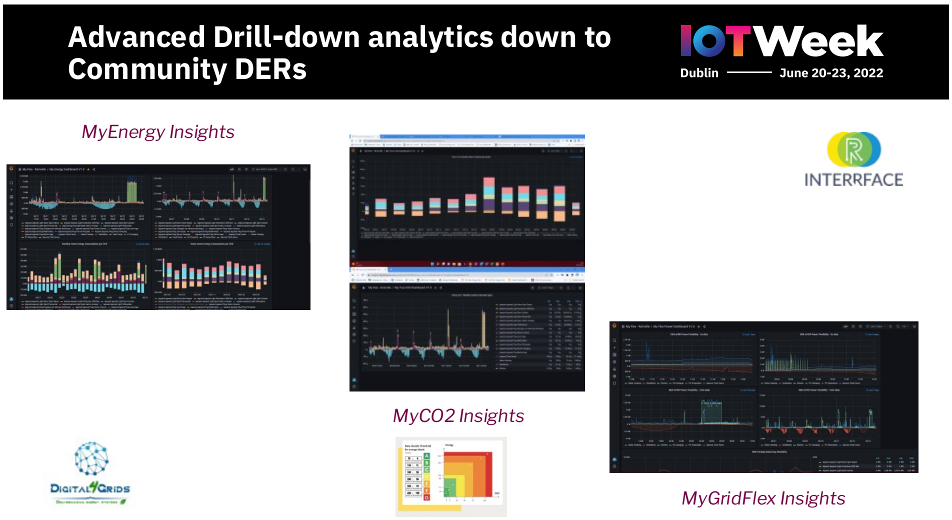

Advanced Drill-down analytics down to Community DERs

Figure 18: Carbon analytics example Source: Digital4Grids

6.3 Examples of benefits

6.3.1 Applying Port Environmental Review System (PERS) in the ports

Port Environmental Index (PEI)

Introduction

Smart ports refer to those ports with a strong (real) will incorporate ICT in order to renew and/or update the maritime transport of goods as well as the public transport in port environments. Note that 80% of all worldwide commercialized goods use the maritime means, thus it is critical to optimize, harmonize and develop sustainable ports, which for some countries and cities count as critical Infrastructure.

Unfortunately, the disparity and heterogeneity of ports makes the overall digitalization step slow, as well as its green transition, unless new regulation laws enforce port authorities and operators to adapt within fixed deadlines. Though there is no common methodology in the adoption of ICT technologies, big ports act typically as drivers and propose several options in the go-green path, sometimes enriched with technology:

- Connection of vessels to the wired electricity network, allowing the ship engines to be stopped and thus reducing CO2 emission
- Deployment of PV panels in various areas to reduce the amount of consumed electricity from the public network
- Deployment of fiber networks and 5G to guarantee a reliable network connection able to support Industry 4.0 requirements
- Deployment of IoT sensors (land and sea), sometimes even aerial sensors via drones. Depending on the degree of IoT coverage, combined with smart data analytics (Big data and Machine Learning), it is possible to achieve a real-time monitorization of some of the port processes, supporting the decision making for optimization scenarios and environmental impact (avoidance, mitigation, adaptation).

EcoPorts was established in 1997 as an initiative of several European ports to raise awareness on environmental protection through intensive cooperation, sharing of knowledge and improvement of environmental management. Since 2011, the program is fully integrated into the European Sea Ports Organisation (ESPO). The ECO Sustainable Logistic Chain Foundation (ECOSLC) allows terminals and ports outside Europe to access the EcoPorts tools.

The tools for achieving the mentioned objectives are: (i) the Self Diagnosis Method (SDM), and (ii) the Port Environmental Review System (PERS). In short, the environmental performance of ports is measured with the help of various environmental performance indicators: (i) Environmental management, (ii) environmental monitoring, (iii) top 10 environmental priorities, and (iv) Green services to shipping. For the two first categories, Indicators are provided in the Table below, being one of them the Carbon footprint.

Table 2: Performance indicators in EcoPorts

Performance indicators			
Environmental management indicators		**Environmental monitoring indicators**	
A.	Existence of a Certified Environmental Management System –EMS (ISO, EMAS, PERS)	**1.**	Waste
B.	Existence of an Environmental Policy	**2.**	Energy consumption
C.	Environmental Policy makes reference to ESPO's guideline documents	**3.**	Water quality
D.	Existence of an inventory of relevant environmental legislation	**4.**	Water consumption
E.	Existence of an inventory of Significant Environmental Aspects (SEA)	**5**	Noise
F.	Definition of objectives and targets for environmental improvement	**6.**	Air quality
G.	Existence of an environmental training programme for port employee	**7.**	Sediment quality
H.	Existence of an environmental monitoring program	**8.**	Carbon footprint
I.	Environmental responsibilities of key personnel are documented	**9.**	Marine ecosystem
J.	Publicly available environmental report	**10.**	Soil quality
		11.	Terrestrial habitats

Emissions to the air and GHGs

Air emissions are identified to be significant in different type of studies: environmental impact of port activities, environmental management in seaport, effects of ships pollution, and environmental indexes (Trozzi & Vaccaro 2000, Darbra et al. 2009, European Sea Ports Organization (ESPO) 2012, Puig et al. 2017, Kegalj et al. 2018). However, the main problem relies in the capability to be correctly measured, as stated in the table below where the related environmental KPIs are summarized.

Table 3: Indicators for air emissions

Indicators	Description	Significant	Representative	Measurable	Usefulness
CO_2 emissions (g)	Measure or calculation of the total amount of CO_2 emissions that is directly and indirectly caused by an activity	🟩	🟩	🟥	
Fine particles emissions (NOx, SOx,..)	Measure or estimation of the total amount of particles emissions	🟩	🟩	🟥	🟩
Fine particles emissions (NOx, SOx,.)	Total emission of fine particles linked to dredging activities in a year	🟩	🟩	🟩	🟩
Non-Methane volatile organic compounds emissions (NMVOC)	Total emissions of non-methane volatile organic compounds in ports	🟩	🟩	🟥	
Nitrogen Oxides (NOx) emissions (g)	Total emissions of Nitrogen oxides in ports	🟩	🟩	🟥	
Carbon monoxide (CO)	Measure or estimation of the total amount of CO emissions in ports	🟩	🟩	🟥	
Particulate Matter (PM) emissions (g)	Measure or estimation of the total amount of particulate matter emissions	🟩	🟩	🟥	
Total Greenhouse Gas (GHG) Emissions	Total amount of greenhouse gas (GHG) emissions that is directly and indirectly caused by an activity	🟩	🟩	🟥	🟩

Carbon dioxide emissions of port include the total amount of CO2 emissions that are directly and indirectly caused by port activities. The CO2 is one of the most emitted greenhouse gases contributing to global climate change and warming. This indicator is used as a reference against which to rate the global warming potential (GWP) of other greenhouse gases. At environmental concentrations in air (0.04%), CO2 has no impacts on human health.

Direct measurements would require the installation of sensors on all the machines of the supply chain of ports, which is not feasible. However, GHG emissions in general and CO2 emissions, in particular, can be derived using emission factors based on proxy data which includes fuel consumption, fuel type and technical specifications of the engine. This is the method that is used by the Port Environmental Index (PEI), a quantitative index intended to measure the whole environmental impact at ports, as result of the H2020 PIXEL project. We will provide here an overview summary of the PEI focussing on the CO2 aspect.

Core model in the PEI

The employed model is called Port Activity Scenario (PAS), and tries to build an initial digital twin of port activities focussing on the different supply chains. In doing so, complex processes are broken down into simpler elements, energy sources are identified and local emission of pollutants are estimated, among other. The PAS is virtually a meta-model that also allows to study energy production needs in different scenarios and therefore facilitate the transition to greener energy sources.

Basically, for this model it is important to distinguish among four data types: activity, cargo, area and machine (equipment). An activity is the use of one machine in order to handle one cargo unt between two areas. **Figure *19*** shows an example of what the activity data structure looks like.

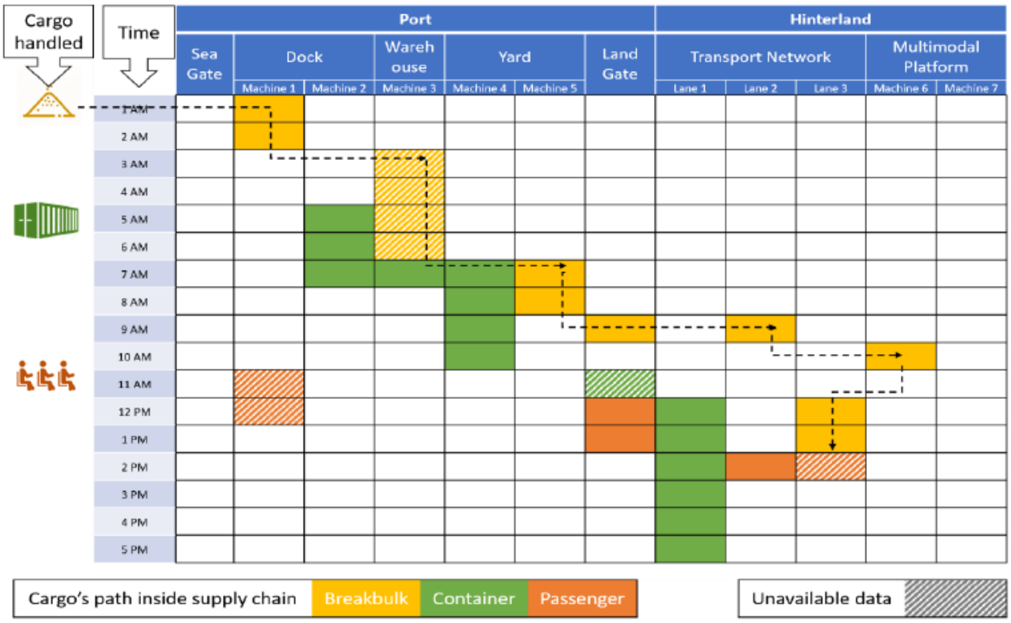
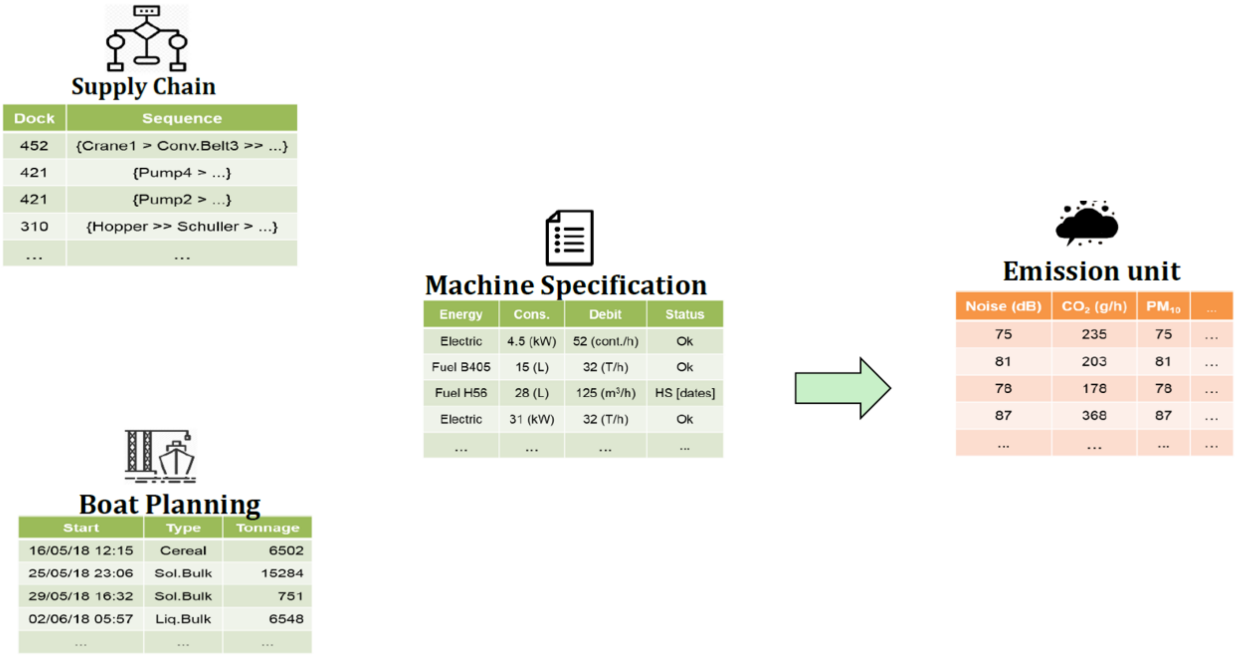


Figure 19: Activity data structure by handling cargo projection over time and space

In order to perform a modelling of the port operations, scenarios and activities, we need to know the data types:

- The activity data refer to the details related to a transition of a cargo: duration of the operation, type of machine used, distance travelled, etc. These data thus mainly refer to the logistics chain linked to a cargo.
- The operational data (machine specification) refer to the technical specifications of the machinery and equipment used. These data will specify the type of energy used, the consumption according to the mode of operation, the status of the machine, its operating limitations, etc
- The emission source data detail for each machine, engines or other sources used in the transition of a cargo, the sources of emissions linked to it. These data are very often obtained and based on emission factors allowing to translate the consumption of energy into quantity of pollutants emitted
- The vessel planning data refer to the vessels arriving at the ports with the description of the type of cargo, the tonnage, their expected date of arrival and departure. These data thus make it possible to know the expected flow rate for each type of cargo.



Supply Chain

Dock	Sequence
452	{Crane1 > Conv.Belt3 >> ...}
421	{Pump4 > ...}
421	{Pump2 > ...}
310	{Hopper >> Schuller > ...}
...	...

Machine Specification

Energy	Cons.	Debit	Status
Electric	4.5 (kW)	52 (cont./h)	Ok
Fuel B405	15 (L)	32 (T/h)	Ok
Fuel H56	28 (L)	125 (m^3/h)	HS [dates]
Electric	31 (kW)	32 (T/h)	Ok
...	...	...	...

Emission unit

Noise (dB)	CO_2 (g/h)	PM_{10}	...
75	235	75	...
81	203	81	...
78	178	78	...
87	368	87	...
...	...	...	...

Boat Planning

Start	Type	Tonnage
16/05/18 12:15	Cereal	6502
25/05/18 23:06	Sol.Bulk	15284
29/05/18 16:32	Sol.Bulk	751
02/06/18 05:57	Liq.Bulk	6548
...	...	...

Figure 20: Core input elements for the PAS model

The quantification of air emissions resulting from port activities can be based in the use of emission factors (EF). The average air emissions potential of equipment is quantified by using the following formulas:

$E = A \times EF$

$A = FC / T$

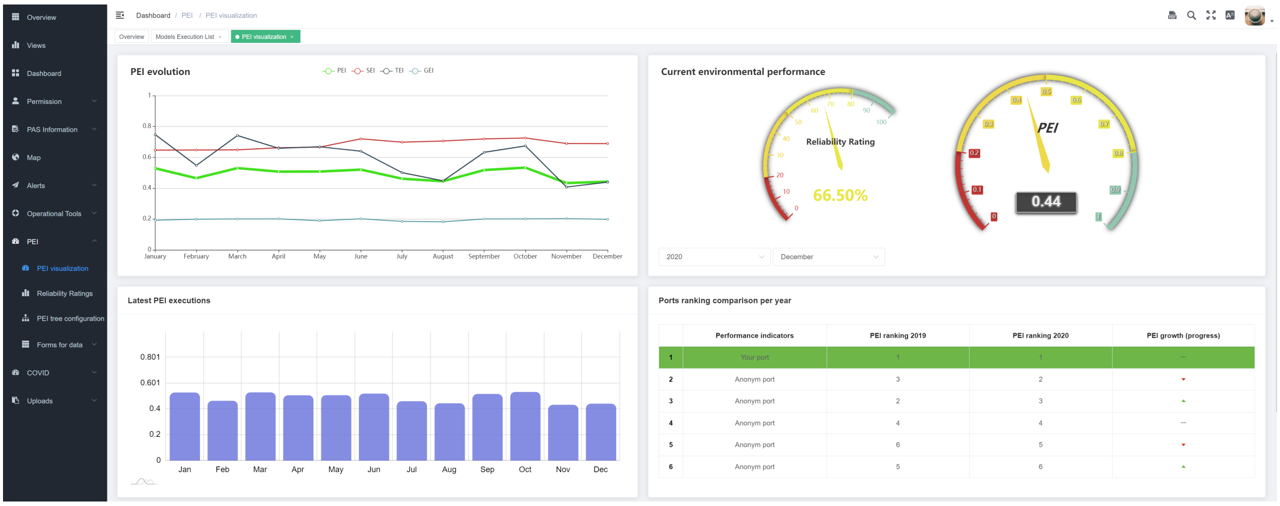
Where,

- E = total emission in kg/T
- A = the activity
- EF = emission factor (g/kg fuel),
- T = the working time in the port (h) of an equipment within the port,
- FC = fuel consumption (g/kWh).

PEI results

The PEI is able to provide quantitative information about the environmental impact (PEI) as a composite number considering the influence of three sub-indices:

- Ships (Ship Environmental Index)
- Terminals (Terminal Environmental Index)
- Port authority (Port Authority Environmental Index)
- GEI (Global Environmental Index)



Ports ranking comparison per year

	Performance indicators	PEI ranking 2019	PEI ranking 2020	PEI growth (progress)
1	Your port	1	1	—
2	Anonym port	3	2	▼
3	Anonym port	2	3	▲
4	Anonym port	4	4	—
5	Anonym port	6	5	▼
6	Anonym port	5	6	▲

Figure 21: PEI results for a port (year 2020). General indices

The information can be calculated and visualized graphically on a monthly basis considering that all required input is provided with that frequency.

Besides the PEI, a Reliability Rating (RR) is also provided. The Reliability Ratings is a way of indicating PEI readiness to IoT. Ideally all (or nearly all) information should flow in real time in the system, allowing a constant monitoring; however, the current situation in ports is far from a 100% digitalization status, and other ways of importing data needs to be used to calculate the PEI. Basically, different weights are assigned depending on that aspect, and therefore will be in the position of assessing a technology readiness index.

Within the same visualization Dashboard of the PEI, there is an additional widget as important as the previous ones, as it decomposes the PEI in environmental KPIs (eKPIs), which constitutes the groundings for the calculation of the PEI and allows an environmental manager to easily detect where and how much impact is causing to the environment. An example for 2020 is shown in the **Figure 22**.

There you can find all eKPIs that have been used by the PEI model, classified y ships, terminal and global. As the values are normalized, those eKPIs that are close to 1 mean that their impact on the environment is irrelevant and does not need urgent action; per contrary, those values that are close to 0 imply a significant impact on the environment and therefore, some strategy plan to transition to a greener status. This could be an excellent example to lean from other ports how they are targeting a specific eKPI in order to reduce its impact. As can be seen, CO2 in particular and emissions to the air in general contribute significantly to the overall impact and represents a great challenge to reduce in the upcoming years.

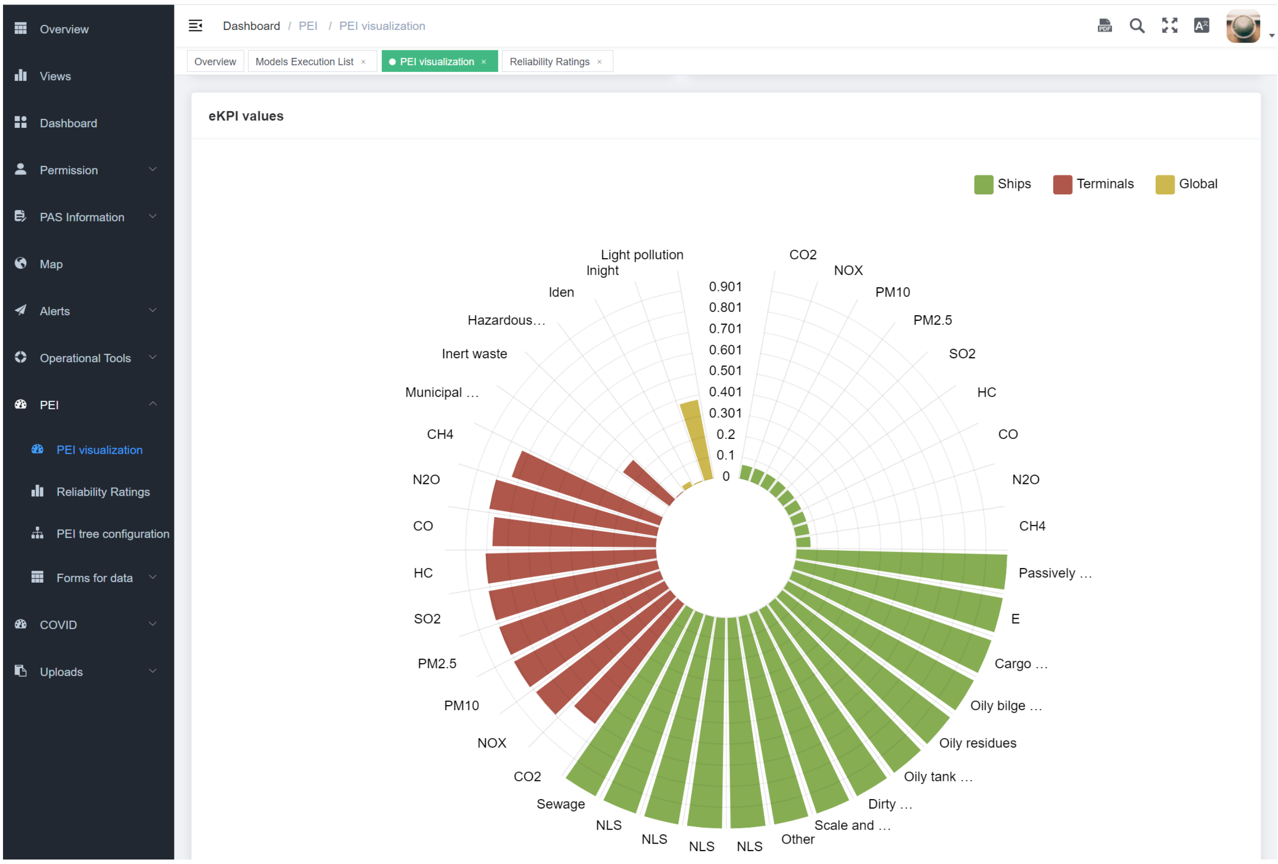


Figure 22: PEI results for a port (year 2020). eKPIs

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6.3.2 ZVEI-Show-Case "PCF@Control Cabinet"

In the ZVEI-Show-Case "PCF@Control Cabinet", the ZVEI presents a flexible, efficient and future-proof concept for the technical implementation of a digital product passport and demonstrates its feasibility using a demonstrator. The ZVEI-Show-Case "PCF@Control Cabinet" has been presented at the Hannover Messe event in Germany during 30 May – 2 June 2022, where the product carbon footprint of a control cabinet is calculated, see ZVEI white paper. The concept is based on the ZVEI Digital Nameplate (via IEC 61406 "Identification Link", under development) and the Asset Administration Shell (AAS).

As discussed in the previous sections of this report the carbon footprints are currently a much-discussed topic with far-reaching implications for individuals as well as companies. In particular, companies can make a proactive contribution to transparency by reporting their corporate or product-related CO_2 footprint, which is named PCF (Product Carbon Footprint).

In particular, the AAS serves as a technical tool that allows the automated interpretation of the documented product information because of its standardised semantic descriptions.

The communication and data exchange between stakeholders and different data providers, e.g., data bases and networks can be realized via data interfaces (connectors) to retrieve the needed information as shown in **Figure 23**.

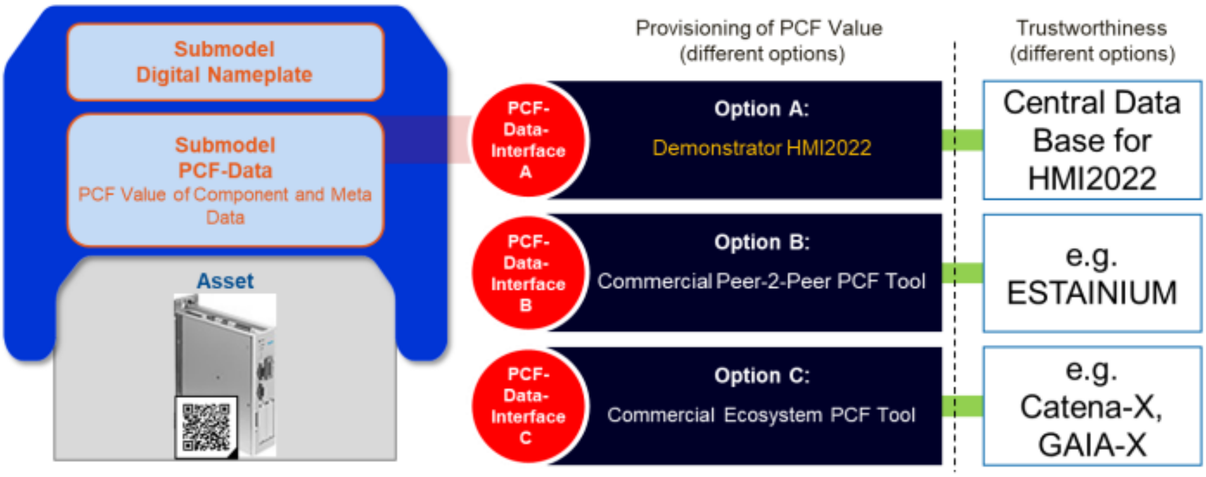

Figure 23: Different exemplary data providers that can be contacted via interfaces, from ZVEI white paper

The ZVEI-Showcase showed a control cabinet that was put together from products and components of participating companies, by simulating the entire value chain. One of the goals in this project/show case, the control cabinet stands symbolically for every type of system integration for which an exchange of data between different companies and different engineering systems is necessary. In particular, standard components are combined to form a functioning electrical system, with its very individual character, places very high demands on system interoperability and the associated almost data exchange.

The process of building an electrical system, see **Figure *24***, consists of very many interfaces between the companies and IT systems involved, where engineering data is transferred. In addition, the data of the individual components must also be transferred from the suppliers to the system integrators.

In particular, in this ZVEI showcase, there are already 15 companies involved, from which data on 56 different products and components, which finally lead to a system of 93 parts in total, are required to fulfil the value add.

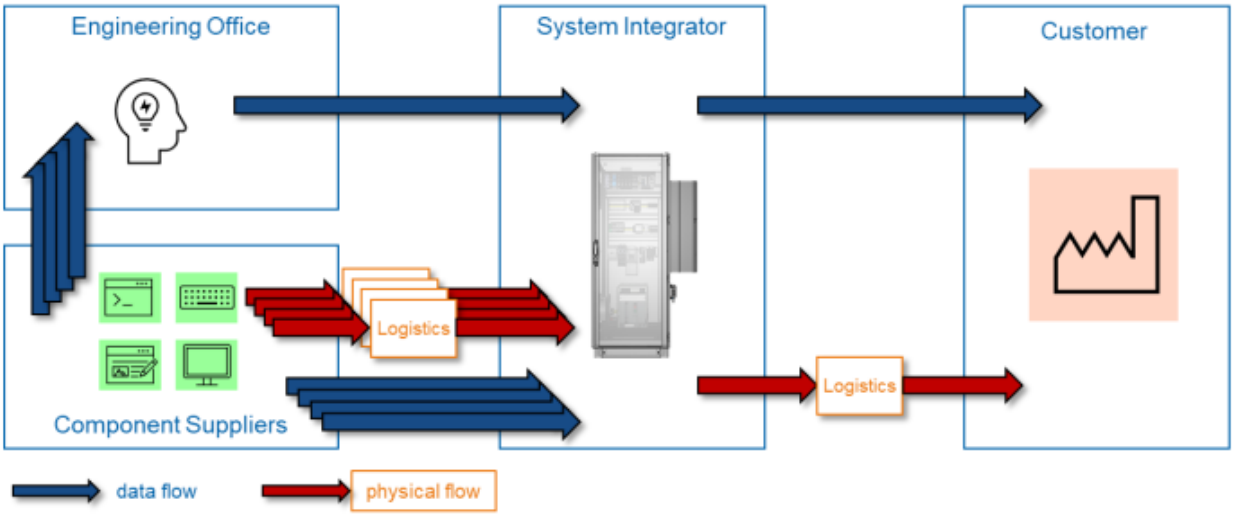

Figure 24: Data and component flow in the system integration process, from ZVEI white paper

The ZVEI-Showcase presents also the way of overcoming the organizational and IT system boundaries using the example of the Product Carbon Footprint in order to minimise the effort required to transfer product information from the manufacturer to the user. In particular, it uses the existing technologies of the Asset Administration Shell and concept repositories (e.g. ECLASS, IEC CDD) that are applied within the framework of the Digital Product Passport.

Note however, at the Hanover Fair 2022, the control cabinet will only consist of the components of the participating companies, without having as goal the realization realise a function of the system, see **Figure 25**.

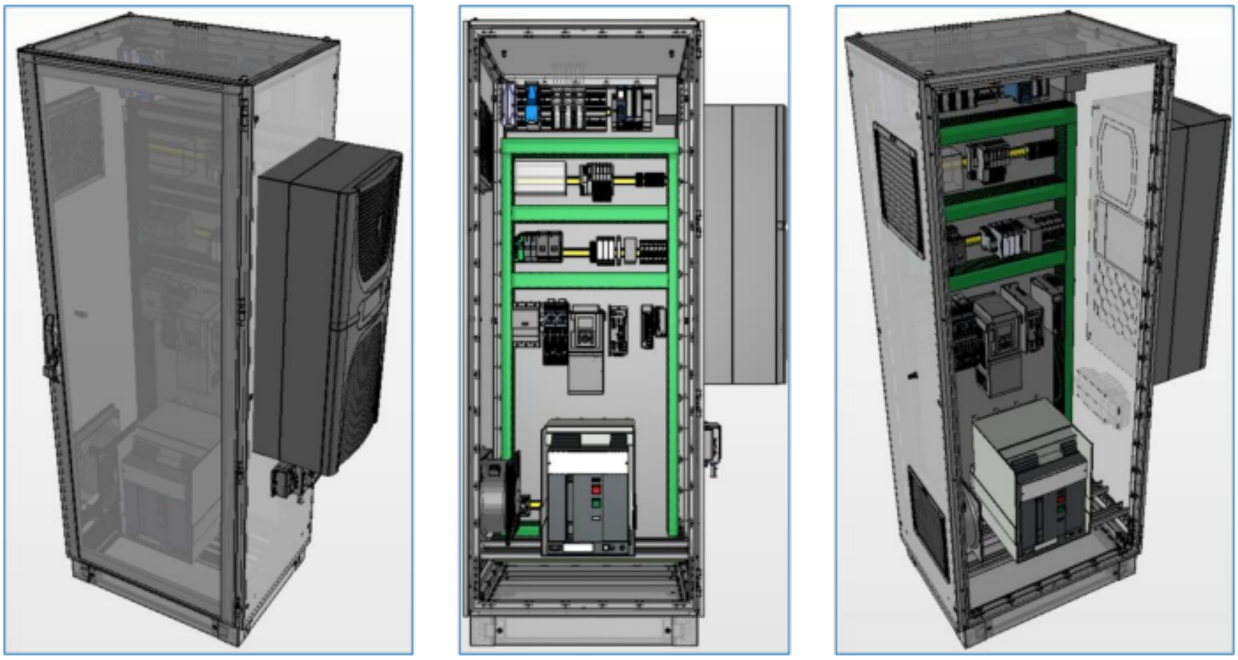

Figure 25: CAD-model of the control cabinet presented at the Hannover Fair 2022, from ZVEI white paper

As described in Section 3, there is today a wide landscape of standards and guidelines when it comes to greenhouse gas (GHG) quantification and product carbon footprint, where not all GHG calculation and PCF methods are equivalent and comparable.

The calculation of PCF values for products along the life cycle consists of scope 1 and scope 2, from the usage of directly CO2-equivalent emitting energy sources (such as fossil fuels) and the used electric energy mix.

Additionally, scope 3 includes the supply chain, upstream transport processes and manufacturing, but these values are mostly modelled and no primary data. To increase the reliability of scope 3 PCF values, an automated transfer of PCF values across the supply chain would be a conceivable approach. In this context, the concept of digital product passport (ZVEI DPP4.0) has been used to transfer data between stakeholders.

One key goal of the ZVEI-Show-Case "PCF@Control Cabinet" is to especially demonstrate the feasibility of using the ZVEI DPP4.0 in order to calculate the PCF of an integrated product or system across the supply chain, see **Figure 26**. Please note that for the demonstrator on the Hannover Fair 2022, only the tier 1 relation between product manufacturer and system integrator has been investigated.

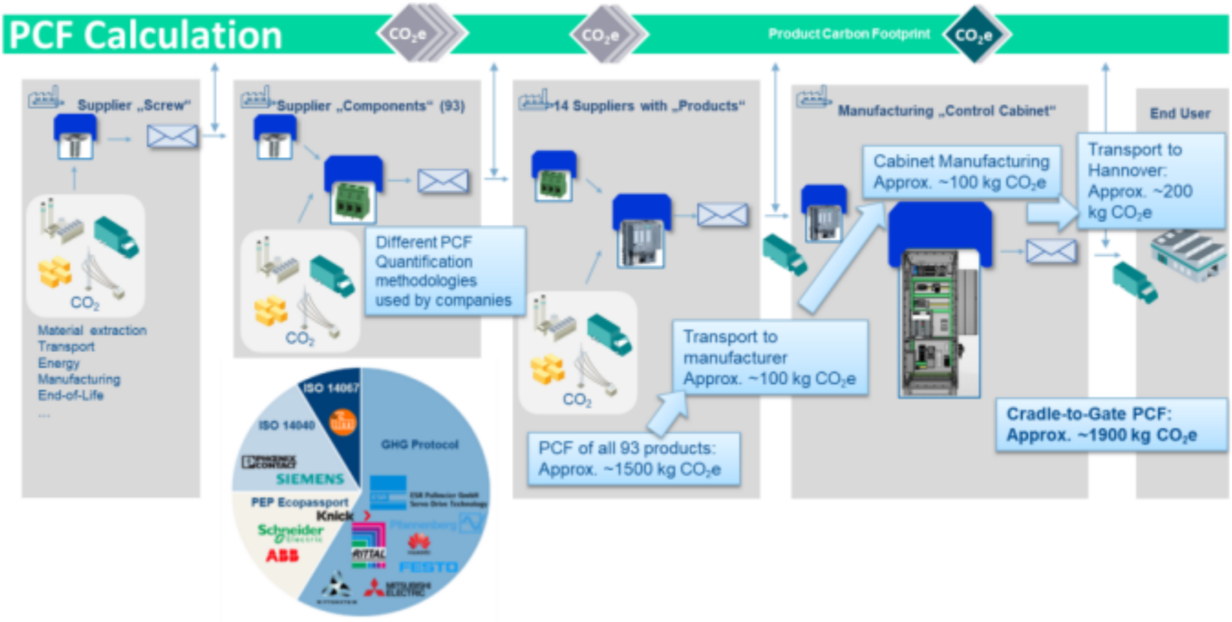

Figure 26: Exemplary applied PCF methodologies and calculated PCF values supply of the integrated product, from ZVEI white paper

As can be seen in **Figure 26**, several Carbon Footprint methodologies, described in Section 3, have been applied in the ZVEI-Show-Case "PCF@Control Cabinet", such as ISO 14067, PEP Ecopassport, GHG protocol. In addition, the Carbon Footprint values are displayed, i.e., PCF of all 93 products: Approx. 1500 kg CO_2e; Transport to manufacturer: Approx. 100kg CO_2e; Cabinet Manufacturing: Approx. 100 kg CO_2e; Transport to Hannover: Approx. 200 kg CO_2e; Cradle-to-Gate PCF total: Approx. 1900 kg CO_2e.

6.3.3 Smart-farming as an enabler to Carbon footprint reduction: the gaiasense approach

The gaiasense[1] system realizes the Smart-Farming-as-a-Service (SfaaS) paradigm [2](AdKa20) aiming to support the farmers by taking over the technological investment burden and offer next generation farming advice through the combined utilization of heterogeneous information sources. The gaiasense SF approach was initiated in 2015 in Greece and until today is available to 26 different areas, in six EU countries, covering > 60,000 ha and 17 different crops.

The gaiasense integrates a set of information sources that include IoT-enabled agro-environmental sensing stations, Earth Observation services, farmer's digital calendar, and on-the-field observations of the cultivation.

The gaiasense system utilizes telemetric autonomous stations—called gaiatrons—which collect data from sensors installed in the field and record atmospheric, soil, and plant parameters (e.g., temperature, relative humidity, precipitation, atmospheric pressure, wind speed/direction, soil moisture, leaf temperature, humidity, and wetness). The digital farmer's calendar contains the respective recording of the actions that the farmer/advisor performs at the field. The gaiasense offers the proper ICT tools and information system to record all information that is related to the daily cultivation work of the producer, such as fertilization application, plant protection, time, and duration of irrigation. This information provides the full and detailed picture of the exploitation, which contributes significantly to the decision-making process on irrigation, pest management, and fertilization tailored to the context of the targeted parcel.

Aiming to extend the functionalities of gaiasense system and to further elaborate on environmentally friendly farming the Ag-Cluster initiative was formulated in 2021. Within the scope of Ag-Cluster a Legal Entity was formed in Central Macedonia between Research Institutes, Agro-Cooperatives and leading ICT SMEs, focusing on the Agri-Food sector. More precisely, Ag-Cluster leveraged on state-of-the-art Smart Farming technologies and methodologies **with the aim to calculate and reduce the environmental (Carbon) Footprint of the whole production chain**, covering activities such as ploughing, cultivation, fertilisation, plant protection, irrigation etc. Ag-Cluster's scope is being accomplished, through 10 pilot studies for 2 growing seasons, covering two main crops (Kiwi and Peach) in the region of Central Macedonia- Greece.

For the needs of Carbon Footprint calculation, the gaiasense smart farming system leverages on and integrates with the "Open source Life Cycle and Sustainability Assessment" (OpenLCA) software. OpenLCA supports:

- compiling an inventory of relevant inputs and outputs of a product system, which is the most time consuming part of the LCA. In our case a third party inventory used from (https://nexus.openlca.org/)
- evaluating the potential environmental impacts associated with those inputs and outputs
- interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study. This approach is standardised in ISO 14040, 14044.

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[1] https://www.gaiasense.gr/en/gaiasense-smart-farming

[2] (AdKa20) Adamides, G.; Kalatzis, N.; Stylianou, A.; Marianos, N.; Chatzipapadopoulos, F.; Giannakopoulou, M.; Papadavid, G.; Vassiliou, V.; Neocleous, D. Smart Farming Techniques for Climate Change Adaptation in Cyprus. *Atmosphere* **2020**, *11*, 557. https://doi.org/10.3390/atmos11060557

Figure 27 illustrates the process of converting recorded farm level activities to carbon-footprint through the use of OpenLCA.

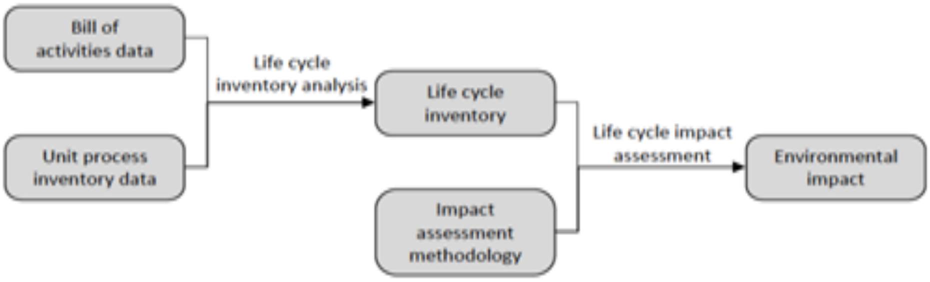


Figure 27 Steps to convert bill of activities data to environmental impact

For this purpose, we have developed an automated way to simulate the steps described in the image above. More specifically we have managed to implement this workflow by connecting three major components between them which are the Gaiasense ICM, the «gaiasense-OpenLCA connector (GOC)» and the OpenLCA. A short description of each component follows:

- **Gaiasense ICM** contains all the relevant activities that take place in a particular field providing us in this way with the necessary unit data to be used as inputs-outputs in the calculations.
- **OpenLCA** has been utilised through the olca-ipc (JSON-RPC) based protocol for remote connection in order to have access to its methods for environmental impact analysis.
- **Gaiasense-OpenLCA connector** (GOC) acts as an intermediate node which bridges the two other components by retrieving data from the GaiasenseICM on one hand and connecting with the OpenLCA on the other hand applying life cycle analysis on imported data.

Gaiasense-OpenLCA connector (GOC) runs on demand or in a chronologically scheduled way to feed a database with the results. We have implemented an API to extract these results and visualise them on a front-end system running under the Gaiasense-AGCluster domain name in the carbon-footprint section.

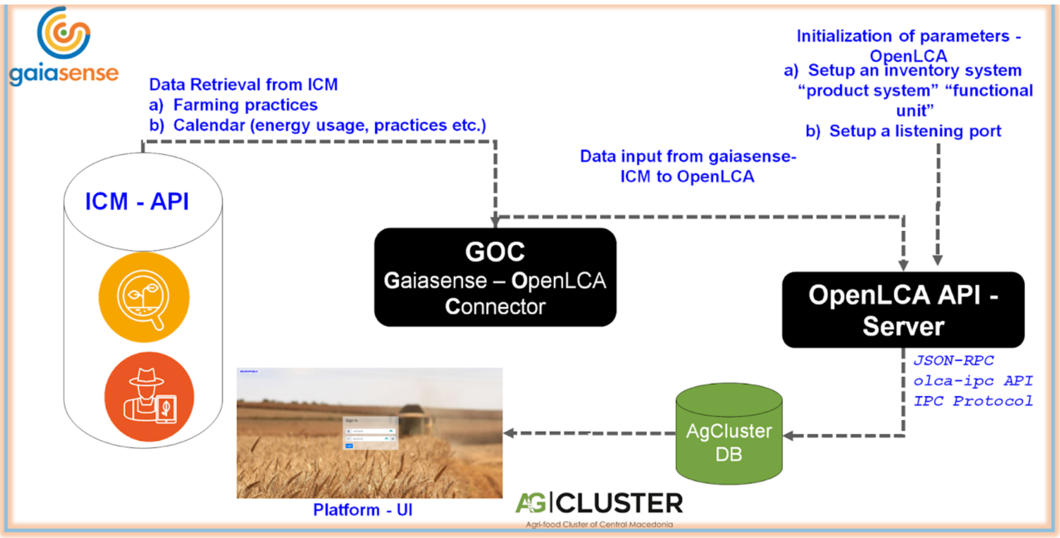


Figure 28. High level view for the calculation of carbon footprint of applied farming practices

6.3.4 F5GOptical Lab PoC report: Edge/Cloud-based visual inspection in production

6.3.4.1 Overview

This section is based on the content provided in the **AIOTI Report Computing Continuum Scenarios, Requirements and Optical Communication Enablers R2,** see [AIOTI-Fr24].

The objective of this Proof of Concept (PoC) demonstration is to showcase the use case edge/cloud-based visual inspection in production, in which an AI-based visual inspection model runs on an edge/cloud sorts out 3D printed objects in different classes. The broadband connectivity between the edge/cloud and the Visual Inspection Station (VIS) is provided by a PON. Specifically, the VIS is connected to the edge/cloud through three ONUs. Each ONU supports one camera or a robot arm in the VIS. The demo forms an E2E control loop (camera (observe) → edge/cloud (analyse) → robot arm (act)). The E2E observe-analyse-act (OAA) offers an E2E video processing pipeline with remote compute capability.

Additionally, all the devices are powered by a smart Power Distribution Unit (PDU), which provides real-time energy consumption monitoring that can be used for carbon footprint analysis. The power consumption data together with several networking parameters (e. g. data rate, throughput) are streamed live to a data lake for further pro-cessing or visualization. The telemetry pipeline is based on the architecture presented in [BESH23].

6.3.4.2 Topics of investigation

Figure 29 shows an overview of the entire setup. The setup involves a VIS comprising two 5GigE cameras (Basler a2A2840-67g5BAS), one robot arm (COBOTTA IP30), and a conveyer belt. A 3D printer (Ultimaker S3) was also used to print the 3D objects. Figure 30 and Figure 31 show the Basler camera and the COBOTTA, respectively. The VIS is provided broadband connectivity through an XGS-PON testbed with three ONUs. The Basler cameras are connected to two OptiXstar P812E ONUs, as they offer 2.5 Gbit/s interfaces. The robot arm is connected to an S892E ONU. We have set up dedicated network slices for each camera and the robot arm to connect them in an isolated slice to the cloud. The network slice for the cameras is set with assured bandwidth (BW) of 2.5 Gbit/s and maximum BW of 5.0 Gbit/s, while the network slice of the robot arm is set with max BW of 100 Mbit/s. As the network slicing feature does not span out of the PON network, three distinct virtual LANs (VLAN) were set up from the uplink of the OLT to the edge/cloud. The routes of the network slices and their extension VLANs to the edge/cloud are illustrated in Figure 29. This specific architecture follows the specifications described in [ETSIGR] and [POSA22]. Finally, in order to monitor the power consumption, a smart PDU is installed in the VIS. The PDU powers the PON elements as well the cameras and the robot arm. When it comes to the edge/cloud, there are three Virtual Machines (VMs) set up, two of them with GPU capability for running the vision inspection models and one for the control of the COBOTTA. The COBOTTA is controlled via an external middleware running in the edge/cloud which sends different commands depending on the output of the AI model. The physical setup Is shown in Figure 35.

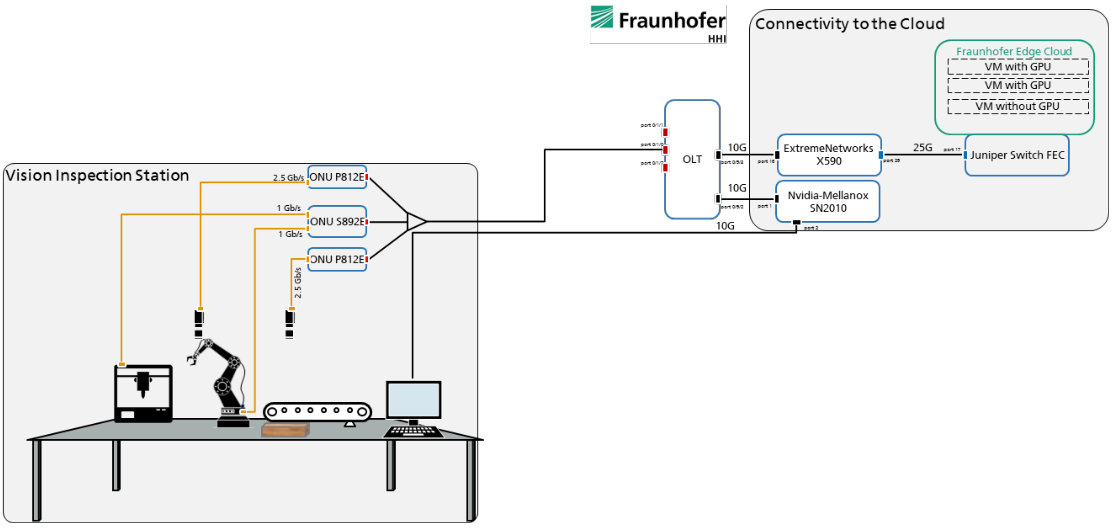


Figure 29: Testbed architecture and network slicing configuration.

Figure 30: Basler Camera.

Figure 31: COBOTTA IP30.

The sequence diagram in Figure 32 and Figure 33 explains the entire vision inspection process related to the camera used to sort the objects (camera 1). The main methods involved in the communication between devices are sendVideo, sendDecision, sendCommand and sendLabelledVideo. The camera calls the sendVideo method to share the recorded images of the objects to be inspected by the AI model. ONU1 forwards the traffic associated with the images to the OLT and the OLT forwards them to the edge/cloud for processing by the AI. The AI model processes the data sent by the cameras and classifies the objects as faulty or non-faulty . The AI model calls the sendDecision method to share the result of the classification with the middleware, which invokes the sendCommand method to instruct the robot on the proper action. Given that the goal of our VIS is to be able to distinguish between faulty (with residue) and non-faulty objects (Figure 34), the two actions will be “discard” and “process”. The robot arm places the faulty objects in a tray (discard), and the non-faulty ones on the conveyor belt for further analysis by the second camera (process).

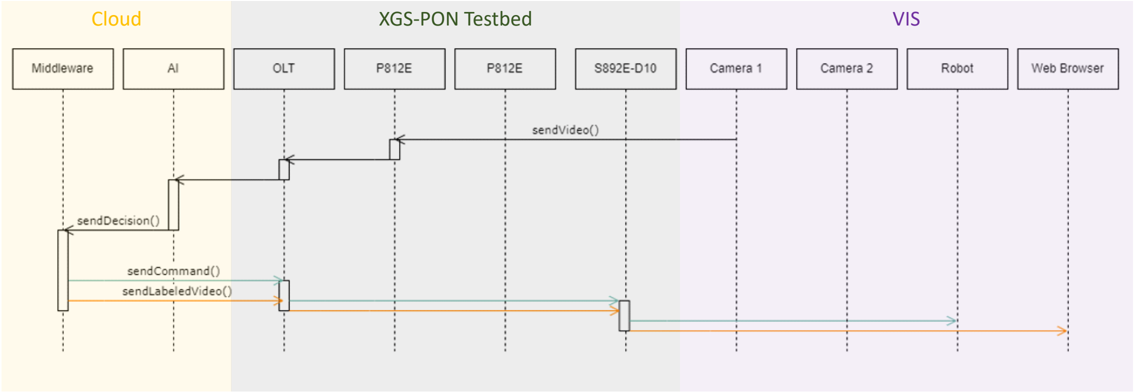


Figure 32: Testbed architecture and network slicing configuration.

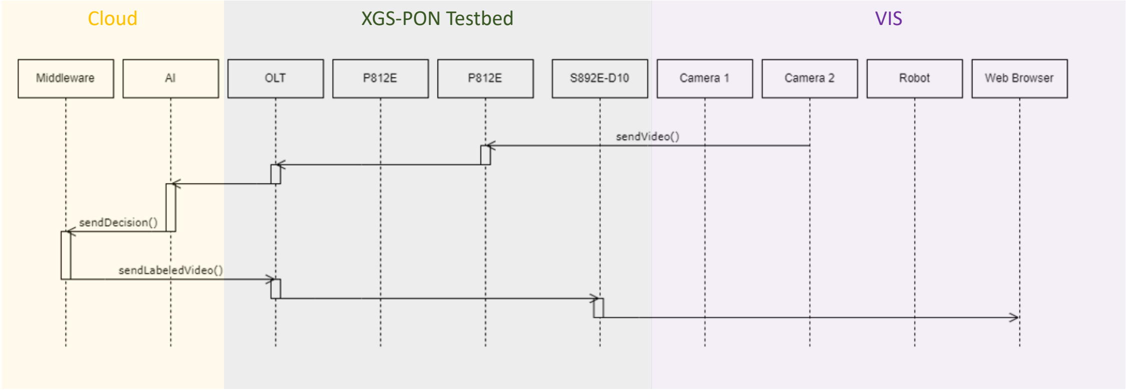


Figure 33: Sequence diagram for camera 2 operation.

Figure 34: Faulty(left), non-faulty (right) objects.

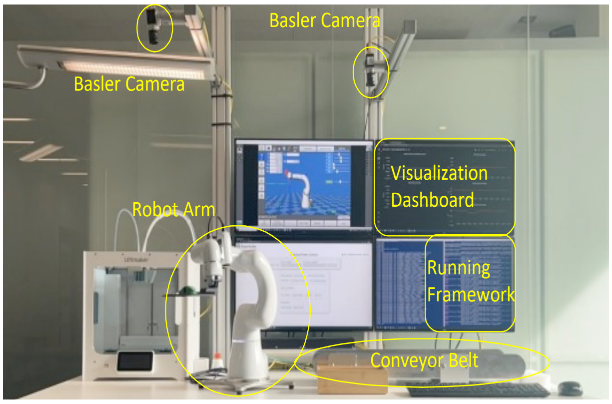


Figure 35: Physical setup.

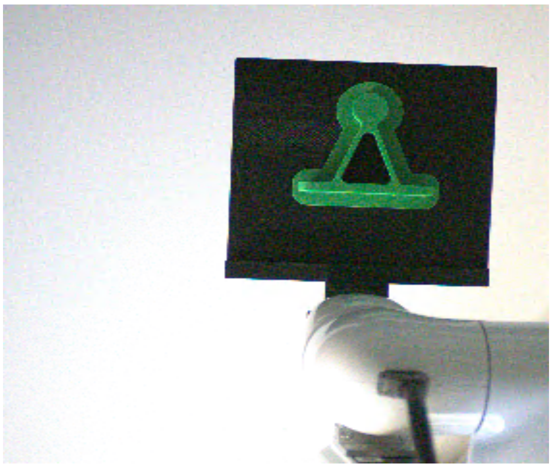
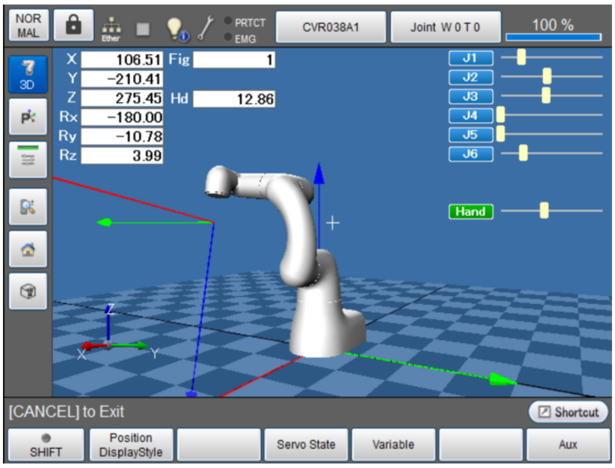


Figure 36: Camera 1 view from PylonViewer.



X 106.51
Y −210.41
Z 275.45
Rx −180.00
Ry −10.78
Rz 3.99
Fig 1
Hd 12.86

Figure 37: VirtualTP's main screen.

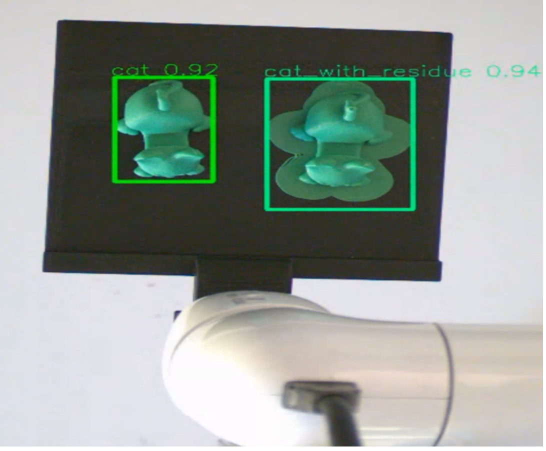


Figure 38: Classification output first camera.

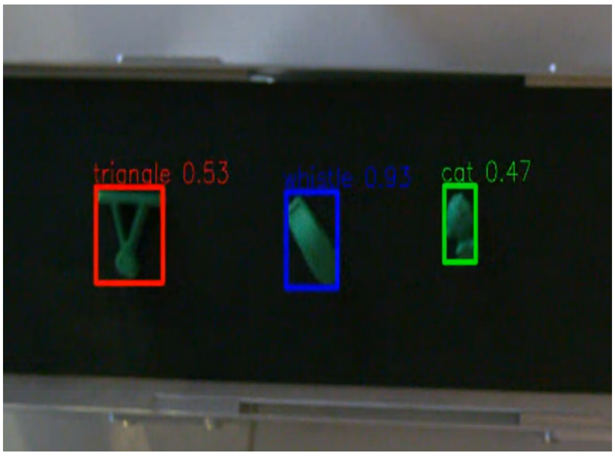


Figure 39: Classification output second camera.

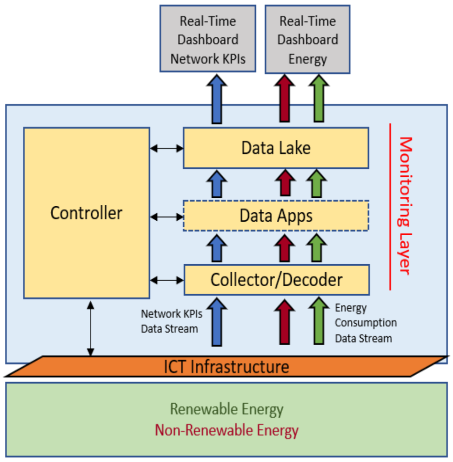
The middleware also calls the sendLabelledVideo command, which is used by the Web Browser to show the results of the classification in real-time within the lab premises (Figure 35).The sequence diagram in Figure 33 shows the routine for the camera located on top of the conveyor belt (camera 2). The process is identical to the one for camera 1 with the exception that no command is sent to the robot, since the objective of the camera 2 is to perform an additional screening of the objects on the conveyor belt.

The VIS hardware (cameras and robot) can be controlled by means of two proprietary software's: VirtualTP and PylonViewer. VirtualTP can receive commands from the middleware to control the robot remotely, however the capabilities of VirtualTP extend further than remote control. PylonViewer offers a GUI to configure the cameras and fine tune the recording quality (Figure 36). It is also capable of managing the robot autonomously through a Graphical User Interface (GUI) which can be used for testing and programming (Figure 37). The outcome of the vision inspection models based on the captures from camera1 and camera2 are provided in Figure 38 and Figure 39,respectively.

6.3.4.3 Monitoring of the PoC

While the selection process takes place, a real-time telemetry framework runs in the background to collect crucial analytics about the PoC operation (data rates, energy, etc.). The framework can provide real-time visibility with second granularity into the network's energy consumption and traffic data. The high-level architecture diagram in Figure 40 shows how the different components of the framework interact together.

At the bottom we have the energy source, renewable or not, which feeds the ICT infrastructure. From the infrastructure, the network and energy data streams are processed by the data pipeline described in [BESH23] with an updated Kafka broker. We redesigned the Kafka broker by increasing the number of devices from which data is collected (Figure 41). Each network device has its own topic, which is then divided into as many partitions as, the number of data outlets (ports, sockets, etc.), available. Data consumers can selectively query only the information they are interested in, reducing the network overhead associated with data transfer and by limiting the number of topics. Figure 42 and Figure 43 show the telemetry retrieval process for traffic and energy data, respectively, as a sequence diagram.



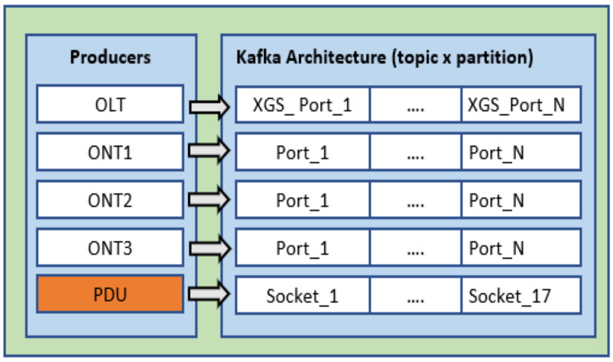
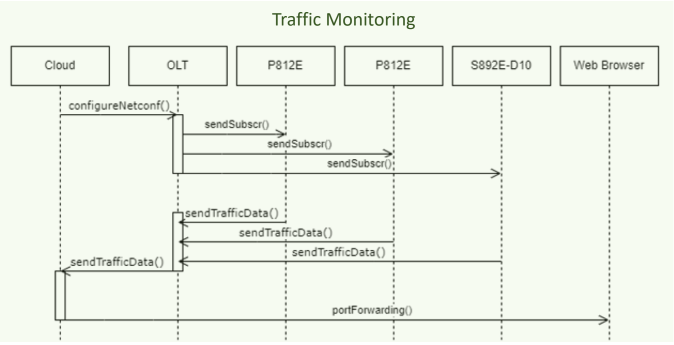


Figure 40: Framework architecture.

Figure 41: Kafka architecture.

The code running in the edge/cloud starts the traffic monitoring process (Figure 42) by instructing the OLT on how to configure the ONUs via a method called configureNetconf which carries the XML commands needed to configure the telemetry subscriptions on the network devices. The OLT sends a Netconf sendSubscr command to all the ONUs specifying the needed data and the retrieval granularity. The sendSubscr command configures the ONUs to send traffic data (throughput, packet loss etc.) every 10 seconds to the OLT via the sendTrafficData command. The latter sends the data from the OLT to the edge/cloud where it is displayed in a Grafana dashboard accessible on-premise via the Web Browser thanks to port forwarding. The code running in the cloud starts the energy collection process as well (Figure 43). It sends a pollSNMP command to the PDU with information regarding the data to collect and the associated granularity. Once the data is ready, the PDU forwards it to the cloud for display in the Grafana dashboard, where also the traffic data is shown.



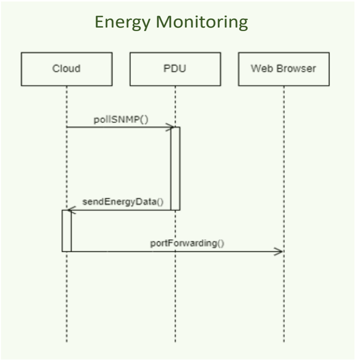


Figure 42: Sequence diagram for traffic monitoring.

Figure 43: Sequence diagram for energy monitoring.

There has been a growing interest in the scientific community towards the CO_2 emissions of the telecommunications infrastructure due to the raising concerns related to global warming. A piece of evidence is the 22% increase of energy consumption of telecom networks in Germany from 2015 to 2020. In this regards we decided to make use of the telemetry provided by the PDU to study the carbon emissions and provide some projections over multiple scenarios. To prove the capabilities of our framework, we decided to model three different VIS setups involving a different number of cameras transmitting at different data rates. All the setups model a variation of the standard VIS shown in Figure 29. The first setup consists of 2 cameras transmitting at 1 Gbit/s, the second one of 4 cameras recording at 1 Gbit/s and the last one of 2 cameras recording at 4.5 Gbit/s. To further investigate the customization capabilities of our framework, we decided to categorize the devices in ICT devices and non-ICT devices. ICT devices are the OLT and the ONUs while non-ICT devices are the robot arm, the conveyor belt and the cameras. In this section we extend the results obtained over the period of one hour to one year and to multiple contemporary-running VIS. The OLT available in the testbed can support up to 40 XGS-PON ports which means that we can scale up our computations to three different scenarios based on one OLT. For each scenario we compute the total amount of traffic generated, the energy required to run, the Network Carbon Intensity energy (NCIe) and the total Kg of Emitted CO_2 (ECO_2) [ITU T L.1333]. Specifically, the last two metrics are also compared to the expected emissions in 2028 when, e. g., Germany plans to expand the use of renewable energies. The results are shown in Figure 44. Scenario 1 leads the way as the most energy hungry and polluting scenario, which makes sense given the much higher number of devices involved with proportionally not as much traffic flowing. In fact, scenario one has ~77 % higher energy consumption than scenario 3 and only ~10 % more traffic, which also justifies the worse performance in terms of NCIe. It is interesting to notice that in every scenario the highest energy consumption, hence emissions, is due to non-ICT equipment. The results also show that when using more renewable energies, the emissions decrease substantially for every scenario by up to ~75 %. If instead we considered an extreme scenario, such as all the ICT equipment running on renewable energy, then all the emissions (NCIe, ECO_2) will be zeroed leaving us with only the emissions of the non-ICT devices. By considering the opposite scenario we would be left with the emissions of the ICT devices only.

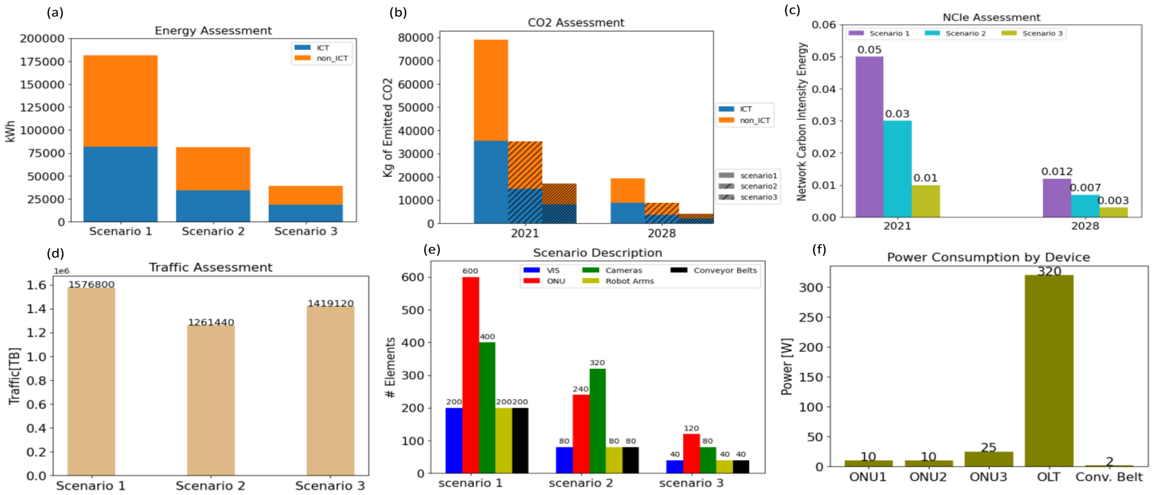


Figure 44: (a) energy assessment; (b) CO_2 assessment; (c) NCIe assessment; (d) traffic assessment; (e) scenario description (f) power consumption of other devices.

6.3.4.4 Major findings

The following insights were gained when setting up and executing the PoC:

- Latency sensitive and bandwidth hungry industrial use cases can be successfully realized in a scenario where PON is used as the base broadband connectivity solution.
- It has been challenging to set up an E2E precision time protocol to accurately measure the E2E latency between the vision Inspection station and the cloud as the multitude of networking devices in the middle have compliancy issues with the protocol, which has to be improved.
- The power consumption monitoring has been realized using smart power meters. There is a need from component manufacturer to incorporate real-time monitoring of power consumption of their networking components.
- This use case imposes a significant upstream bandwidth requirement compared to a negligible downstream amount. This is totally in contrast to the home users, where the downstream is larger in capacity. This may require modifications of the PONs for taking into account different asymmetric bandwidth flows.

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[ETSIGR] Standardization Document ETSI GR F5G 008 V1.1.1

[POSA22] Pooyan Safari, et al. "Edge Cloud Based Visual Inspection for Automatic Quality Assurance in Production." 13th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP). IEEE, 2022.

[ITU-T L.1333] Recommendation ITU-T L.1333 (2022), "Carbon Data Intensity for Network Energy Performance Monitoring".

6.4 Proposal on calculating the total avoided carbon emissions of industrial scenarios when ICT solutions are applied to enable carbon emission reduction

6.4.1. Life Cycle Assessment Phases

The Life Cycle Assessment (LCA) is defined as a methodology for assessing the environmental impacts associated with all the stages of the life cycle of a commercial product, process, or service.

The life cycle (LC) phases build an economic system. The methodology to assess the environmental impact of this system is defined in ISO14040/14044 within 4 steps:

- Goal and scope definition
- Inventory analysis
- Life cycle impact assessment
- Interpretation.

The life cycle (LC) phases are (please see **Figure 45**):

- Materials: collection of materials needed to realise the commercial product, process, or service;
- Product: is the phase of producing/creating the commercial product, process, or service;
- Use or operation: the phase where the user is using or operating the commercial product, process, or service;
- Disposal: includes, usually two phases:

  Waste disposal: destroying the disposed product by e.g., burning it;

  Landfill disposal: burying the disposed product, e.g., under the ground;
- Reuse: phase of reconstructing, when needed, parts of the product such that they can be reused in producing a renewed commercial product, process, or service; This includes as well its transport from the user to the production location;
- Recycle: phase of recycling, including the process of generating the raw material needed for rebuilding a product and its transport from the user to the production location.

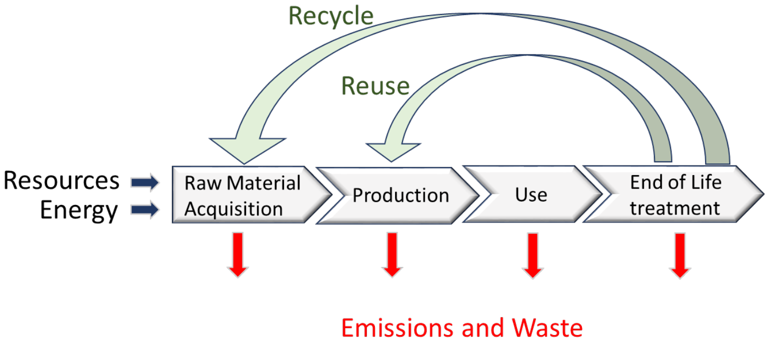

Figure 45: Life Cycle Phases, based on- August 2020 Journal of Cleaner Production 277:123741, "Circular business models: A review", DOI:10.1016/j.jclepro.2020.123741

6.4.2 Assumptions

In order to derive the equation on calculating the avoided carbon emissions in an industrial sector, when ICT is used as a Green enabling technology, the following assumptions are considered:

- The AIOTI equation on calculating the avoided carbon emissions in an industrial sector, when ICT is used as a Green enabling technology, complements the guidelines specified in the current version of ITU-T L.1480 specification, by adding a quantification method of calculating the benefits of applying ICT to reduce carbon emissions in vertical industry sectors.
- When ICT solutions are used, to among other features, reduce carbon emissions in Industrial sectors, it is assumed that in the Use/Operation LC phase the carbon emissions are measured under a certain Load ("l" index) and for a certain type of service;

- Load = data processed by the network during a unit of time, e.g., 1 week, 1 month, 1 year; The "I" index is defined as the "percentage of (average bandwidth ICT infrastructure / total bandwidth that ICT infrastructure can handle). If "I=1", it means that the applied Load equals the total bandwidth that ICT infrastructure can handle;

- TS = Type of Service (follow the 5G type of services, e.g., URLLC, see **Figure 46**);

- LC = Life Cycle, composed by Life Cycle (LC) phases Materials, Production, Use/Operation, Disposal;

- Unit: kgCo2e

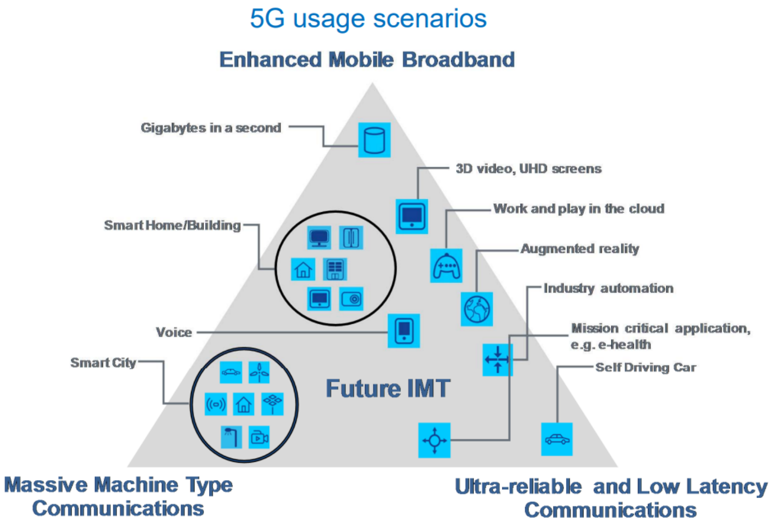

Figure 46: Usage scenarios of IMT for 2020 and beyond, copied from ITU-R, Figure 2 in: https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

6.4.3 Proposal of calculation of avoided carbon emissions

This section provides a proposal of an equation to be used for calculating the avoided carbon emissions in an industrial sector, when ICT is applied as a Green enabling technology.

The AIOTI equation on calculating the avoided carbon emissions in an industrial sector, when ICT is used as a Green enabling technology, complements the guidelines specified in the current version of ITU-T L.1480 specification, by adding a quantification method of calculating the benefits of applying ICT to reduce carbon emissions in vertical industry sectors.

Note that this version of the report (Release 3.0) updates the equations that were introduced in versions (Release 2.0) and (Release 1.1) of the report, which address the calculation of avoided carbon emissions in industrial sectors when ICT is applied by focusing on following updates:

- updated the equations including the impact of higher order effects including rebound effects,

- included a "simplified avoided carbon emissions equation", introduced in ITU-T (rev)L.1480,

This version (Release 3.0) of the report considers the carbon emission study of two versions of the same industrial scenario.

The first version of the industrial scenario under investigation, is called Baseline (industrial) scenario. Furthermore, in order to be aligned with work of EGDC (European Green Digital Coalition), it is considered that in this Baseline scenario an ICT infrastructure/solution is applied used for features related to connectivity, which could include as well, emission reduction capabilities. This ICT infrastructure/solution is denoted in this report as *ictBs*. The baseline scenario, which is supported by *ictBs*, is denoted in this report as scenario *Bs*. In the situation that entities/components applied in this Baseline scenario are recycled, then this scenario is denoted as *Bs_rcyc*.

The second version of the same industrial scenario under investigation, is called Green enabled scenario. The main difference between the Green enabled scenario and the Baseline scenario, is the use of an advanced ICT infrastructure/solution, denoted as *ictGr*, which is applied to replace features provided by the *ictBs* infrastructure, in order to reduce the carbon emissions of the industrial sector under investigation.

The Green enabled scenario, which is supported by *ictGr*, is denoted in this report as scenario *Gr*. In the situation that entities/components applied in this Green enabled scenario are recycled, then this scenario is denoted as *Gr_rcyc*

The equation used to calculate the avoided carbon emissions in an industrial sector, when ICT is applied for both Baseline and Green enabled scenario , i.e., *ictBs* and *ictGR*, includes as well factors, as type of service and the load that the ICT infrastructure needs to support over a period of time. The "l" index is defined as the "percentage of (average bandwidth ICT infrastructure / total bandwidth that ICT infrastructure can handle). If "l=1", it means that the applied Load equals the total bandwidth that ICT infrastructure can handle;

In this version of the report, it is considered that the industrial scenarios under investigation, i.e., the *Bs* and *Gr* industrial scenarios can either contain recycled entities/components or not contain such recycled entities/components. Therefore, two types of avoided carbon emissions equations are derived for the industrial sector investigation, (1) Total Avoided Carbon Emission equation when no recycling is applied and (2) Total Avoided Carbon Emission equation when recycling is applied. Note that in a subsequent version of this report the capability of reusing entities/components will be applied, but in this version of the report, the reuse capability is not applied.

Moreover, this version of the report (Release 3.0) provides a proposal for the calculation of the Total ICT avoided Carbon Emissions, which is a metric to measure the ICT carbon emission benefits, when replacing the ICT infrastructure used in the Baseline scenario, i.e., *ictBs*, with the ICT solution used in a Green enablement scenario, i.e., *ictGr*.

6.4.3.1 Total Avoided Carbon Emissions when no recycling and no reuse is applied

The proposed Total Avoided Carbon Emissions equation, when no recycling and no reuse is applied, is provided below and is visualized in **Figure 47**. The applied assumptions are listed in Section 6.4.2.

In addition to the Total Avoided Carbon Emissions equation, this section introduces as well, the Total ICT Avoided Carbon Emissions equation, having as target to measure the ICT carbon emission benefits, when replacing the ICT infrastructure used in the Baseline scenario, i.e., *ictBs*, with the ICT solution used in a Green enablement scenario, i.e., *ictGr*.

Equation for Total Avoided Carbon Emissions of an industrial sector:

Equation 1: $\mathbf{TAE_{(l)(ts)} = (T\_EBs\_nict_{(l)(ts)} + T\_\ EictBs_{(l)(ts)}) - (T\_EGr\_nict_{(l)(ts)} + T\_\ EictGr_{(l)(ts)}) - T\_Eict_{RB}}$

Where:

- $\mathbf{TAE_{(l)(ts)}}$ Total Avoided Carbon Emission Scenario for: (1) the complete LC, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services; Note that the “l” index is defined as the “percentage of (average bandwidth ICT infrastructure / total bandwidth that ICT infrastructure can handle). If “l=1”, it means that the applied Load equals the total bandwidth that ICT infrastructure can handle;

- $\boldsymbol{T\_EBs\_nict_{(l)(ts)}}$ Total Carbon Emission Scenario, for Baseline scenario (*Bs*), but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictBs*, for: (1) the complete LC phases, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

  Where: $\boldsymbol{T\_EBs\_nict_{(l)(ts)} = T\_EBs\_nict^{M}_{(l)(ts)} + T\_EBs\_nict^{P}_{(l)(ts)} + T\_EBs\_nict^{O}_{(l)(ts)} + T\_EBs\_nict^{D}_{(l)(ts)}}$

- $\boldsymbol{T\_EictBs_{(l)(ts)}}$ Total ICT Carbon Emission for Baseline Scenario, i.e., *ictBs,* for: (1) the complete LC, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

  Where: $\boldsymbol{T\_EictBs_{(l)(ts)} = T\_EictBs^{M}_{(l)(ts)} + T\_EictBs^{P}_{(l)(ts)} + T\_EictBs^{O}_{(l)(ts)} + T\_EictBs^{D}_{(l)(ts)}}$

- $\boldsymbol{T\_EGr\_nict_{(l)(ts)}}$ Total Carbon Emission Scenario, for Green enabled scenario, but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictGr*, for: (1) the complete LC, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

  Where: $\boldsymbol{T\_EGr\_nict_{(l)(ts)} = T\_EGr\_nict^{M}_{(l)(ts)} + T\_EGr\_nict^{P}_{(l)(ts)} + T\_EGr\_nict^{O}_{(l)(ts)} + T\_EGr\_nict^{D}_{(l)(ts)}}$

- $\boldsymbol{T\_EictGr_{(l)(ts)}}$ Total Carbon Emission for Green enabled Scenario, i.e., *ictGr*, for: (1) the complete LC, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

  Where: $\boldsymbol{T\_EictGr_{(l)(ts)} = T\_EictGr^{M}_{(l)(ts)} + T\_EictGr^{P}_{(l)(ts)} + T\_EictGr^{O}_{(l)(ts)} + T\_EictGr^{D}_{(l)(ts)}}$

- $\mathbf{T\_Eict_{RB}}$ Total Carbon Emissions from studied product system for the *ictGr* applied solution due to higher order effects including rebound effects.

- Note that the superscripts **M**, **P**, **O**, **D**, shown in the equation terms introduced above and in **Figure 47**, denote that the carbon emissions calculations are related to the LC phases: Material, Product, Operation, Discard, respectively.

It can be derived that:

Equation 2 $\boldsymbol{T\_EBs\_nict^{M}_{(l)(ts)} = \sum_{m=1}^{LBs\_nict} EBs\_nict^{M}_{(m)(l)(ts)}}$

Equation 3 $\boldsymbol{T\_EBs\_nict^{P}_{(l)(ts)} = \sum_{m=1}^{LBs\_nict} EBs\_nict^{P}_{(m)(l)(ts)}}$

Equation 4 $\boldsymbol{T\_EBs\_nict^{O}_{(l)(ts)} = \sum_{m=1}^{LBs\_nict} EBs\_nict^{O}_{(m)(l)(ts)}}$

Equation 5 $\boldsymbol{T\_EBs\_nict^{D}_{(l)(ts)} = \sum_{m=1}^{LBs\_nict} EBs\_nict^{D}_{(m)(l)(ts)}}$

Where:

- $\boldsymbol{EBs_{nict}{}^{M}_{(m)(l)(ts}}$: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Material phase; Note that in this case the subscripts (l) and (ts) can be discarded, since they are not relevant;

- $\boldsymbol{EBs_{nict}{}^{P}_{(m)(l)(ts}}$: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Production phase. Note that in this case the subscripts (l) and (ts) can be discarded, since they are not relevant;

- $\boldsymbol{EBs_{nict}{}^{O}_{(m)(l)(ts}}$: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Operation phase;

- $\boldsymbol{EBs_{nict}{}^{D}_{(m)(l)(ts}}$: represents carbon emission of each product/components (m) used in in the Baseline scenario, excluding the ICT infrastructure, obtained in the LC Disposal phase. Note that in this case the subscripts (l) and (ts) can be discarded, since they are not relevant;

- **LBs_nict**: total number of product/components (m) used in the Baseline scenario, excluding the ICT infrastructure

- Note that the superscripts **M**, **P**, **O**, **D**, shown in the equation terms used above, denote that the carbon emissions calculations are related to the LC phases: Material, Product, Operation, Discard, respectively.

Note that the same type of equations can be derived for:
$\mathbf{T\_EGr\_nict_{(l)(ts)}}$; $\mathbf{T\_EictBs_{(l)(ts)}}$; $\mathbf{T\_EictGr_{(l)(ts)}}$;

Equation for Total ICT Avoided Carbon Emissions:

Equation 6: $\boldsymbol{TAE\_ICT_{(l)(ts)} = T\_\ EictBs_{(l)(ts)} - T\_\ EictGr_{(l)(ts)}}$,

Where:

- $TAE\_ICT_{(l)(ts)}$: Total ICT Avoided Carbon Emission is a metric to measure the ICT carbon emission benefits, when replacing the ICT infrastructure used in the Baseline scenario, i.e., *ictBs*, with the ICT solution used in a Green enablement scenario, i.e., *ictGr*.

- Note that in certain situations, e.g., including advanced ICT features, to reduce significantly $TAE_{(l)(ts)}$, it might result that $TAE\_ICT_{(l)(ts)}$ becomes to be a negative number, due to the carbon emissions additions of these advanced ICT features.

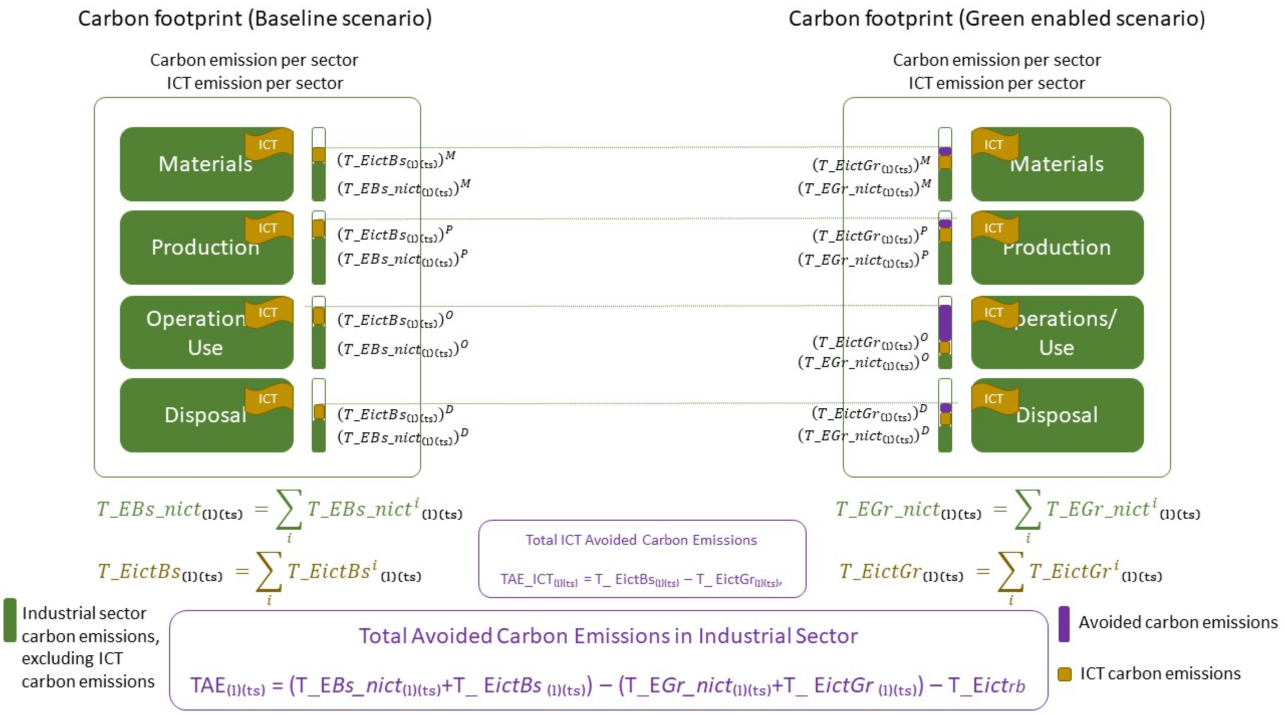

Figure 47: Visualisation of the Total avoided carbon emissions, with no circularity support and when ICT is applied as an enabling technology

6.4.3.2 Total Avoided Carbon Emissions when recycling (and no reuse) is applied

The proposed Total Avoided Carbon Emissions equation, when recycling (and no reuse) is applied, is provided below. The applied assumptions are listed in Section 6.4.2.

In order to address the impact of recycling on the Total Avoided Carbon Emissions equation, a literature study has been done, among published SDO specifications and scientific based publications.

The following references were used to update the Total Avoided Carbon Emissions equation, considering that recycling is applied:

- Introduction of the closed loop allocation/recycling GHG (Green House Gas) emission equation as defined in ISO14067 and introduced in ISO 14044. Note that the closed loop allocation/recycling is a manufacturing process that leverages the recycling of post-consumer products to supply the material used to create a new version of the same product.

- Introduction of the carbon emissions generated by a recycling process, denoted in this report as *Ecpr*, which encompasses the carbon emissions of the recycling process assuming that the complete product is being recycled, and was introduced in [3](LiHu2023). Note that a circularity process includes more processes than recycling, but in this version of this report only the recycling process is considered.

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[3] (LiHu2023) Circular built environment with innovative life cycle data use, unpublished work and teaching material for master course (TVB 4505) and Phd course (VB8000) at NTNU.

In order to provide clarity on the concepts used in the closed loop allocation/recycling process, **Figure 48** is used. In particular, this figure visualizes the GHG emissions composition during the material LC phase (left part of **Figure 48**) and the disposal (or end of life) LC phase (right part of this figure). *R* is the recycling rate of the material, see *Equation 7*, *Rin* is the recycling rate of the product as seen during the LC Material phase and Rout is the recycling rate of the product as seen during the LC Disposal phase. In the current version of this report, it is considered that *Rin=Rout=R*, since the Circular waste, see **Figure 48** is considered to be addressed during the LC Disposal phase, and will not impact the value of *Rin*.

Equation 7 $\boldsymbol{R} = \frac{Q_{cpr}}{Q_M}$

Where:

$$Q_M = Total\ quantity\ of\ material$$

$$Q_{cpr} = Total\ quantity\ of\ recycled\ material$$

Moreover, according to [ISO14067], for closed-loop allocation/recycling, each GHG emission tied to raw material acquisition and end-of-life operations can be calculated in accordance with the following equation:

Equation 8: $\mathbf{E_M = E_v + E_{EOL\_rcyc\_material} - R*E_v}$,

Where:

$\mathbf{E_M}$: represents the GHG emissions tied to raw material acquisition and end-of-life operations, when the closed loop allocation/recycling procedure is applied;

$\mathbf{E_v}$: represents the GHG emissions tied to extracting or producing the raw material needed for the product, from natural resources, as if it were primary material;

- $\mathbf{E_{EOL\_rcyc\_material}}$: represents the GHG emissions tied to end-of-life operations, being part of the product system that delivers the recycling material; When the recycled product, uses the closed loop allocation/recycling procedure, it has been derived that this $\mathbf{E_{EOL\_rcyc\_material}}$ term represents the the carbon emissions generated by the applied recycling process, i.e., $\boldsymbol{E_{EOL\_rcyc\_material} = R*E_{cpr}}$, see as well **Figure 48**. Furthermore, note that it can as well easily derived that:

Equation 9: $\boldsymbol{E_{EOL\_not\_rcyc\_material} = E_{EOL} - R*E_{EOL}}$;

- $\mathbf{E_{EOL}}$: represents the GHG emissions tied to end-of-life operations, being part of the product that uses primary material, i.e., when R=0;

- $\mathbf{E_{EOL\_not\_rcyc\_material}}$: represents the GHG emissions tied to end-of-life operations, being part of the product that is not being recycled and will be wasted: $\boldsymbol{E_{EOL\_not\_rcyc\_material} = E_{EOL} - R* E_{EOL}}$;

- **R:** represents the recycling rate of the material;

- $\mathbf{R*E_v}$: represents the recycling credit

- $\mathbf{E_{cpr}}$: represents the carbon emissions of the circularity process assuming that R=1 (complete product is recycled)

Since $\mathbf{E_{EOL\_rcyc\_material} = R*E_{cpr}}$, Then:

Equation 10: $\mathbf{E_M = E_V + R*E_{cpr} - R*E_V}$,

Equation 11: $\mathbf{E_M = E_V - R*E_V + R*E_{cpr}}$

Figure 48: Visualisation of the concepts used in the closed loop allocation/recycling process

The Total Avoided Carbon Emissions equation, see Equation 1, introduced in Section 6.4.3.1, can be impacted by recycling, depending on which of the 4 terms used in Equation 1, will be impacted by the recycling process;

In particular six key recycling combinations can be distinguished.

Recycling combination 1:

In this recycling combination, see **Figure 49**, it is considered that both the Baseline scenario (Bs) and the Green enabled scenario (Gr) include entities/components that are recycled, but no entities/components used by the ICT infrastructures, i.e., *ictBs* and *ictGr* are being recycled.

In this recycling combination Equation 1, becomes:

Equation 12: $\mathbf{TAE_{(l)(ts)} = (T\_EBs\_rcyc\_nict_{(l)(ts)} + T\_\ EictBs_{\ (l)(ts)}) - (T\_EGr\_rcyc\_nict_{(l)(ts)} + T\_\ EictGr_{\ (l)(ts)}) - T\_Eict_{RB}}$,

Where:

- $\boldsymbol{T\_EBs\_rcyc\_nict_{(l)(ts)}}$ Total Carbon Emission Scenario, for recycled Baseline scenario (*Bs_cir*), but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictBs*, for: (1) the complete LC phases, excluding the Reuse phase, (2) for a certain Load ("l" index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

  Where: $\boldsymbol{T\_EBs\_rcyc\_nict_{(l)(ts)} = T\_EBs\_rcyc\_nict^{M}_{(l)(ts)} + T\_EBs\_nict^{P}_{(l)(ts)} + T\_EBs\_nict^{O}_{(l)(ts)} + T\_EBs\_rcyc\_nict^{D}_{(l)(ts)}}$, see as well

  Equation *17;*

- $\boldsymbol{T\_EGr\_rcyc\_nict_{(l)(ts)}}$ Total Carbon Emission Scenario, for recycled Green enabled scenario (*Gr_rcyc*), but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictGr*, for: (1) the complete LC, excluding the Reuse phase, (2) for a certain Load ("l" index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

Where: $T\_EGr\_rcyc\_nict_{(l)(ts)} = T\_EGr\_rcyc\_nict^{M}_{(l)(ts)} + T\_EGr\_nict^{P}_{(l)(ts)} + T\_EGr\_nict^{O}_{(l)(ts)} + T\_EGr\_rcyc\_nict^{D}_{(l)(ts)}$, see as well Equation 18: ;

All the terms used in the above equations can be calculated as follows:

Using Equation 11 (**$E_M = E_v - R{*}E_{v'} + R{*}E_{cpr}$**) and as well the fact that **E_M** represents the GHG emissions tied to raw material acquisition and end-of-life operations, when the closed loop allocation/recycling procedure is applied, it can be derived that:

Equation 13 $T\_EBs\_rcyc\_nict^{M}_{(l)(ts)} = \sum_{m=1}^{LBs\_nict} EBs\_nict^{M}_{(m)(l)(ts)} - \sum_{m=1}^{LBs\_nict}\left(R_{Bs\_nict_m} * EBs\_nict^{M}_{(m)(l)(ts)}\right) + \sum_{m=1}^{LBs\_nict}\left(R_{Bs\_nict_m} * E_{cpr\_Bs\_nict_m}\right)$

Equation 14 $T\_EGr\_rcyc\_nict^{M}_{(l)(ts)} = \sum_{k=1}^{LGr\_nict} EGr\_nict^{M}_{(k)(l)(ts)} - \sum_{k=1}^{LGr\_nict}\left(R_{Gr\_nict_k} * EGr\_nict^{M}_{(k)(l)(ts)}\right) + \sum_{k=1}^{LGr\_nict}\left(R_{Gr\_nict_k} * E_{cpr\_Gr\_nict_k}\right)$

Where:

- $\mathbf{E_{cpr\_Bs\_nict_m}}$ represents GHG emissions of the circularity process of each product/component (*m*) of the recycled Baseline scenario assuming that: (1) $\mathbf{R_{Bs\_nict_m}}$=1 (complete product is recycled) and (2) excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictBS*.
- $\mathbf{E_{cpr\_Gr\_nict_k}}$: represents GHG emissions of the circularity process of each product component (*k*) of the recycled Green enabled scenario assuming that: (1) R_{Gr_nict} =1 (complete product is recycled) and (2) excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictGr*.
- $\mathbf{R_{Bs\_nict_m}}$: represents the recycling rate of the material of each product/component (*m*) used for the recycled Baseline scenario, excluding the materials used for the ICT infrastructure;
- $\mathbf{R_{Gr\_nict_k}}$: represents the (estimated) recycling rate of the material of each product/component (*k*) used for the recycled Green enabled scenario, excluding the materials used for the ICT infrastructure;
- ***LBs_nict****: total number of product/components used in the Baseline scenario, excluding the ICT infrastructure*
- ***LGr_nict****: total number of product/components used in the Green enabled scenario, excluding the ICT infrastructure*
- Note that the superscripts **M**, **P**, **O**, **D**, shown in these equation terms, denote that the carbon emissions calculations are related to the LC phases: Material, Product, Operation/Use, Discard, respectively.

Moreover, applying the previously derived equation *Equation 9* (**$E_{EOL\_not\_rcyc\_material} = E_{EOL} - R{*}E_{EOL}$**) and as well the fact that $E_{EOL\_not\_rcyc\_material}$ represents the GHG emissions tied to end-of-life operations, being part of the product that is not being recycled and is being wasted, it can be derived that:

Equation 15 $T\_EBs\_rcyc\_nict^{D}_{(l)(ts)} = \sum_{m=1}^{LBs\_nict} EBs\_nict^{D}_{(m)(l)(ts)} - \sum_{m=1}^{LBs\_nict}\left(R_{Bs\_nict_m} * EBs\_nict^{D}_{(m)(l)(ts)}\right)$

Equation 16 $$T\_EGr\_rcyc\_nict^{D}_{(l)(ts)} = \sum_{k=1}^{LGr\_nict} EGr\_nict^{D}_{(k)(l)(ts)} - \sum_{m=1}^{LGr\_nict}\left(R_{Gr\_nict_k} * EGr\_nict^{D}_{(k)(l)(ts)}\right)$$

Combining the above provided equations, then:

Equation 17: $$T\_EBs\_rcyc\_nict_{(l)(ts)} = \sum_{m=1}^{LBs\_nict} EBs\_nict^{M}_{(m)(l)(ts)} - \sum_{m=1}^{LBs\_nict}\left(R_{Bs\_nict_m} * EBs\_nict^{M}_{(m)(l)(ts)}\right) + \sum_{m=1}^{LBs\_nict}\left(R_{Bs\_nict_m} * E_{cpr\_Bs\_nict_m}\right) + T\_EBs\_nict^{P}_{(l)(ts)} + T\_EBs\_nict^{O}_{(l)(ts)} + \sum_{m=1}^{LBs\_nict} EBs\_nict^{D}_{(m)(l)(ts)} - \sum_{m=1}^{LBs\_nict}\left(R_{Bs\_nict_m} * EBs\_nict^{D}_{(m)(l)(ts)}\right)$$

Equation 18: $$T\_EGr\_rcyc\_nict_{(l)(ts)} = \sum_{k=1}^{LGr\_nict} EGr\_nict^{M}_{(k)(l)(ts)} - \sum_{k=1}^{LGr\_nict}\left(R_{Gr\_nict_k} * EGr\_nict^{M}_{(k)(l)(ts)}\right) + \sum_{k=1}^{LGr\_nict}\left(R_{Gr\_nict_k} * E_{cpr\_Gr\_nict_k}\right) + T\_EGr\_nict^{P}_{(l)(ts)} + T\_EGr\_nict^{O}_{(l)(ts)} + \sum_{k=1}^{LGr\_nict} EGr\_nict^{D}_{(k)(l)(ts)} - \sum_{k=1}^{LGr\_nict}\left(R_{Gr\_nict_k} * EGr\_nict^{D}_{(k)(l)(ts)}\right)$$

Note that the equation for Total ICT Avoided Carbon Emissions as depicted in *Equation* 6, applies as well for this recycling combination.

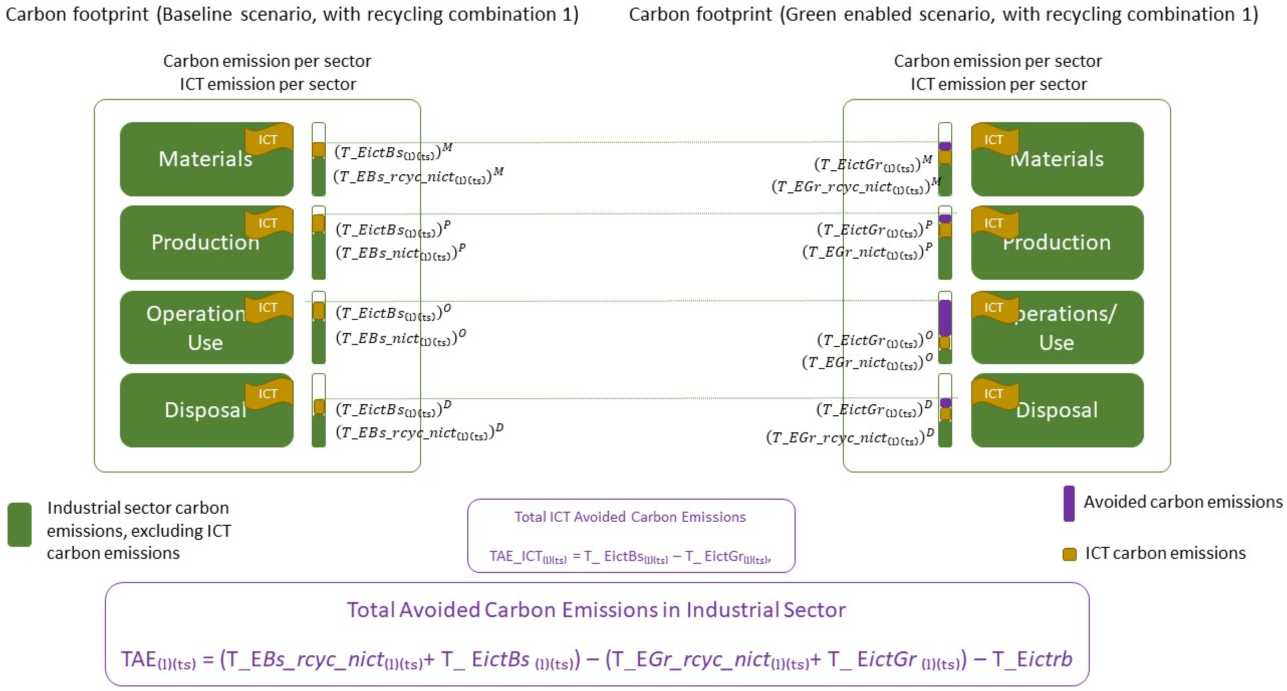

Figure 49: Visualisation of the Total avoided carbon emissions, when ICT is applied as an enabling technology, for recycling combination 1

Recycling combination 2:

In this recycling combination, see **Figure 50**, it is considered that in the Baseline scenario (Bs) and the Green enabled scenario (Gr) the only entities/components that are recycled are the ones used by the ICT infrastructures, i.e., *ictBs* and *ictGr*.

In this recycling combination, Equation 1, becomes:

Equation 19: $TAE_{(l)(ts)} = (T\_EBs\_nict_{(l)(ts)} + T\_\ EictBs\_rcyc_{(l)(ts)}) - (T\_EGr\_nict_{(l)(ts)} + T\_\ EictGr\_rcyc_{(l)(ts)}) - T\_Eict_{RB}$,

Where:

- $T\_EictBs\_rcyc_{(l)(ts)}$ Total recycled ICT Carbon Emission for Baseline Scenario, i.e., *ictBs,* for: (1) the complete LC, excluding the Reuse phase, (2) for a certain Load ("l" index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

- $T\_EictGr\_rcyc_{(l)(ts)}$ Total recycled ICT Carbon Emission for Green enabled Scenario, i.e., *ictGr,* for: (1) the complete LC, excluding the Reuse and Recycle phases, (2) for a certain Load ("l" index) and (3) for a type of service, e.g. follow the classification specified by ITU-T for 5G type of services;

Following the same method as discussed in the recycling combination 1, it can be derived that:

Equation 20: $T\_EictBs\_rcyc_{(l)(ts)} = \sum_{n=1}^{LictBs} EictBs^{M}_{(n)(l)(ts)} - \sum_{n=1}^{LictBs}\left(R_{ictBs_n} * EictBs^{M}_{(n)(l)(ts)}\right) + \sum_{n=1}^{LictBs}\left(R_{ictBs_n} * E_{cpr\_ictBs_n}\right) + T\_EictBs^{P}_{(l)(ts)} + T\_EictBs^{O}_{(l)(ts)} + \sum_{n=1}^{LictBs} EictBs^{D}_{(n)(l)(ts)} - \sum_{n=1}^{LictBs}\left(R_{ictBs_n} * EictBs^{D}_{(n)(l)(ts)}\right)$

Equation 21: $T\_EictGr\_rcyc_{(l)(ts)} = \sum_{r=1}^{LictGr} EictGr^{M}_{(r)(l)(ts)} - \sum_{r=1}^{LictGr}\left(R_{ictGr_r} * EictGr^{M}_{(r)(l)(ts)}\right) + \sum_{r=1}^{LictGr}\left(R_{ictGr_r} * E_{cpr\_ictGr_r}\right) + T\_EictGr^{P}_{(l)(ts)} + T\_EictGr^{O}_{(l)(ts)} + \sum_{r=1}^{LictGr} EictGr^{D}_{(r)(l)(ts)} - \sum_{r=1}^{LictGr}\left(R_{ictGr_r} * EictGr^{D}_{(r)(l)(ts)}\right)$

Where:

- $\mathbf{E_{cpr\_ictBs_n}}$ represents GHG emissions of the circularity process of each product/component (*n*) of the ICT infrastructure, i.e., *ictBs*, applied in the recycled Baseline scenario, assuming that $\mathbf{R_{ictBs_n}}$=1 (complete product is recycled);

- $\mathbf{E_{cpr\_ictGr_r}}$ represents GHG emissions of the circularity process of each product/component (*r*) of the ICT infrastructure, i.e., *ictGr*, applied in the recycled Green enabled scenario, assuming that $\mathbf{R_{ictGr_r}}$=1 (complete product is recycled);

- $\mathbf{R_{ictBs_n}}$: represents the recycling rate of the material of each product/component (*n*) used the ICT infrastructure, i.e., *ictBs*, applied in the recycled Baseline scenario;

- $\mathbf{R_{ictGr_r}}$: represents the recycling rate of the material of each product/component (*r*) used the ICT infrastructure, i.e., *ictGr*, applied in the recycled Green Enabled scenario;

- ***LictBs**: total number of product/components used in ICT infrastructure, i.e., ictBs, applied in the recycled Baseline scenario**;***

- ***LictGr***: total number of product/components used in ICT infrastructure, i.e., *ictGr*, applied in the recycled Green Enabled scenario**;**

The equation for Total recycled ICT Avoided Carbon Emissions for the recycling combination 2 becomes:

Equation 22 $TAE\_ICT\_rcyc_{(l)(ts)} = T\_\ EictBs\_rcyc_{(l)(ts)} - T\_\ EictGr\_rcyc_{(l)(ts)}$,

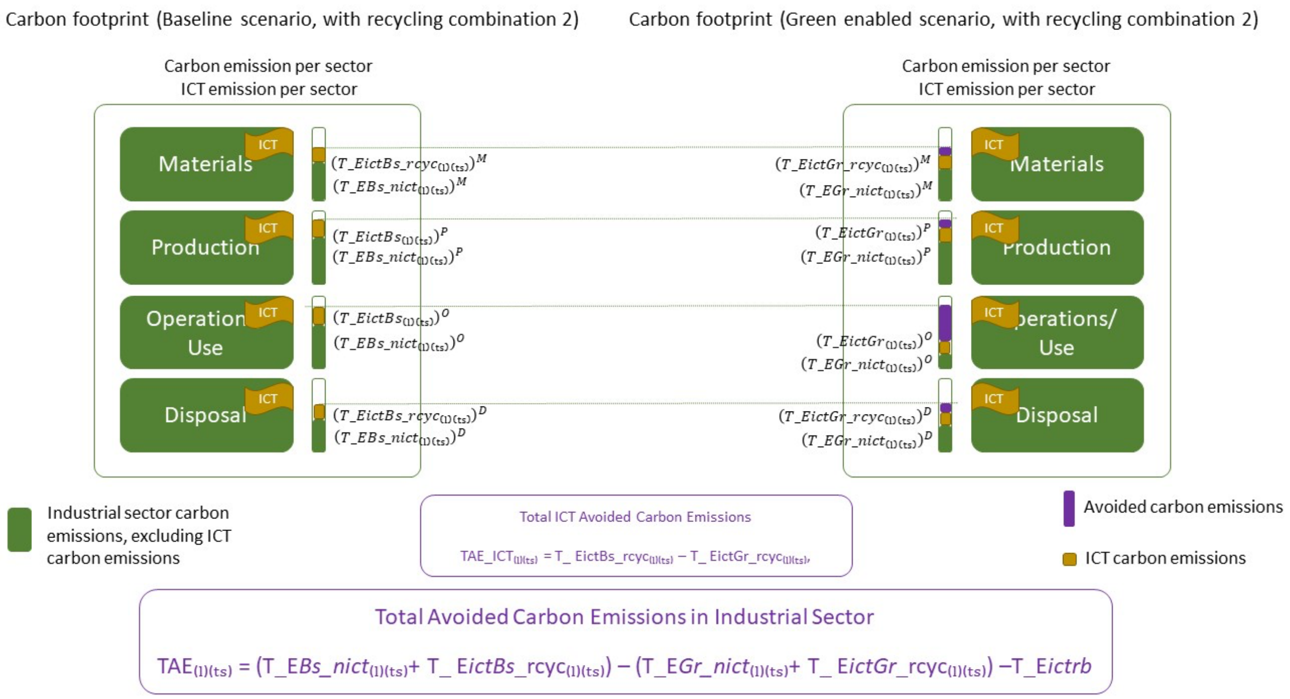

Figure 50: Visualisation of the Total avoided carbon emissions, when ICT is applied as an enabling technology, for recycling combination 2

Recycling combination 3:

In this recycling combination, see **Figure 51**, it is considered that in the Baseline scenario (Bs) and the Green enabled scenario (Gr) all the entities/components can be recycled, so this recycling combination can be considered as being a merge of recycling combination 1 and recycling combination 2.

In this recycling combination, Equation 1 becomes:

Equation 23: $TAE_{(l)(ts)} = (T\_EBs\_rcyc\_nict_{(l)(ts)} + T\_\ EictBs\_rcyc_{(l)(ts)}) - (T\_EGr\_rcyc\_nict_{(l)(ts)} + T\_\ EictGr\_rcyc_{(l)(ts)}) - T\_Eict_{RB},$

Where all the terms used in this equation are derived as introduced in recycling combinations 1 and 2.

The equation for Total recycled ICT Avoided Carbon Emissions for the recycling combination 3 becomes:

Equation 24 $TAE\_ICT\_rcyc_{(l)(ts)} = T\_\ EictBs\_rcyc_{(l)(ts)} - T\_\ EictGr\_rcyc_{(l)(ts)},$

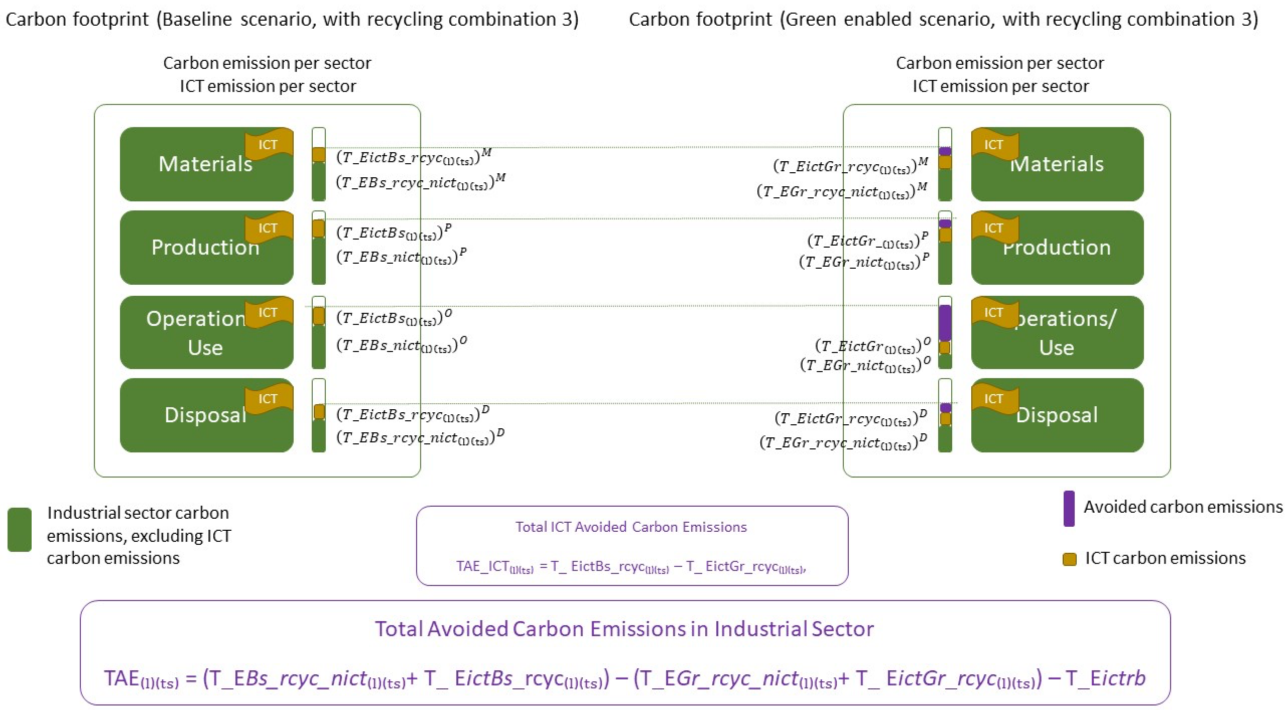

Figure 51: Visualisation of the Total avoided carbon emissions, when ICT is applied as an enabling technology, for recycling combination 3

Recycling combination 4:

In this recycling combination, see **Figure 52**, it is considered that (1) the Baseline scenario is not being recycled and (2) the Green enabled scenario (Gr) include entities/components that are recycled, but no entities/components used by the ICT infrastructures, i.e., *ictBs* and *ictGr* are being recycled.

In this recycling combination, Equation 1, becomes:

Equation 25: $\boldsymbol{TAE_{(l)(ts)} = (T\_EBs\_nict_{(l)(ts)} + T\_\ EictBs_{\ (l)(ts)}) - (T\_EGr\_rcyc\_nict_{(l)(ts)} + T\_\ EictGr_{\ (l)(ts)}) - T\_Eict_{RB},}$

Where all the terms used in this equation are derived as introduced in recycling combinations 1.

Note that the equation for Total ICT Avoided Carbon Emissions as depicted in *Equation* 6, applies as well for this recycling combination.

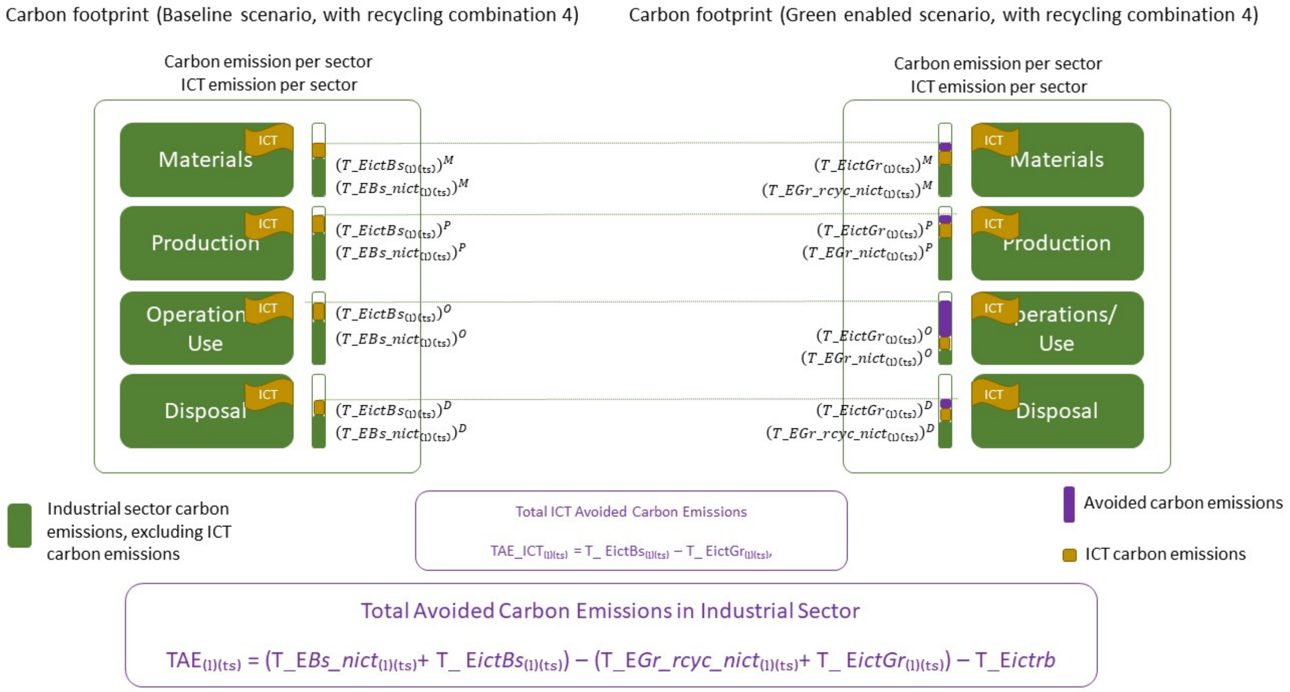

Figure 52: Visualisation of the Total avoided carbon emissions, when ICT is applied as an enabling technology, for recycling combination 4

Recycling combination 5:

In this recycling combination, see **Figure 53**, it is considered that (1) the Baseline scenario is not being recycled and (2) in the Green enabled scenario (Gr) the only entities/components that are recycled are the ones used by the ICT infrastructure, i.e., *ictGr*.

In this recycling combination, Equation 1, becomes:

Equation 26: $TAE_{(l)(ts)} = (T\_EBs\_nict_{(l)(ts)} + T\_ EictBs_{(l)(ts)}) - (T\_EGr\_nict_{(l)(ts)} + T\_ EictGr\_rcyc_{(l)(ts)}) - T\_Eict_{RB},$

Where all the terms used in this equation are derived as introduced in recycling combinations 2.

The equation for Total recycled ICT Avoided Carbon Emissions for the recycling combination 5 becomes:

Equation 27 $TAE\_ICT\_rcyc_{(l)(ts)} = T\_ EictBs_{(l)(ts)} - T\_ EictGr\_rcyc_{(l)(ts)},$

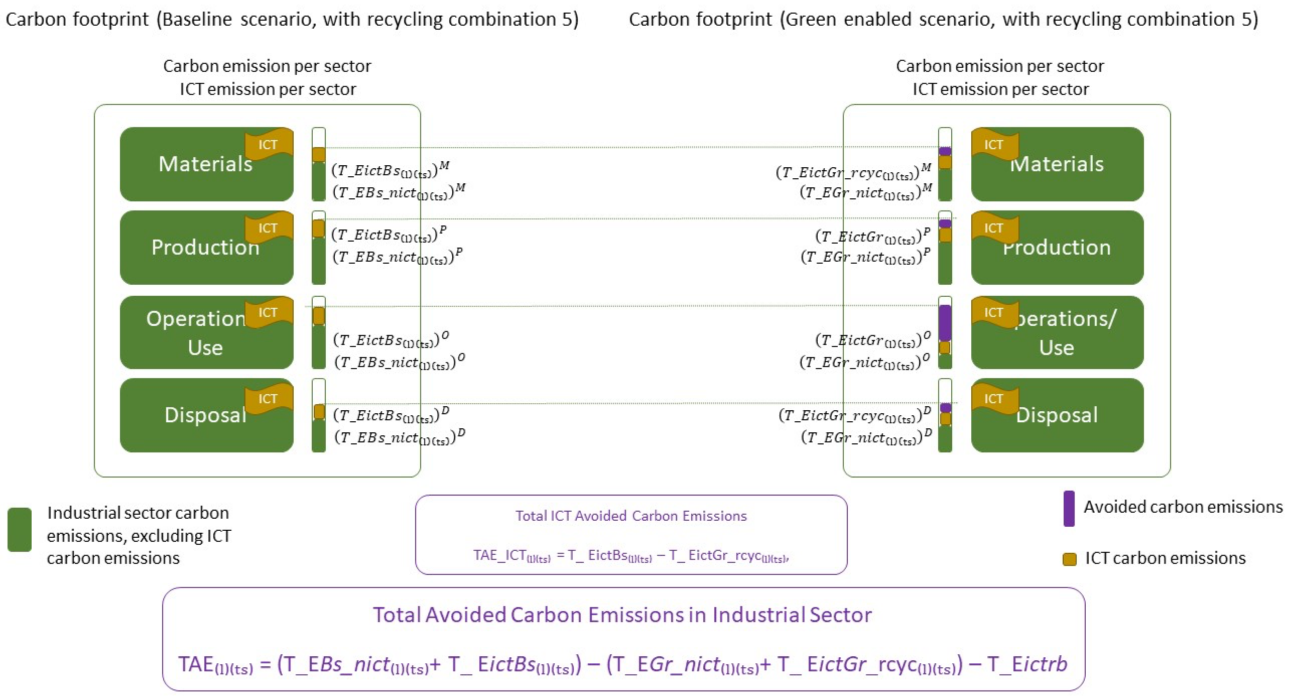

Figure 53: Visualisation of the Total avoided carbon emissions, when ICT is applied as an enabling technology, for recycling combination 5

Recycling combination 6:

In this recycling combination, see **Figure 54**, it is considered that (1) the Baseline scenario is not being recycled and (2) in the Green enabled scenario (Gr) all the entities/components can be recycled, so this recycling combination can be considered as being a merge of recycling combination 4 and recycling combination 5.

In this recycling combination, Equation 1, becomes:

Equation 28: $\mathbf{TAE_{(l)(ts)} = (T\_EBs\_nict_{(l)(ts)} + T\_\ EictBs_{(l)(ts)}) - (T\_EGr\_rcyc\_nict_{(l)(ts)} + T\_\ EictGr\_rcyc_{(l)(ts)}) - T\_Eict_{RB}},$

Where all the terms used in this equation are derived as introduced in recycling combinations 2.

The equation for Total recycled ICT Avoided Carbon Emissions for the recycling combination 6 becomes is equal to the one derived for the recycling combination 5:

Equation 29 $\mathbf{TAE\_ICT\_rcyc_{(l)(ts)} = T\_\ EictBs_{(l)(ts)} - T\_\ EictGr\_rcyc_{(l)(ts)}},$

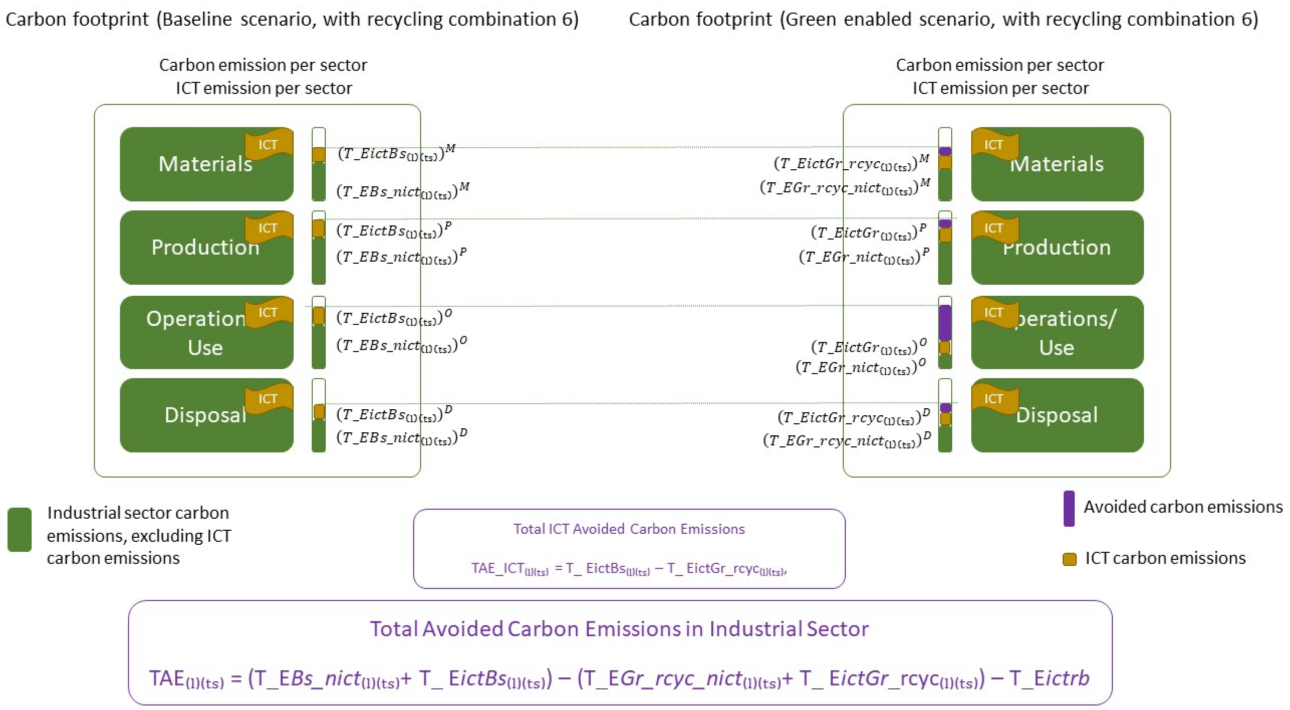

Figure 54: Visualisation of the Total avoided carbon emissions, when ICT is applied as an enabling technology, for recycling combination 6

6.5 Examples considering ITU-T SG5 / ETSI TC EE recommendation based on ITU-T Recommendation (rev)L.1480

The examples included in this section follow the guidelines specified in the current version of ITU-T L.1480 specification. However, in addition these examples apply the equation proposed in ITU-T SG5 ETSI TC EE EEPS(24)000041 on simplified avoided emissions calculation, see Equation 30, on calculating the avoided carbon emissions in an industrial sector, when ICT is used to reduce carbon emissions in the described use cases.

6.5.1 Simplified avoided emissions calculation

This section shows an equation that can be used for a simplified avoided emission calculation and that was presented in the ITU-T SG5 / ETSI TC EE EEPS(24)000041 contribution, see Section 6.5.2 and is based on [Andrae2024] and [OmBe2023].

The ITU-T SG5 is working on the revision of the ITU-T Recommendation L.1480 and this example was provided as an input to the ongoing discussions. For more, please see ***here***.

Equation 30: $F_{AC_i} = F_{C_{SOE}} - \left(F\_C_{FOE,ICTS} + F\_C_{RB}\right)$

Where:

F_AC_i= All avoided CO2e emissions from the use of ICT solution *i* at hand per functional unit. Note that this equation can be denoted as well *net* second order effect of the ICT solution

F_C_{SOE}= All CO2e emission changes in the studied product system per functional unit created by the use of ICT solution *i*. This is the second order effect.

$F\_C_{FOE,ICTS}$= All ICT related CO2e emissions from studied product system per functional unit for the use of ICT solution scenario. This is the first order effect.

F_C_{RB}= All emissions CO2e emissions for higher order effects including rebound from studied product system per functional unit for the ICT solution scenario.

i = type of ICT solution.

6.5.2 Example: 5G and improved sustainability in action – Healthcare

This example is designed by Dr. Anders S.G. Andrae from Huawei Technologies Sweden AB and is based on [Andrae2024] and as well on [Analysis_Mason2020] and and [OmBe2023].

The ITU-T SG5 is working on the revision of the ITU-T Recommendation L.1480 and this example was provided as an input to the ongoing discussions. For more, please see ***here***.

The assessment example (pages 26-28 in [Analysis_Mason2020]) is ex-ante although the replacement of on-site CT consultations with 5G-enabled CT consultations is common since 2019 in China.

In particular, since the middle of 2019, hospitals in less-affluent tier-three cities in China have replaced on-site CT consultations with 5G-enabed remote CT consultations.

According to [Analysis_Mason2020], the 5G-enabled CT consultations can achieve environmental benefits compared to face-to-face consultations, as the GHG emissions of vehicles and aircrafts previously used by the medical experts are completely eliminated, at the cost of additional monitors to display CT scans and high-throughput, In the baseline scenario (**Figure 55**) there are 4 employees living in City 1 using one car each travelling 40 km to the airport. They then travel to City 2 where they spend 8 hours at a hospital in City 2 on 24 consultations involving CT scans provided by the CT Machine in City 2 hospital. They use one CT Monitor and one PC. They then travel 40 km in one car each from the airport in City 1 to their homes.

Cut-off: 4 employees air travel from City 1 to City 2. 4 employees travel from City 2 airport to the hospital in City 2.

Airplane emissions cannot be assumed to be affected in this case study. However, if included as in [Analysis_Mason2020], they would be very large per functional unit. [Analysis_Mason2020] lacks information about the details for transport of the 4 employees from City 2 airport to the hospital in City 2.

In the ICT Solution scenario (**Figure 56**), the 4 employees living in City 1 spend 13 hours per day at a hospital in City 1 on 24 consultations involving CT scans. They use 3 CT Monitors and 3 PCs for collaboration features and multi-screen discussions, analysing the pictures from the CT machine (facilitated by 5G networks and data centres) located in City 2 hospital

Cut-off: 4 employees commuting from homes in City 1 to the hospital in City 1. [Analysis_Mason2020] lacks information about the details for transport of the 4 employees commuting from homes in City 1 to the hospital in City 1.

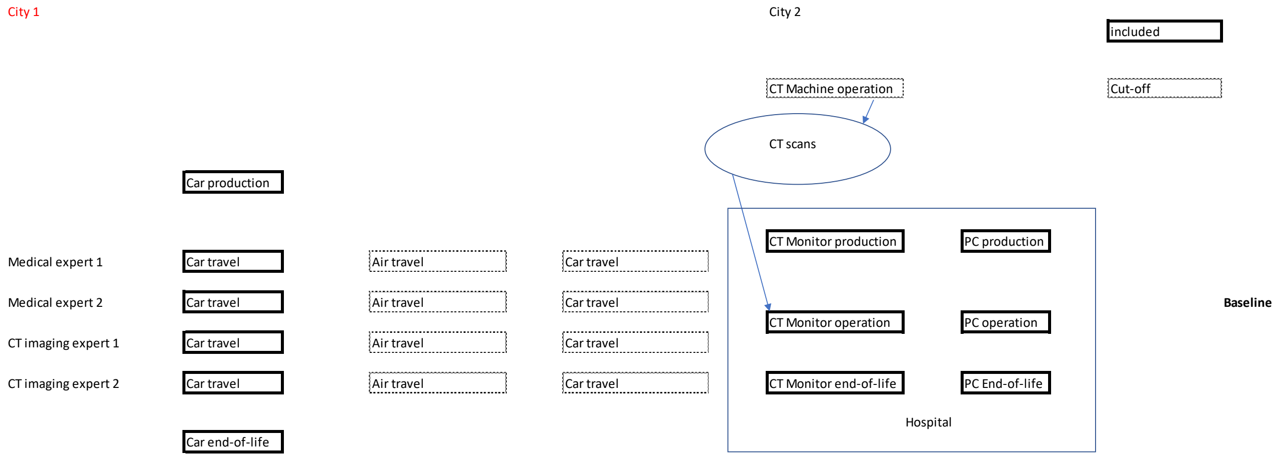

Figure 55: System boundary, studied product system and cut-off for baseline scenario.

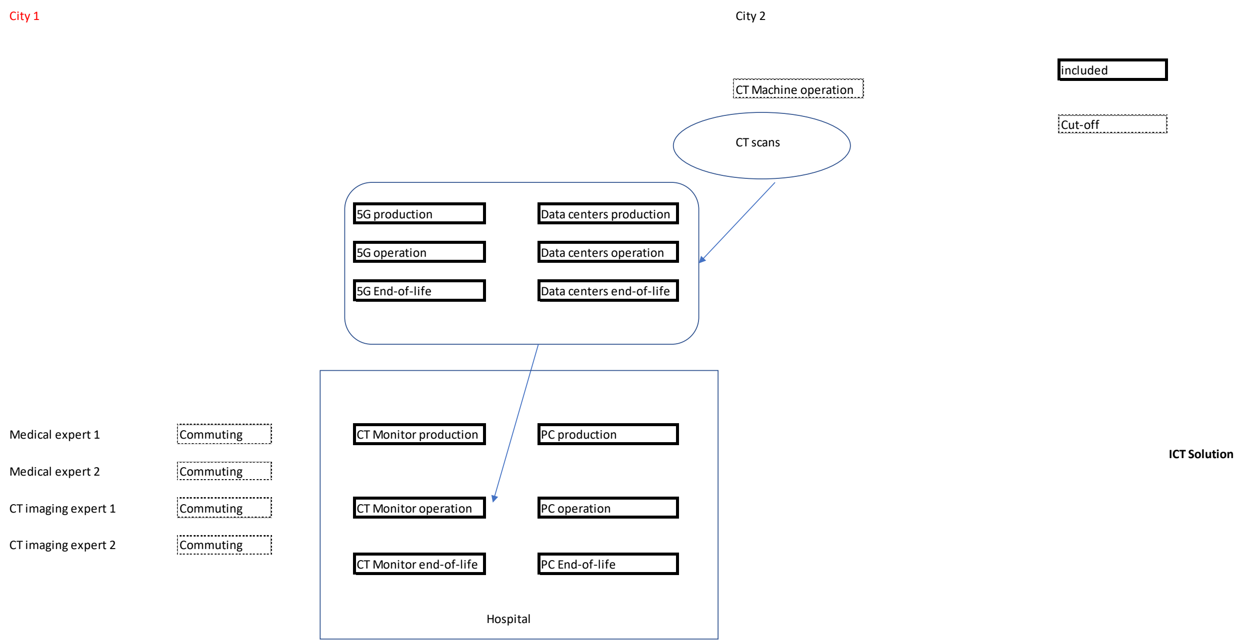

Figure 56: System boundary, studied product system and cut-off for ICT Solution scenario.

The assessment is considering the effects of one ICT solution implemented in a specific context, assessed for a specific time interval. The expected changes in emissions from the usage of ICT solution are targeted.

Here follows a description and example of calculation following Equation 30.

Description of solution:

5G enables remote health consultation such as analysis of CT scans [Analysis_Mason2020].

This reduces the need for some travelling to complete the same task, thus reducing fuel usage and associated GHG emissions.

The baseline is on-site consultation of CT scans.

The ICT Solution is remote consultation of CT scans.

Deployment of ICT solution:

The ICT solution is currently being deployed in China. The ICT solution has the potential to be deployed widely.

Functional unit:

“A health consultation subsystem for 24 consultations per day involving analysis of CT scans to be suited for the needs of the purchasing customer”.

Reference scenario:

The reference scenario is that 2 medical experts and 2 CT imaging experts travel in total 80 km each by car to and from the airport. They use 1 PC and one CT Monitor for 8 hours in and make 24 consultations in the city they travelled to.

Description of second order effects:

As the main second order effect, the 5G solution enables remote consultation and therefore saves fuel and the associated GHG emissions from car travelling.

Description of higher order effects:

The cars not used to drive to the airport could be used for other travel. The money saved from avoiding air travel could be spent on other activities.

Digital components:

PCs, CT Monitors, 5G Network, Data Center.

First order effects:

The first order effects calculation captures the life cycle emissions for the ICT solution per functional unit, considering the average GHG emissions associated with average Chinese electricity grids.

Second order effects:

The second order effects calculation captures GHG savings achieved through the solution, in this case study by reducing car travel.

Higher order effects:

The main higher order effects calculation captures the increased emissions from extra car travelling. However, with the available data such a calculation cannot currently be made. Still twice the first order effect is added to the calculation.

Long-term higher order effects:

Long-term higher order effects are that the medical experts (two CT imaging experts and two medical experts) no longer have to make regular flights to non-metropolitan cities, and they make additional time savings due to avoiding flight delays and traffic jams on the way to and from the airports.

Adverse environmental and social effects:

A minority of patients from non-metropolitan cities who might otherwise take time off work to travel to metropolitan cities need not undertake such journeys, thus eliminating a major cause of disruption to their and their families' lives.***Table 4*** shows the parameter comparison for Health Consultation Technology comparison.

Table 4: Parameter comparison for Health Consultation Technology comparison

Parameters	Reference scenario	ICT Solution scenario
People	4	4
Cars	4	0
Consultations	24/day	24/day
Work time	8 hours	13 hours
Car travel	320 km	0

Airplane travel (not included in analysis)	8000 km	0
PCs	1	3
Computerized Tomography (CT) Monitors	1	3

Table 5 shows the detailed description of the parameters and calculations.

Table 5: Items, descriptions and calculations for health consultation avoided emissions case study.

Item	Description
Goal	Health Consultation Technology comparison, effect of digitalization
Scope	CO$_2$e emissions resulting from • driving of the petrol vehicle during on-site consultation • production of the petrol • production and end-of-life treatment of the petrol vehicle • use of personal computers (PCs) and CT monitors • production and end-of-life treatment of PCs and CT monitors • use of wireless networks for 5G for the remote consultation • use of data centers for the remote consultation. • production and end-of-life treatment of wireless networks for 5G for the remote consultation. • production and end-of-life treatment of data centers for the remote consultation.

System related avoided emissions

	Reference Scenario	*ICT Solution scenario*
Description	On-site consultation	Remote 5G enabled health consultation
System Boundary	Use, production and end-of-life stages for 24 consultations in China on average.	Use, production and end-of-life stages for 24 consultations in China on average.
Function	Providing health consultation of computerized tomography (CT) scans.	
Functional unit	"A health consultation subsystem for 24 consultations per day involving analysis of CT scans to be suited for the needs of the purchasing customer".	

Avoided emissions calculations

Calculation formula:

Avoided emissions = Second order effect – (First order effect of ICT Solution scenario including induction + Higher order effects including rebound)

Reference scenario:

Parameter	**Value**	**Unit**	**Comment**
Reference scenario			
Car transport	320	km	Distance driven in total for all cars used
Cars	4	pieces	Number of cars used
Car distance	250000	km	Lifetime distance per car
Car assembly electricity	8340	kWh	Electricity used to assemble one car
Carbon intensity of electricity	0.6	kgCO$_2$e/kWh	Average carbon intensity for the area in which the ICT Solution is produced and used
Car manufacturing non-electricity	5000	kgCO$_2$e/car	Upstream carbon emissions from cradle-to-gate
Petrol consumption	5.58	dm^3	Petrol used per 100 km
Density petrol	0.73	kg/dm^3	Petrol average density
Petrol manufacturing electricity	0.375	kWh/kg	Electricity used to manufacture one kg of petrol from cradle-to-gate
Petrol manufacturing non-electricity	0.225	kgCO$_2$e/kg	CO$_2$e released when manufacturing one kg petrol from cradle-to-gate
Carbon emission car use	2.31	kgCO$_2$e/dm^3	Tailpipe emission per dm^3 for average petrol car
PCs	1	pieces	Number of PCs used
Time PC use	8	hours	Time each PC is used

PC manufacturing electricity	202	kWh/PC	Electricity needed to manufacture one PC cradle-to-gate
PC manufacturing non-electricity	121.4	kgCO_2e/PC	CO_2e released when manufacturing one PC cradle-to-gate
Annual hours	8760	hours	Hours during 1 year
Lifetime PC	4	years	Average lifetime of new PC
Power consumption PC	0.01	kW	Average power use of new PC
CT Monitors	1	piece	Number of CT Monitors used
Time CT Monitor use	8	hours	Time each CT Monitor is used
CT Monitor manufacturing electricity	222	kWh/Monitor	Electricity needed to manufacture one CT Monitor cradle-to-gate
Monitor manufacturing non-electricity	200	kgCO_2e/Monitor	CO_2e released when manufacturing one CT Monitor cradle-to-gate
Lifetime CT Monitor	4	years	Average lifetime of new CT monitor
Power consumption CT Monitor	0.01	kW	Average power use of new CT Monitor

ICT Solution scenario:

Parameter	**Value**	**Unit**	**Comment**
ICT Solution Scenario			
Carbon intensity of electricity	0.6	kgCO_2e/kWh	Average carbon intensity for the area in which the ICT Solution is produced and used
PCs	3	pieces	Number of PCs used
Time PC use	13	hours	Time each PC is used. Additional time savings due to avoiding flight delays and traffic jams on the way to and from the airports is added.
PC manufacturing electricity	202	kWh/PC	Electricity needed to manufacture one PC cradle-to-gate
PC manufacturing non-electricity	121.4	kgCO_2e/PC	CO_2e released when manufacturing one PC cradle-to-gate
Annual hours	8760	hours	24hours×365 days
Lifetime PC	4	years	Average lifetime of new PC
Power consumption PC	0.01	kW	Average power use of new PC
CT Monitors	3	pieces	Number of CT Monitors used
Time CT Monitor use	13	hours	Time CT Monitors are used. Although the same number of consultations are performed as in the on-site baseline scenario, the remote ICT Solution scenario fosters more use of the CT Monitors and PCs.
CT Monitor manufacturing electricity	222	kWh/CT Monitor	Electricity needed to manufacture one Monitor/Screen cradle-to-gate

CT Monitor manufacturing non-electricity	200	kgCO_2e/CT Monitor	CO_2e released when manufacturing one CT Monitor, cradle-to-gate
Lifetime CT Monitor	4	years	Average lifetime of new monitor
Power consumption CT Monitor	0.01	kW	Average power use of new CT monitor

Parameter	**Value**	**Unit**	**Comment**
ICT Solution Scenario			
Data volume	5	GB/hour	Average data consumption of ICT Solution
Time solution use	13	hours	Time ICT Solution is used
Power	7	kW	Average power use of 5G Equipment
Throughput	0.05	GB/s	Average data throughput of 5G Equipment
PUE	1.3		PUE of 5G Equipment
Carbon intensity of electricity	0.6	kgCO_2e/kWh	Average carbon intensity for the area in which the ICT Solution is produced and used
Mass	200	kg	Mass of 5G Equipment
Carbon intensity of Equipment	20	kgCO_2e/kg	Average carbon intensity for 5G upstream production
Lifetime Equipment	5	years	Average lifetime of 5G Equipment
Electricity use	10230	(kWh/year)/kW	Annual electricity use by data center at hand
Equipment used	1585590	kg/year	Mass of equipment and infrastructure used in data center per year [WhAn2015]
Power use	15064.3	kW	Power use data center at hand [WhAn2015]
Global Data Center IP traffic	4.7×10^{13}	GB/year	Annual Data flowing to/from, within and between data centers [AnEd2015]
Power use	4.7×10^{7}	kW	Power use globally of data centers [AnEd2015]
Carbon intensity	10	kgCO_2e/kg	Carbon intensity of data center materials (all kinds)

Baseline of Reference scenario:
320km × (4 cars/250000km × ((8340kWh×0.6 kg CO_2e/kWh)+5000) kg CO_2e/car)) {Petrol car production}
+ 320km× ((5.58dm^3/100km×0.73kg/dm^3×(0.375kWh×0.6 kg CO_2e/kWh + 0.225 kgCO_2e/kg)) {Petrol manufacturing}
+ 320km×(5.58dm^3/100km×2.31 kgCO_2e/dm^3) {Use of petrol car}
+ 0.5122 kgCO_2e {End-of-life treatment of petrol cars}

+ 1 PC×8hours×((202kWh×0.6 kg CO_2e/kWh + 121.4 kg CO_2e/PC))/(4years×8760hours)
+ 0.01kW×0.6 kg CO_2e/kWh) {PC production and use}
+ 0.00055 kgCO_2e {End-of-life treatment of PC}
+ 1 CT monitor×8hours×((222kWh×0.6 kg CO_2e/kWh
+ 200 kg CO_2e/CT Monitor))/(4years×8760hours) + 0.01kW×0.6 kg CO_2e/kWh)) {CT Monitor production and use}
+ 0.00091 kgCO_2e {End-of-life treatment of CT Monitor}
= 99.074 kg CO_2e/24 consultations

Second order effect:
The ICT Solution results in reduced travel which translates to decreased CO_2e emissions.
320km × (4 cars/250000km × ((8340kWh×0.6 kg CO_2e/kWh)+5000) kg CO_2e/car)) {Petrol car production}
+ 320km× ((5.58dm^3/100km×0.73kg/dm^3×(0.375kWh×0.6 kg CO_2e/kWh + 0.225 kgCO_2e/kg)) {Petrol manufacturing}
+ 320km×(5.58dm^3/100km×2.31 kgCO_2e/dm^3) {Use of petrol car}
+ 0.5122 kgCO_2e {End-of-life treatment of petrol cars}
= 98.84 kg CO_2e/24 consultations

First order effect of ICT Solution scenario including induction:
3 PCs×13hours×((202kWh×0.6 kg CO_2e/kWh + 121.4 kg CO_2e/PC))/(4years×8760hours)
+ 0.01kW×0.6 kg CO_2e/kWh) {PC production and use}
+ 0.0027 kgCO_2e {End-of-life treatment of PCs}
+ 3 CT monitors×13hours×((222kWh×0.6 kg CO_2e/kWh}
+ 200 kg CO_2e/CT Monitor))/(4years×8760hours) + 0.01kW × 0.6 kg CO_2e/kWh)) {CT Monitors production and use}
+ 0.00445 kgCO_2e {End-of-life treatment of CT Monitor}

+ 5GB/hour×13hours×7kW/(0.05GB/s) × 1/1000 kJ/MJ×1/3.6 MJ/kWh×1.3×0.6kgCO_2e/kWh {5G wireless network use
+ 5GB/hour×13hours/(0.05×3600 GB/h) × (200 kg×20kgCO_2e/kg)/(5×8760 hours) {5G wireless network production}
+ 0.0003 kgCO_2e {End-of-life treatment of 5G hardware}
+ 5GB/hour×13hours×(10230 kWh/kW/year) × 1/(4.7×10^{13} GB/year)/(4.0×10^{7} kW)×0.6kgCO_2e/kWh {data centres use}
+ 5GB/hour×13hours × (1585590 kg/year×10kgCO_2e/kg)/(15064.3 kW) × 1/(4.7×10^{13} GB/year)/(4.0×10^{7} kW) {data centers production}
+ 0.0006 kgCO_2e {End-of-life treatment of Data Centers}
= 3.519 kg CO_2e/24 consultations

Higher order effects:
Assumed as twice the total first order effect (7.038 kg CO2e/24 consultations) rounded upwards to the nearest order of magnitude, so around **10 kg CO_2e/24 consultations.**
EoLT emissions:
Assumed as 1% of production emissions, i.e. insignificant.
Avoided emissions = 98.84 – (3.519 + 10) = **85.321 kg CO_2e per 24 health consultations.**

Figure 57 shows the results graphically.

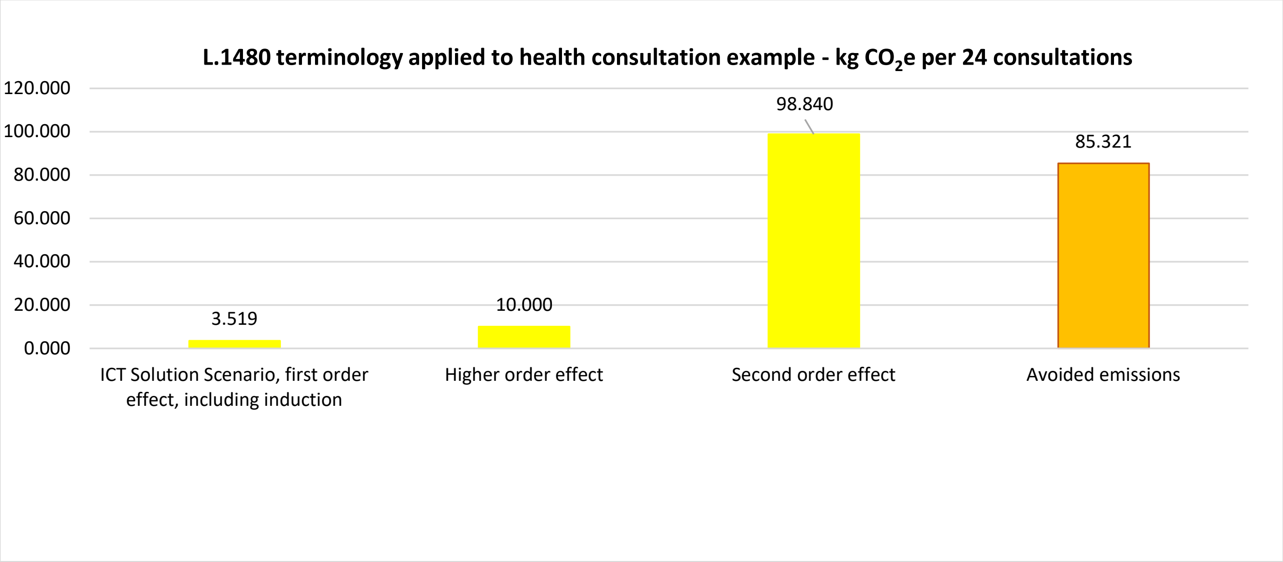

Figure 57: Health consultation avoided emissions shown by effect.

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6.5.3 Example: Windfarm Use Case, using the "simplified avoided emissions calculation"

This use case, see **Figure 58** is showing the benefits of using a Smart Monitoring System in a windfarm to: (1) reduce maintenance efforts and (2) reduce the loss of wind energy production due to maintenance works.

Figure 58: Smart Monitoring System in a Windfarm, based on Fraunhofer IIS - Q-Bo® Technology

Note that this example follows the guidelines specified in the current version of ITU-T L.1480 specification. However, this example applies the equation proposed in ITU-T SG5 ETSI TC EE EEPS(24)000041 on simplified avoided emissions calculation, see Equation 30, on calculating the avoided carbon emissions in an industrial sector, when ICT is used to reduce carbon emissions in the windfarm use case.

*The ITU-T SG5 is working on the revision of the ITU-T Recommendation L.1480 and this example was provided as an input to the ongoing discussions. For more, please see **here**.*

Table 6 uses as much as possible the clause “7. Guidance on how to use this Recommendation”, from ITU-T L.1480. However, shows that the calculation in the present example covers the specified items for Tier 3 according to Table 2 (of L.1480).

A preliminary consequence tree of the ICT solution in the windfarm use case has been added and shown in **Figure 62**.

Table 6: Checklist for assessment depth and Tier 3 assessment depth of present case study

Specification	Tier 3 in Table 2 (of L.1480)	Present case study
Type	Screening / first approximation	Yes
Lifecycle stages	All (as material)	All
Data quality	Secondary (generic, proxies, averages)	Generic
ICT solution boundaries	Full life cycle	Full life Cycle
Reference scenario boundaries	Full life cycle	No: Use cycle
Data coverage and cut-off within boundaries	Proxy data used to cover data gaps. Cut-off rules apply	Cut-off rules apply
Second order effects including induction	Yes	Yes
Higher order effects	Should be identified	Yes
Long term effect of any order	To be identified and reported. Considered in accordance with Tier 3 rules.	Yes
Adverse environmental and social effects	To be identified and reported. Considered in accordance with Tier 3 rules.	Yes
Contextual factors	Should be identified	Yes

This assessment example is an **ex-ante** case.

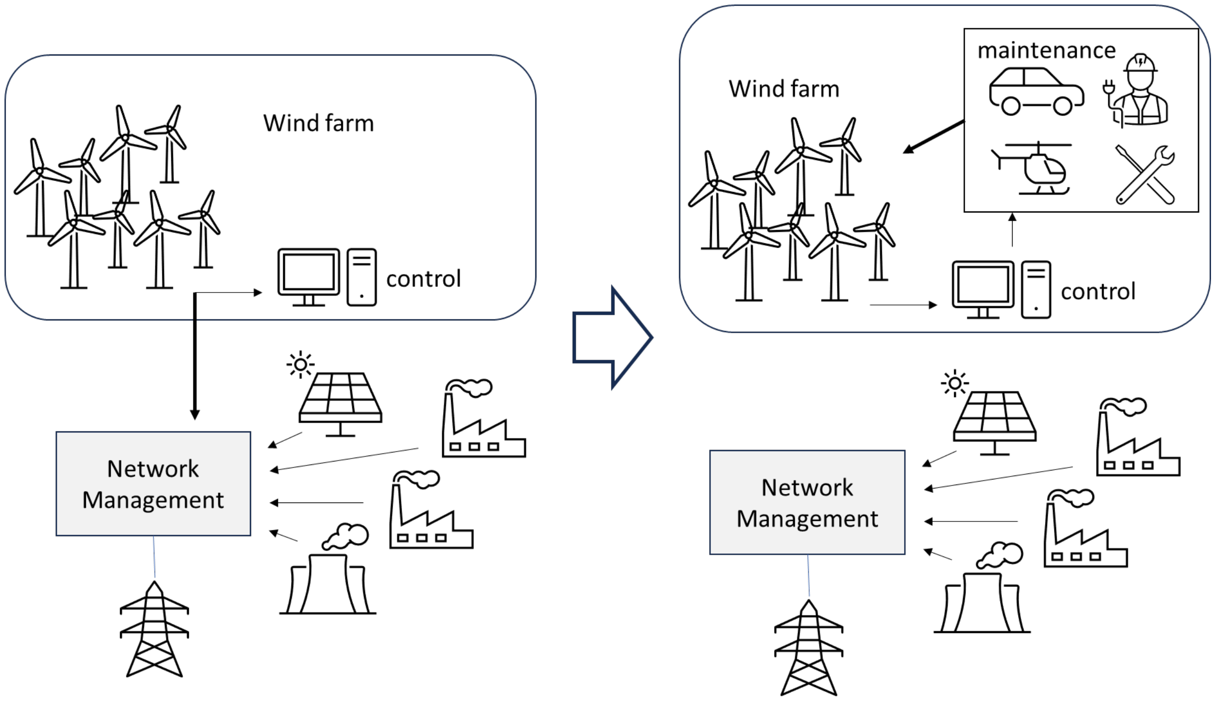

Figure 59: System boundary studied product system for baseline scenario.

ICT solution: Smart remote monitoring of screw connections of wind turbines

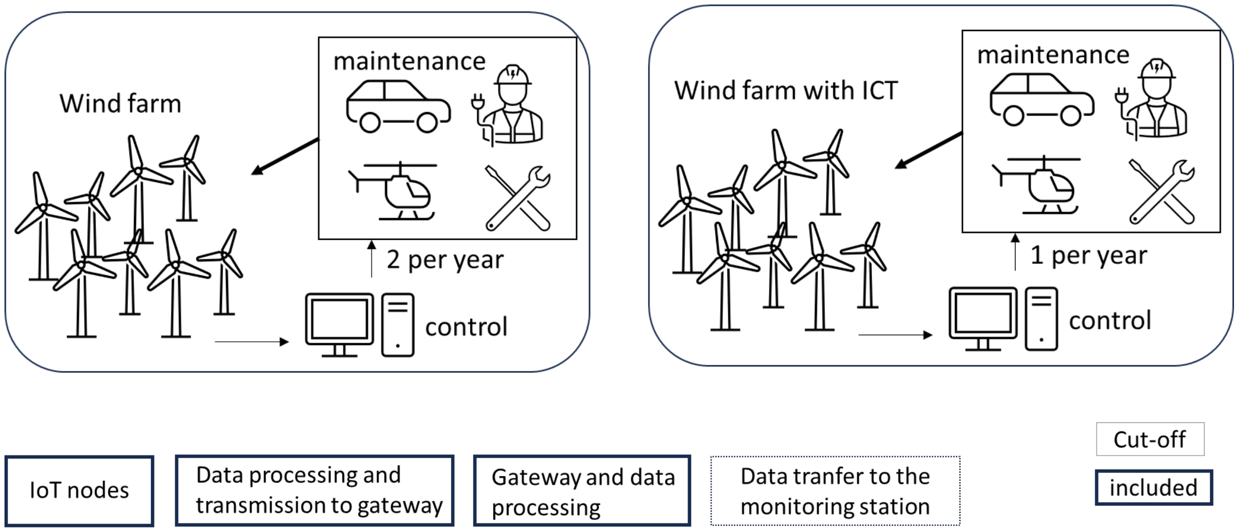

Figure 60: System boundary studied product system and cut-off for the ICT Solution scenario.

The impact of the data transfer to the monitoring station is not included since it depends on the windfarm installation.

This table shows the key parameters of the case study.

Table 7 Key parameters of the case Maintenance of wind turbines in Europe

Parameters	***Reference scenario***	*ICT Solution scenario*
Maintenances on site over the lifetime of 10 years	20	10
Not produced energy during maintenance to be replaced by local mixed Energy sources	160 hours	80 hours
Transport for maintenance (not included in this analysis)	Car, boot, helicopter	Car, boot, helicopter (1/2 from the reference scenario avoided)
Smart screw monitoring system	No	Yes

Item	Description	
Goal	Reduce maintenance effort in onshore and offshore wind farms using a smart screw monitoring ICT solution	
Scope	CO_2e emissions resulting from • Replacement of the not produced wind energy with energy from mixed sources • Transport to the wind farm location	
System related avoided emissions		
	Reference Scenario	*ICT Solution scenario*
Description	On site maintenances – 2 per year over 10 years	Reduction to half of the maintenances on site and continuous monitoring of the screw connections
System Boundary	• 20 maintenances on site for all wind turbines in Europe. • A maintenance on site lasts a day. • A turbine produces 8h wind energy per day in average. • No production of wind energy during 160h to be replaced by mixed energy sources	• 10 maintenances on site for all wind turbines in Europe. • A maintenance on site lasts a day. • A turbine produces 8h wind energy per day in average. • No production of wind energy during 80h to be replaced by mixed energy sources
Function	Providing remote screw monitoring for wind farms maintenance purpose.	
Functional unit	"A remote screw monitoring solution for wind farm".	
Avoided emissions calculations		

Calculation formula, see Equation 30:

$$F\_AC_i = F\_C_{SOE} - (F\_C_{FOE,ICTS} + F\_C_{RB})$$

F_AC_i : All avoided CO2e emissions from the use of ICT solution i at hand per functional unit.
F_C_{SOE} : All CO2e emission changes in the studied product system per functional unit created by the use of ICT solution i. This is the second order effect.
$F\_C_{FOE,ICTS}$: All ICT related CO2e emissions from studied product system per functional unit for the use of ICT solution scenario. This is the first order effect.
F_C_{RB} : All emissions CO2e emissions for higher order effects including rebound effects from studied product system per functional unit for the ICT solution scenario

With the specific case in this case study:
F_C_{RB} includes the impact of the transport due to reduced maintenance effort in the ICT solution scenario compared to the reference scenario

The second order effect is focusing on the replacement of not produced wind energy by mixed energy sources

Reference scenario:

Parameter	Value	Unit	Comment
Reference scenario			
Windpower installed capacity in Europe onshore	209.961	MW	statista 2024 / IRENA; ID 468679
Windpower installed capacity in Europe offshore	30.663	MW	statista 2024 / IRENA; ID 468679
Power wind turbine onshore	3,5	MW	From 2 MW – 5 MW here mean value
Number wind turbines onshore	60000	pieces	
Power wind turbine offshore	15	MW	
Number wind turbines offshore	2000	pieces	
Not produced wind energy because of maintenance on all onshore farms	1.680.000	MWh/maintenance	Based on 8h of loss of wind energy production per maintenance case
Not produced wind energy because of maintenance on all offshore farms	240.000	MWh/maintenance	Based on 8h of loss of wind energy production per maintenance case
Total Energy to be replaced	1.920.000	MWh/maintenance	For all onshore and offshore wind farms
Energy Mix	300	kgCO2e/MWh	This value takes into account the evolution over the next 10 years
CO2e because of the replacement energy	576.000.000 576.000	kgCO2e/maintenance tCO2e/maintenance	
CO2e because of the replacement energy	**11.520.000**	**tCO₂e**	CO₂e released because of energy replacement over 20 maintenances

ICT Solution scenario:

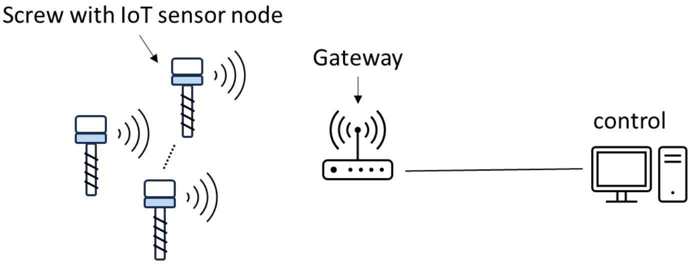

Figure 61: Components of the smart screw monitoring solution

Parameter	Value	Unit	Comment
ICT Solution Scenario			
Energy self-sufficient Screw monitoring IoT device	50	Units/turbine	Maximal number required for a reliable monitoring
Gateway	1	Unit/10 turbines	Very low power WLAN technology for IoT application ETSI TS 103 357
Gateway	1	W	Power consumption
Number of screw monitoring IoT nodes	3.100.000	units	For all onshore and offshore wind farms

Carbon Footprint of the screw IoT nodes (Material/production and EoL)	4,6	kgCO_2e	CO_2e released when manufacturing one IoT node
Carbon Footprint of the IoT node (in operation)	0	kgCO_2e	This IoT device is energy self-sufficient (energy harvester)
Total Carbon Footprint of one IoT node	4,6	kgCO_2e	CO_2e released for one smart screw IoT node Full life cycle
Number of Gateway	6200	units	For all onshore and offshore wind farms
Gateway Carbon Footprint (Material/production and EoL)	14	kgCO_2e	CO_2e released when manufacturing one gateway incl. EoL phase
Gateway Energy consumption in operation	87,6	kWh	Energy used over the 10 years
Gateway Carbon Footprint in operation	26	kgCO_2e	Energy used with the same Energy mix value as in the reference scenario
Total Gateway Carbon Footprint	40	kgCO_2e	CO_2e released for one gateway Full life Cycle
Total Footprint of the screw monitoring solution in Europe	14.509.736 **14.510**	kgCO_2e **tCO2e**	For all IoT nodes and Gateways in all screw monitoring installations in Europe

Parameter	**Value**	**Unit**	**Comment**
ICT Solution Scenario			
Maintenances on site	10		With the use of the smart screw monitoring solution the number of maintenances on site could be reduced to one annually – the remote monitoring system works continuously
Total Energy to be replaced	1.920.000	MWh/maintenance	For all onshore and offshore wind farms
Energy Mix	300	kgCO_2e/MWh	This value takes into account the evolution over the next 10 years
CO2e because of the replacement energy	576.000.000 576.000	kgCO2e/maintenance tCO2e/maintenance	
CO2e because of the replacement energy in the ICT scenarios	**5.760.000**	**tCO_2e**	CO_2e released because of energy replacement over 10 maintenances

Second order effect of Reference scenario:

(60.000 x 3,5MW + 2.000 x15MW) x 8h = 1.920.000 MWh {not produced wind energy because of one maintenance for all wind farms in Europe}

1.920.000 MWh x 300kgCO2e/MWh = 576.000.000 kgCO2e or 576.000 tCO2e {not produced wind energy because of one maintenance for all wind farms in Europe converted in Carbon footprint with a predicted mean value of the Energy Mix for the next 10 years}

576.000 tCO2e x 20 = 11.520.000 tCO2e {not produced wind energy because of maintenance service for all wind farms in Europe converted in Carbon footprint with a predicted mean value of the Energy Mix for the next 10 years}

Not produced wind energy = 11.520.000 tCO_2e

First order effect of Reference scenario:

Not included in this case study – this has no impact on the avoided emission calculation case study here. The reference installation is also use in the ICT solution scenario.

First order effect of ICT Solution scenario:

(60.000 + 2000) x 50 x 4,6 kgCO2e = 14.260.000 kgCO2e {smart screw IoT units full life cycle}

(60.000 + 2000) x 0,1 x 14 kgCO2e = 86.800 kgCO2e {gateways material, production and EoL phases}

(60.000 + 2000) x 0,1 x 1W x 24 x 365 x 10 = 543.120.000 Wh or 543,120 MWh {gateways energy consumption over 10 years}

543,120 MWh x 300 kg CO2e/MWh = 162.936 kgCO2e {gateways energy consumption over 10 years in carbon footprint with a predicted mean value of the Energy Mix for the next 10 years}

14.260.000 kgCO2e + 86.800 kgCO2e + 162.936 kgCO2e {all ICT solutions full life cycle}

$F\_C_{FOE,ICT}$ = 14.509.736 $kgCO_2e$

14.510 tCO2e for the ICT solution scenario in all windfarms in Europe and for a 10 years lifetime

Second order effect of the ICT solution scenario:

Using the smart screw monitoring solution in all windfarms in Europe the effect described in this study case is that the number of maintenances on site is reduced by a factor of 2**.**
This means that the carbon footprint resulting from the replacement of the not produced wind energy is also reduced by a factor 2.
This means that the emissions due to the replacement of the energy by mixed energy sources is in the case of the ICT solution scenario:
F_C_{SOE} = 11.520.000/2 = 5.760.000 tCO_2e

Higher order effect of the ICT solution scenario:
Reduction of transport carbon emission due to avoided maintenance. This affects positively the avoided emissions assessment.
Its positive impact has to be evaluated with concrete usecases

- onshore: car transport / distance from the maintenance service office to the onshore site
- offshore: transport with a car from the maintenance office to the shore and then with boot or helicopter to the offshore site– transport time and distance

To complete this usecase with a calculation of the transport impact as higher effect of the ICT solution we add following assumptions:

- the average transport time for the maintenance workforce is 1 hour both ways (onshore as offshore)
- the transport vehicle used for onshore windfarms is a transporter car with 7l diesel/100km with 17kgCO2e/h
- the transport vehicle used for offshore windfarms is a helicopter with 225l kerosin/h that means 570kgCO2e/h
- in order to determinate the number of transport ways required – one transport is related to a windfarm site and not to each turbine – we setup the number of
  - onshore farms in Europe to 2000 and
  - offshore farms in Europe to 68.

The Carbon footprint impact due to the higher effect transportation of the maintenance workers in Europe considering 20 maintenances (reference scenario) is:

- onshore: 17*0,001*2000*20= 680 tCO2e
- offshore: 570*0,001*68*20= 775,2 tCO2e

The total carbon footprint impact due to transportation of the maintenance workforce considering the assumptions is of 1455,2 tCO2e

In the ICT solution scenario, the impact of the maintenance transportation is reduced by 2 compared to the reference scenario. This means that its impact is **reduced to 727,6 tCO2e**

$F\_C_{RB} = - 727{,}6$ tCO2e

Adverse environmental effects:
The use of ICT in this scenario has an adverse environmental effect since at least half of the maintenance transport will not happen, this means that less pollution due to transport on the road or on the sea will be produced.

Possible rebound effects:

- Use the smart screw monitoring installation installing further IoT nodes for further purposes like environment sensing. This would increase the carbon footprint of the ICT solution as the data volume to be processed and transferred.
- Also adding camera for other environmental studies, but this means to change the edge (the involved radio communication is a low throughput/long range communication medium) to another more energy demanding remote communication system like 5G.
- Investment of the saved money - at least part of it - in new wind turbines

Contextual factors:

- national or European safety/security regulations regarding the maintenance of windfarms in the future

Avoided emissions: $F\_AC_i = F\_C_{SOE} - (F\_C_{FOE,ICTS} + F\_C_{RB})$

F_AC_i = 5.760.000 – (14.510 - 727) = **5.746.217 tCO_2e** or 574.622 tCO_2e/year

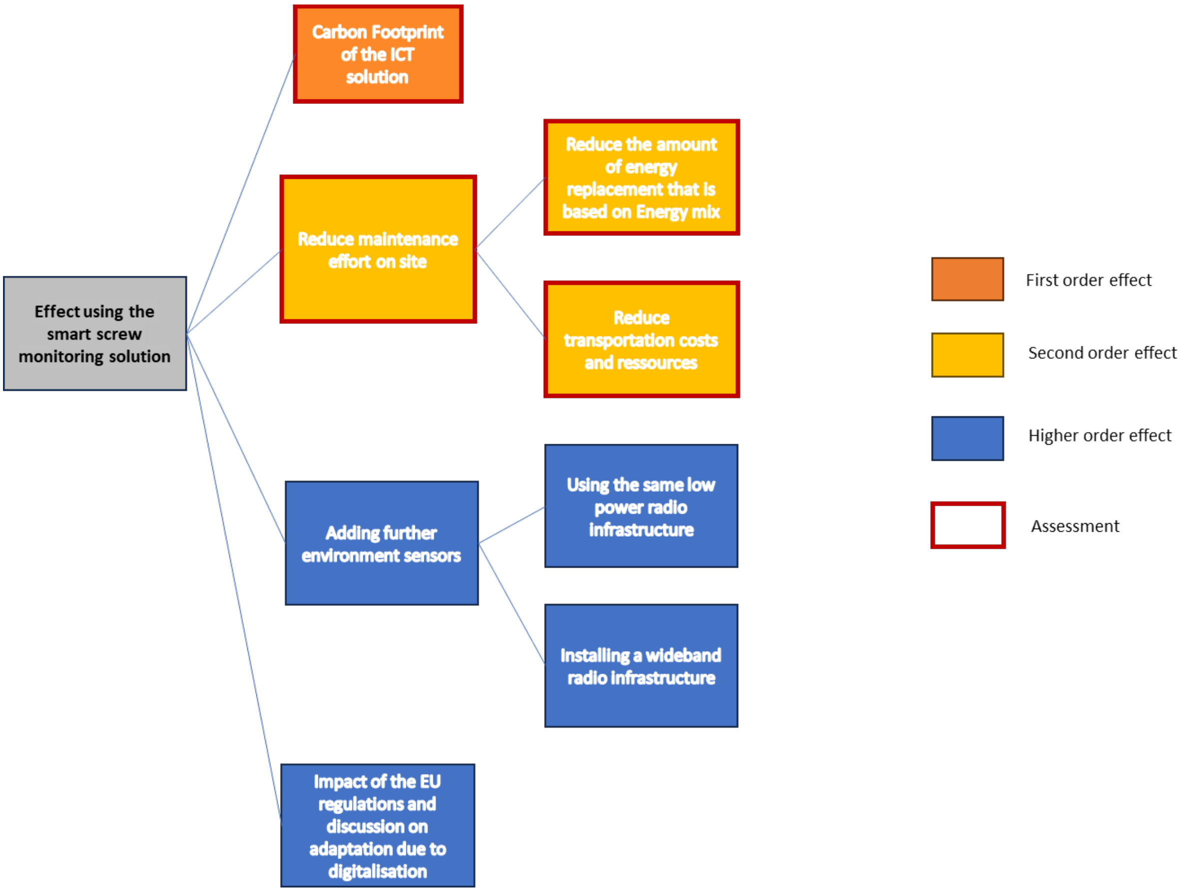

Figure 62: Consequence tree of the ICT solution in the windfarm use case

6.6 Examples considering AIOTI measurement methodology

This section includes examples of use cases that apply the guidelines specified in the current version of ITU-T L.1480 specification, but in addition it applies the AIOTI method and Equation 1, described in Section 6.4.3.1, as the quantification method of calculating the benefits of applying ICT to reduce carbon emissions in vertical industry sectors.

The ITU-T SG5 is working on the revision of the ITU-T Recommendation L.1480 and this example was provided as an input to the ongoing discussions. For more, please see ***here***.

6.6.1 Mapping of the AIOTI quantification method for the calculation of the *net* second order effect of the ICT solution in a standalone scenario to the simplified avoided emissions equation

This section provides a mapping of the equation proposed by AIOTI (Equation 1 shown in Section 6.4.3.1) as "total avoided carbon emissions in an industrial sector, when ICT is applied as a Green enabling technology" to Equation 30 shown in Section 6.5.1, see below:

- ***Equation 31:*** $F_{AC_{(l)(i)}} = F\_AC_{_{(l)(ts)}} = TAE_{(l)(ts)}$
- ***Equation 32:*** $F_{C_{SOE_{(l)(ts)}}} = T\_EBs\_nict_{(l)(ts)} + T\_EictBs_{(l)(ts)} - T\_EGr\_nict_{(l)(ts)}$
- ***Equation 33*** $F_{C_{FOE,ICTS_{(l)(ts)}}} = T\_EictGr_{(l)(ts)}$
- ***Equation 34*** $F\_C_{RB} = T\_Eict_{RB}$
- ***Equation 35*** $F_{AC_{(l)(i)}} = F\_AC_{_{(l)(ts)}} == T\_EBs\_nict_{(l)(ts)} + T\_EictBs_{(l)(ts)} - T\_EGr\_nict_{(l)(ts)} - T\_EictGr_{(l)(ts)} - T\_Eict_{RB}$

Where

- $F_{AC_{(l)(i)}} = F\_AC_{_{(l)(ts)}}$= All avoided CO$_2$e emissions from the use of ICT solution *i* (denoted in AIOTI equation as *ts* = Type of Service (e.g., the 5G type of services, provided by ITU-R)), at hand per functional unit and for a certain *Load* ("l" index); Note that "*l*" is an additional subscript (load factor) that is added to Equation 30 shown in Section 6.5.1.

- The "l" index is defined as the "percentage of (average bandwidth ICT infrastructure / total bandwidth that ICT infrastructure can handle). If "l=1", it means that the applied Load equals the total bandwidth that ICT infrastructure can handle;

- $F_{C_{SOE_{(l)(ts)}}}$= All CO$_2$e emission changes in the studied product system per functional unit created by the use of ICT solution *i (*i.e., *ts)* and for a certain ("l" index). This is the second order effect.

- $FF_{C_{FOE,ICTS_{(l)(ts)}}}$= All ICT related CO$_2$e emissions from studied product system per functional unit for the use of ICT solution scenario *i (*i.e., *ts)* and for a certain ("l" index). This is the first order effect.

- F_C_{RB}= All emissions CO$_2$e emissions for higher order effects including rebound from studied product system per functional unit for the ICT solution scenario.

- i = type of ICT solution, which is denoted in AIOTI equation as *ts* = Type of Service (e.g., the 5G type of services, provided by ITU-R)), at hand per functional unit.

- Load = data processed by the network during a unit of time, e.g., 1 week, 1 month, 1 year; The "l" index is defined as the "percentage of (average bandwidth ICT infrastructure / total bandwidth that ICT infrastructure can handle). If “l=1”, it means that the applied Load equals the total bandwidth that ICT infrastructure can handle;

- $\mathbf{TAE}_{(l)(ts)}$ Total Avoided Carbon Emission Scenario for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-R for 5G type of services;
- $\boldsymbol{T\_EBs\_nict}_{(l)(ts)}$ Total Carbon Emission Scenario, for Baseline scenario (*Bs*), but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictBs*, for: (1) the complete LC phases, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-R for 5G type of services;

  Where: $\boldsymbol{T\_EBs\_nict}_{(l)(ts)} = \boldsymbol{T\_EBs\_nict}^{\boldsymbol{M}}_{(l)(ts)} + \boldsymbol{T\_EBs\_nict}^{\boldsymbol{P}}_{(l)(ts)} + \boldsymbol{T\_EBs\_nict}^{\boldsymbol{O}}_{(l)(ts)} + \boldsymbol{T\_EBs\_nict}^{\boldsymbol{D}}_{(l)(ts)}$

- $\boldsymbol{T\_\mathrm{E}ictBs}_{(l)(ts)}$ Total ICT Carbon Emission for Baseline Scenario, i.e., *ictBs,* for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-R for 5G type of services;

  Where: $\boldsymbol{T\_EictBs}_{(l)(ts)} = \boldsymbol{T\_EictBs}^{\boldsymbol{M}}_{(l)(ts)} + \boldsymbol{T\_EictBs}^{\boldsymbol{P}}_{(l)(ts)} + \boldsymbol{T\_EictBs}^{\boldsymbol{O}}_{(l)(ts)} + \boldsymbol{T\_EictBs}^{\boldsymbol{D}}_{(l)(ts)}$

- $\boldsymbol{T\_\mathrm{E}Gr\_nict}_{(l)(ts)}$ Total Carbon Emission Scenario, for Green enabled Scenario *(Gr)*,, for Green enabled scenario, but excluding the carbon emission of the applied ICT infrastructure, i.e., carbon emissions of *ictGr*, for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-R for 5G type of services;

  Where: $\boldsymbol{T\_EGr\_nict}_{(l)(ts)} = \boldsymbol{T\_EGr\_nict}^{\boldsymbol{M}}_{(l)(ts)} + \boldsymbol{T\_EGr\_nict}^{\boldsymbol{P}}_{(l)(ts)} + \boldsymbol{T\_EGr\_nict}^{\boldsymbol{O}}_{(l)(ts)} + \boldsymbol{T\_EGr\_nict}^{\boldsymbol{D}}_{(l)(ts)}$

- $\boldsymbol{T\_\mathrm{E}ictGr}_{(l)(ts)}$ Total ICT Carbon Emission for Green enabled Scenario, i.e., *ictGr*, for: (1) the complete LCA, excluding the Reuse and Recycle phases, (2) for a certain Load (“l” index) and (3) for a type of service, e.g. follow the classification specified by ITU-R for 5G type of services;

  Where: $\boldsymbol{T\_\mathrm{E}ictGr}_{(l)(ts)} = \boldsymbol{T\_\mathrm{E}ictGr}^{\boldsymbol{M}}_{(l)(ts)} + \boldsymbol{T\_\mathrm{E}ictGr}^{\boldsymbol{P}}_{(l)(ts)} + \boldsymbol{T\_\mathrm{E}ictGr}^{\boldsymbol{O}}_{(l)(ts)} + \boldsymbol{T\_\mathrm{E}ictGr}^{\boldsymbol{D}}_{(l)(ts)}$

- **T_E*ict***$_{RB}$ Total Carbon Emissions from studied product system for the *ictGr* applied solution due to higher order effects including rebound effects.
- Note that the superscripts **M**, **P**, **O**, **D**, shown in the equation terms introduced above, denote that the carbon emissions calculations are related to the LC phases: Material, Product, Operation, Discard, respectively.

6.6.2 Example: Windfarm Use Case, applying the proposed AIOTI quantification method

This use case is showing the benefits of using a Smart Monitoring System in a wind turbine farm, see **Figure 58**, to (1) reduce maintenance efforts and (2) reduce the loss of wind energy production due to maintenance works.

The ITU-T SG5 is working on the revision of the ITU-T Recommendation L.1480 and this example was provided as an input to the ongoing discussions. For more, please see here.

Table 8 uses as much as possible the clause "7. Guidance on how to use this Recommendation", from ITU-T L.1480. However, shows that the calculation in the present example covers the specified items for Tier 3 according to Table 2 (of L.1480).

The preliminary consequence tree of the ICT solution, shown in **Figure 62**, applies as well for this example.

Table 8: Checklist for assessment depth and Tier 3 assessment depth of present case study

Specification	Tier 3 in Table 2 (of L.1480)	Present case study
Type	Screening / first approximation	Yes
Lifecycle stages	All (as material)	All
Data quality	Secondary (generic, proxies, averages)	Generic
ICT solution boundaries	Full life cycle	Full life Cycle
Reference scenario boundaries	Full life cycle	No: Use cycle
Data coverage and cut-off within boundaries	Proxy data used to cover data gaps. Cut-off rules apply	Cut-off rules apply
Second order effects including induction	Yes	Yes
Higher order effects	Should be identified	Yes
Long term effect of any order	To be identified and reported. Considered in accordance with Tier 3 rules.	Yes
Adverse environmental and social effects	To be identified and reported. Considered in accordance with Tier 3 rules.	Yes
Contextual factors	Should be identified	Yes

This assessment example is an **ex-ante** case.

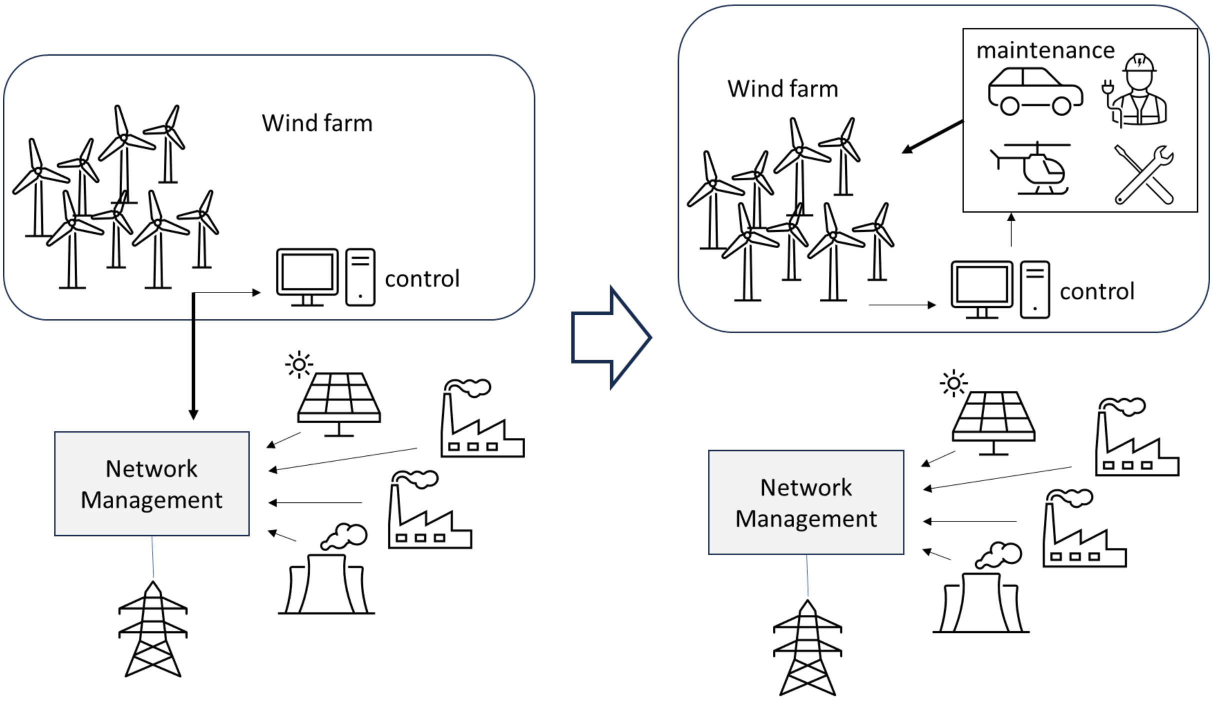

Figure 63: System boundary studied product system for baseline scenario.

ICT solution: Smart remote monitoring of screw connections of wind turbines

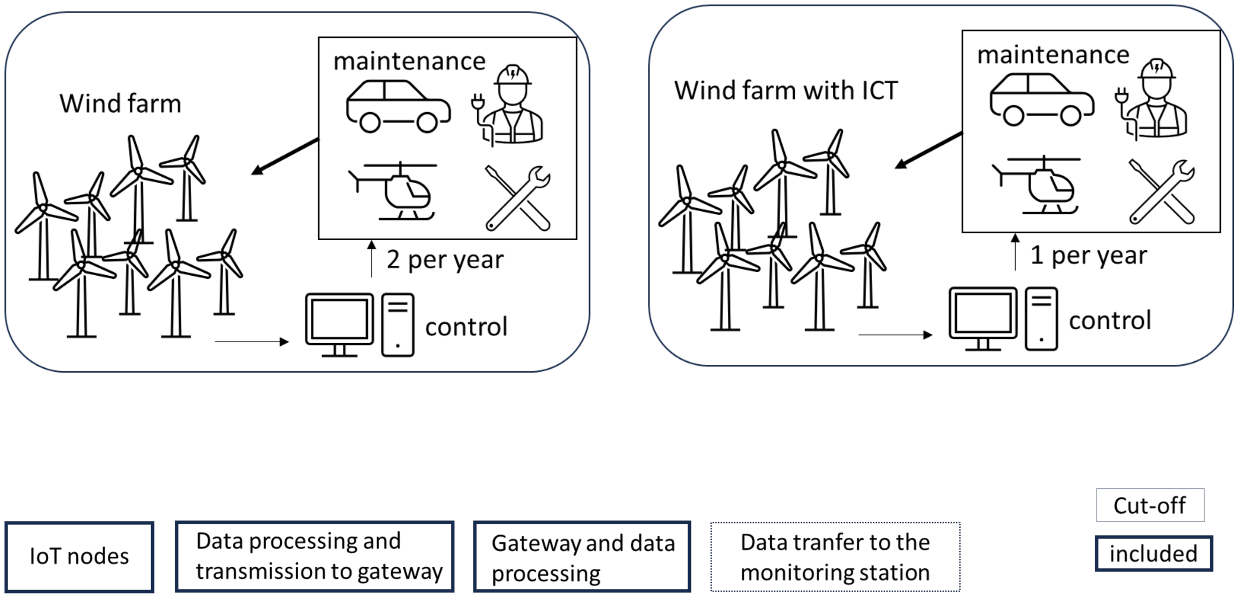

Figure 64: System boundary studied product system and cut-off for the ICT Solution scenario

The impact of the data transfer to the monitoring station is not included since it depends on the windfarm installation.

This table shows the key parameters of the case study.

Maintenance of wind turbines in Europe	***Reference scenario***	***ICT Solution scenario***
Parameters		
Maintenances on site over the lifetime of 10 years	20	10
Not produced energy during maintenance to be replaced by local mixed Energy sources	160 hours	80 hours
Transport for maintenance (not included in this analysis)	Car, boot, helicopter	Car, boot, helicopter (1/2 from the reference scenario avoided)
Smart screw monitoring system	No	Yes

<table>
<tr><th>Item</th><th colspan="2">Description</th></tr>
<tr><td>Goal</td><td colspan="2">Reduce maintenance effort in onshore and offshore wind farms using a smart screw monitoring ICT solution</td></tr>
<tr><td>Scope</td><td colspan="2">CO$_2$e emissions resulting from
• Replacement of the not produced wind energy with energy from mixed sources
• Transport to the wind farm location</td></tr>
<tr><th colspan="3">System related avoided emissions</th></tr>
<tr><td></td><td><i>Reference Scenario</i></td><td><i>ICT Solution scenario</i></td></tr>
<tr><td>Description</td><td>On site maintenances – 2 per year over 10 years</td><td>Reduction to half of the maintenances on site and continuous monitoring of the screw connections</td></tr>
<tr><td>System Boundary</td><td>• 20 maintenances on site for all wind turbines in Europe.
• A maintenance on site lasts a day.
• A turbine produces 8h wind energy per day in average.</td><td>• 10 maintenances on site for all wind turbines in Europe.
• A maintenance on site lasts a day.
• A turbine produces 8h wind energy per day in average.</td></tr>
</table>

	- No production of wind energy during 160h to be replaced by mixed energy sources	- No production of wind energy during 80h to be replaced by mixed energy sources
Function	Providing remote screw monitoring for wind farms maintenance purpose.	
Functional unit	“A remote screw monitoring solution for wind farm”.	

Avoided emissions calculations

Calculation formula:

Equation 1: $\mathrm{TAE}_{(l)(ts)} = (\mathrm{T\_EBs\_}\mathit{nict}_{(l)(ts)} + \mathrm{T\_}\ \mathit{EictBs}_{(l)(ts)}) - (\mathrm{T\_EGr\_}\mathit{nict}_{(l)(ts)} + \mathrm{T\_}\ \mathit{EictGr}_{(l)(ts)}) - \mathrm{T\_}\mathit{Eict}_{RB}$

(Total Carbon Emission Scenario, for Baseline scenario (*Bs*), but excluding the carbon emission of the applied ICT infrastructure + Total ICT Carbon Emission for Baseline Scenario) – (Total Carbon Emission Scenario, for Green enabled scenario, but excluding the carbon emission of the applied ICT infrastructure + Total ICT Carbon Emission for Green enabled Scenario) - Total Carbon Emissions from studied product system for the *ictGr* applied solution due to higher order effects incl. rebound effects

With the specific case in this case study:

$\mathrm{T\_}\ \mathit{EictGr}_{(l)(ts)} = \mathrm{T\_}\ \mathit{EictBs}_{(l)(ts)} + \mathrm{T\_}\ \mathit{EsmartIoTGr}_{(l)(ts)}$

$\mathrm{T\_}\ \mathit{EsmartIoTGr}_{(l)(ts)}$ represent the full cycle carbon footprint emission of the smart IoT solution described in **figure 3.**

This means:

$\mathrm{TAE}_{(l)(ts)} = (\mathrm{T\_EBs\_}\mathit{nict}_{(l)(ts)} + \mathrm{T\_}\ \mathit{EictBs}_{(l)(ts)}) - (\mathrm{T\_EGr\_}\mathit{nict}_{(l)(ts)} + \mathrm{T\_}\ \mathit{EictBs}_{(l)(ts)} + \mathrm{T\_}\ \mathit{EsmartIoTGr}_{(l)(ts)}) - \mathrm{T\_}\mathit{Eict}_{RB}$

$\mathrm{TAE}_{(l)(ts)} = \mathrm{T\_EBs\_}\mathit{nict}_{(l)(ts)} - (\mathrm{T\_EGr\_}\mathit{nict}_{(l)(ts)} + \mathrm{T\_}\ \mathit{EsmartIoTGr}_{(l)(ts)}) - \mathrm{T\_}\mathit{Eict}_{RB}$ [equation 1 adapted to the usecase]

l: load – we are using the situation l=1, the worst case scenario, estimating that the data transmission between IoT node and gateway is always using the full available bandwidth.

Ts: we just have one kind of service here: screw monitoring with one specific kind of sensors.

The second order effect is focusing on the replacement of not produced wind energy by mixed energy sources

Reference scenario:

Parameter	**Value**	**Unit**	**Comment**
Reference scenario			
Windpower installed capacity in Europe onshore	209.961	MW	statista 2024 / IRENA; ID 468679
Windpower installed capacity in Europe offshore	30.663	MW	statista 2024 / IRENA; ID 468679
Power wind turbine onshore	3,5	MW	From 2 MW – 5 MW here mean value
Number wind turbines onshore	60000	pieces	

Power wind turbine offshore	15	MW	
Number wind turbines offshore	2000	pieces	
Not produced wind energy because of maintenance on all onshore farms	1.680.000	MWh/maintenance	Based on 8h of loss of wind energy production per maintenance case
Not produced wind energy because of maintenance on all offshore farms	240.000	MWh/maintenance	Based on 8h of loss of wind energy production per maintenance case
Total Energy to be replaced	1.920.000	MWh/maintenance	For all onshore and offshore wind farms
Energy Mix	300	kgCO$_2$e/MWh	This value takes into account the evolution over the next 10 years
CO2e because of the replacement energy	576.000.000 576.000	kgCO2e/maintenance tCO2e/maintenance	
CO2e because of the replacement energy	**11.520.000**	**tCO$_2$e**	CO$_2$e released because of energy replacement over 20 maintenances

ICT Solution scenario:

Parameter	**Value**	**Unit**	**Comment**
ICT Solution Scenario			
Energy self-sufficient Screw monitoring IoT device	50	Units/turbine	Maximal number required for a reliable monitoring
Gateway	1	Unit/10 turbines	Very low power WLAN technology for IoT application ETSI TS 103 357
Gateway	1	W	Power consumption
Number of screw monitoring devices	3.100.000	units	For all onshore and offshore wind farms
Carbon Footprint of screw monitoring devices (Material/production/EoL)	4,6	kgCO$_2$e	CO$_2$e released when manufacturing one IoT node incl. EoL phase

Carbon Footprint of screw monitoring devices (in operation)	0	kgCO_2e	This IoT device is energy self-sufficient (energy harvester)
Carbon Footprint of the screw monitoring devices	4,6	kgCO_2e	CO_2e released for one device Full life cycle
Number of Gateways	6200	units	For all onshore and offshore wind farms
Gateway Carbon Footprint (Material/production/EoL)	14	kgCO_2e	CO_2e released when manufacturing one gateway incl. EoL phase
Gateway Energy consumption in operation	87,6	kWh	Energy used over the 10 years in full last
Gateway Carbon Footprint in operation	26	kgCO_2e	Energy used with the same Energy mix value as in the reference scenario
Total Gateway Carbon Footprint	40	kgCO_2e	CO_2e released for one gateway Full life cycle
Total Footprint of the screw monitoring solution in Europe	14.509.736 **14.510**	kgCO_2e **tCO2e**	For all screw monitoring installations in Europe

Parameter	**Value**	**Unit**	**Comment**
ICT Solution Scenario			
Maintenances on site	10		With the use of the smart screw monitoring solution the number of maintenances on site can be reduced to one annually – the remote monitoring system works continuously
Total Energy to be replaced	1.920.000	MWh/maintenance	For all onshore and offshore wind farms
Energy Mix	300	kgCO_2e/MWh	This value takes into account the evolution over the next 10 years
CO2e because of the replacement energy	576.000.000 576.000	kgCO2e/maintenance tCO2e/maintenance	

CO2e because of the replacement energy in the ICT scenarios	**5.760.000**	**tCO_2e**	CO_2e released because of energy replacement over 10 maintenances

Second order effect of Reference scenario:

(60.000 x 3,5MW + 2.000 x15MW) x 8h = 1.920.000 MWh {not produced wind energy because of one maintenance for all wind farms in Europe}

1.920.000 MWh x 300kgCO2e/MWh = 576.000.000 kgCO2e or 576.000 tCO2e{not produced wind energy because of one maintenance for all wind farms in Europe converted in Carbon footprint with a predicted mean value of the Energy Mix for the next 10 years}

576.000 tCO2e x 20 = 11.520.000 tCO2q {not produced wind energy because of maintenance service for all wind farms in Europe converted in Carbon footprint with a predicted mean value of the Energy Mix for the next 10 years}

$T\_EBs\_nict_{(l)(ts)}$ = 11.520.000 tCO_2e

First order effect of Reference scenario:

Not included in this case study – this has no impact on the avoided emission calculation case study here. The reference installation is also use in the ICT solution scenario.

First order effect of ICT Solution scenario:

(60.000 + 2000) x 50 x 4,6 kgCO2e = 14.260.000 kgCO2e {smart screw IoT units units full life cycle}

(60.000 + 2000) x 0,1 x 14 kgCO2e = 86.800 kgCO2e {gateways material, production and EoL phases}

(60.000 + 2000) x 0,1 x 1W x 24 x 365 x 10 = 543.120.000 Wh or 543,120 MWh {gateways energy consumption over 10 years}

543,120 MWh x 300 kg CO2e/MWh = 162.936 kgCO2e {gateways energy consumption over 10 years in carbon footprint with a predicted mean value of the Energy Mix for the next 10 years}

14.260.000 kgCO2e + 86.800 kgCO2e + 162.936 kgCO2e {all ICT solutions cradle to gate}

$T\_ EsmartIoTGr_{(l)(ts)}$= 14.509.736 kg CO_2e

14.510 tCO2e for the ICT solution scenario in all windfarms in Europe and for a 10 years lifetime

Second order effect of the ICT solution scenario:

Using the smart screw monitoring solution in all windfarms in Europe the effect described in this study case is that the number of maintenances on site is reduced by a factor of 2.

This means that the carbon footprint resulting from the replacement of the not produced wind energy is also reduced by a factor 2.

This means that the emissions due to the replacement of the energy by mixed energy sources is in the case of the ICT solution scenario:

$T\_EGr\_nict_{(l)(ts)}$= 11.520.000/2 = 5.760.000 tCO_2e

Higher order effect of the ICT solution scenario:

Reduction of transport carbon emission due to avoided maintenance. This affects positively the avoided emissions assessment.

As described in chapter 3 the Carbon footprint impact due to the higher effect transportation of the maintenance workers in Europe considering 20 maintenances (reference scenario) is:

- onshore: 17*0,001*2000*20= 680 tCO2e
- offshore: 570*0,001*68*20= 775,2 tCO2e

The total carbon footprint impact due to transportation of the maintenance workforce considering the assumptions is of 1455,2 tCO2e

In the ICT solution scenario, the impact of the maintenance transportation is reduced by 2 compared to the reference scenario. This means that its impact is **reduced to 727,6 tCO2e**

T_Eict_{RB} = - 727,6 tCO2e

Adverse environment effects, possible rebound effects, contextual factors are already described in chapter 3.

[equation 1 adapted to the usecase]

Avoided emissions: $TAE_{(I)(ts)} = T\_EBs\_nict_{(I)(ts)} - (T\_EGr\_nict_{(I)(ts)} + T\_\ EsmartIoTGr_{(I)(ts)}) - T\_Eict_{RB}$

$TAE_{(I)(ts)}$ = 11.520.000 – (5.760.000 + 14.510) – (-727) = **5.746.217 tCO_2e**

or 574.622 tCO_2e/year

7. Recommendations and conclusions

This Report focused on providing guidelines and a methodology to IoT and Edge Computing technologies and services stakeholders on making informed choices on how to assess the carbon footprint of solutions and services they use, and to as well to measure how these methodologies support carbon footprint reduction of their use. In addition, this Report presented:

(1) Selection criteria that are needed to help stakeholders to select the most suitable PCF methodology for each considered scenario and industry sector,

(2) Initiatives and standards, existing methodologies of measuring ICT carbon footprint and how they can be applied to IoT and Edge Computing,

(3) Method of calculating the avoided carbon emissions in an industrial sector/domain, when ICT is used as an enabling technology.

In conclusion:

- **Smart use** of **clean digital technologies** can serve as a **key enabler** for climate action and environmental sustainability

- **Technology** can improve energy and resource efficiency, facilitate the circular economy, lead to a better allocation of resources; reduce emissions, pollution, biodiversity loss and environmental degradation

- **A method of calculating the avoided carbon emissions** in an industrial sector/domain, when ICT is used as an enabling technology is proposed. In particular, this version of the Report (Release 2) updates the equations that were introduced in version (Release 1.1) of the report, which address the calculation of avoided carbon emissions in industrial sectors when ICT is applied by focusing:

  on a baseline (industrial) scenario that is supported by an ICT solution and a green enabled (industrial) scenario that apply an advanced ICT solution to reduce carbon emissions in the same industrial scenario;

  on the impact that a closed loop recycling/allocation process has on these equations.

- **Examples** that follow the guidelines specified in the current version of ITU-T L.1480 specification and in addition apply:

  either the AIOTI method and Equation 1, described in Section 6.4.3.1, as the quantification method of calculating the benefits of applying ICT to reduce carbon emissions in vertical industry sectors.

  or the equation proposed in ITU-T SG5 ETSI TC EE EEPS(24)000041 on "simplified avoided emissions calculation", see Section 6.5.1 and Equation 30, on calculating the avoided carbon emissions in an industrial sector, when ICT is used to reduce carbon emissions in the described use cases.

- However, more work is needed to calculate as well the carbon avoided emissions, when ICT is used as enabling technology and when the LC reuse phase is taken as well into consideration.

- First steps of aligning the introduced methodology of calculating the avoided carbon emissions in an industrial sector, with the concepts elaborated in ITU-T L.1480. However, more work is needed in this direction.

The following recommendations are derived:

- The ICT sector must **ensure** the environmentally sound design and deployment of digital technologies by minimising the ICT (IoT and Edge computing) carbon footprint:

  Measurement of the benefits provided by ICT in carbon reduction is a struggle – initiatives as EGDC (European Green Deal Coalition) can help

  Important to use **standardised connectivity related metrics/parameters** related to carbon footprint, in order to be used by stakeholders to compare and evaluate the benefit of different connectivity solutions in reducing the carbon footprint of industrial sectors

  Useful to include scope 3 impacts in the CO2e footprint calculation

- How to enable the **DPP (Digital Product Passport)**? Depending on the sectors involved, IoT and Edge computing are important enabling technologies for this realisation:

  A possible implementation for technical industries, is provided by ZVEI, using the DPP4.0 concept, based on DNP4.0 (Digital Name Plate 4.0) and AAS (Asset Administration Shell). For consumer goods, ISO standards play an important role to facilitate interoperability and increased transparency along the chain

- Not all PCF calculation methods are equivalent and Comparable; Selection criteria are needed to help stakeholders to select the most suitable PCF methodology for each considered scenario and industry sector

- An important path to **realise carbon reduction** is to increase awareness and information for the citizens to reduce energy and carbon footprint and at the same time increase the incentives for citizen to realize this reduction

- Usage of digital technologies (e.g. monitoring and controlling energy usage) for an indirect reduction of greenhouse emissions due to, as an example, manufacturing.

- Recycling is not only reducing the dependency on primary raw materials, but it is as well reducing the carbon emissions of products and systems.

- The definition of an agreed and aligned methodology to measure the total avoided carbon emissions in industry scenarios, when applying ICT, is a key requirement for the success of deploying ICT solutions to reduce carbon emissions in industry scenarios.

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About AIOTI

AIOTI is the multi-stakeholder platform for stimulating IoT and Edge Computing Innovation in Europe, bringing together small and large companies, academia, policy makers and end-users and representatives of society in an end-to-end approach. We work with partners in a global context. We strive to leverage, share and promote best practices in the IoT and Edge Computing ecosystems, be a one-stop point of information on all relevant aspects of IoT and Edge Computing Innovation to its members while proactively addressing key issues and roadblocks for economic growth, acceptance and adoption of IoT and Edge Computing Innovation in society. AIOTI's contribution goes beyond technology and addresses horizontal elements across application domains, such as matchmaking and stimulating cooperation in IoT and Edge Computing ecosystems, creating joint research roadmaps, driving convergence of standards and interoperability and defining policies.