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Driving AI-IoT towards the UN Sustainable Development Goals (SDGs)

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Working Group 1: Requirements of AI and other Emerging Technologies to Ensure Environmental Efficiency

Focus Group Technical Report

Summary

The acceleration of climate change and the limited time to meet sustainability milestones calls for a transformation in the way AI-IoT products and services are designed. While AI and IoT technologies have the potential to accelerate UN Sustainable Development Goals (SDGs), their rapid growth can deepen existing sustainability concerns if they are not developed with consideration of *all* sustainability goals. It is essential that all three of the environmental, social and economic dimensions of sustainability are embedded into the design of algorithms and models, and that their interrelations are analysed. This is a challenging task, not only because of the complexity of issues and the heterogeneous resources required, but also because of different, often conflicting, stakeholder perspectives on what it means to be sustainable. This complexity has led to a tendency to focus on specific sustainability issues at the expense of others, often leading to inappropriate decisions that do not promote the UN SDGs as intended.

In this document we discuss the need for integrating and harmonising environmental, social and business needs for the design of AI-IoT products (i.e., their algorithms, models and architecture). In the first sections, we highlight current barriers hampering the adoption of a comprehensive path to sustainability and the risks stemming from single-path sustainability approaches. We then provide suggestions for future work that can accelerate such a transformation to a more comprehensive way of designing sustainable AI-IoT products.

Keywords AI, big data, data analytics, energy consumption, greenhouse gas emissions, IoT, rebound effects, renewable energy, sustainable development.

Change Log

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This version supersedes Version 1, which was approved at the ITU-T Study Group meeting held in Geneva on 7/7/2022.

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1 Scope

This document is intended to raise awareness about the need for a comprehensive approach to AI-IoT product design capable of integrating and harmonizing environmental, social, and economic dimensions of sustainability. It highlights current barriers and future risks for the achievement of sustainability targets that stem from common single-path approaches. The document provides recommendations for future work that can explore how best to embed all three sustainability requirements into the design process of AI-IoT products.

2 References

[1] ITU L.1023

[2] ITU L.1470

[3] ITU L. 1024

[4] IEEE 7000

[5] IEEE 7001

[6] IEEE 7003

3 Terms and definitions

3.1 Terms defined elsewhere

See Draft D.WG1 Glossary of Terms.

3.2 Terms defined here

None

4 Abbreviations

SDG	Sustainable Development Goal
AI	Artificial Intelligence
IoT	Internet of Things
DPP	Digital Product Passport

5 Opportunities and risks of AI-IoT for SDGs

Several studies have highlighted the potential of AI and IoT in accelerating the path towards the UN Sustainable Development Goals (SDGs) [Vinuesa][PwC Strategy]. These include contributions to **environmental sustainability** through a reduction in greenhouse gas emissions and resource consumption (e.g., SDG 6, SDG 7), mitigation of climate change effects (e.g., SDG 13, SDG 1), and protection of ecosystems and their biodiversity (e.g., SDG 14, SDG 15). These technologies can also drive **positive social goals**, including improving health in disadvantaged areas (SDG3), acting as a powerful tool for social integration, education in underprivileged communities (e.g., SDG 1, SDG 2, SDG 5, SDG 16), and reduction of food waste. Moreover, AI and IoT can boost the transformation of productive economic systems by accelerating the adoption of sustainable business models and practices (e.g., SDG 8, SDG 9, SDG 12).

However, these solutions are not exempt from costs and their expansion can have adverse environmental impacts. These include **heavy carbon dioxide emissions** linked to the energy required to generate and process large amounts of data, increased demand for **minerals**, and **e-waste**. The number of IoT connected devices is projected to reach 30.9 billion units by 2025, a sharp increase from 13.8 billion units of 2021, and only a small percentage of electronic devices are currently recycled (e.g., in Europe 20% on the average). In addition, the rapid growth of digital devices has resulted in increased demand for rare materials that are mined mainly in countries of the Global South, sometimes under hazardous and inhumane working conditions. Moreover, mining rare materials has a **negative environmental impact** through, for example, contaminated soils, rivers and water reservoirs, deforestation, and air pollution. As a result, the growing number of IoT devices and electronics not only entails growing energy and resource demands but has other environmental consequences and can elicit human rights violations as well.

While likely improvements in efficiency and the move to renewable energy will no doubt relieve some of these concerns, a focus on digital efficiency and other technological developments as the sole approach to addressing environmental impacts is problematic because **it can lead to *more* rather than less consumption** [Hilty][Alcott]. This means that while AI and IoT-based solutions in the near term may appear to offer environmental advantages through efficiency gains, in the long run, this may not be the case due to the pervasiveness of **rebound effects**. For instance, Coulomber et al. (2019) have shown how and to what extent changes in user behavior may mitigate the environmental benefits of urban ridesharing [Coulombel].

Alongside this, AI-IoT solutions can have adverse social or business effects if all three sustainability aspects (business, social, environmental) are not considered early in the design process and then integrated into the business model (see Section 6). Recommendations that focus on sustainable solutions for AI-IoT must be **contextualised within broader sustainability principles** that consider *all* aspects of sustainability and follow a multi-dimensional approach. Technical decisions related to the design of algorithms, AI models, data sets, and the system architecture should be aligned with environmental needs, as well as consider medium-term product implications on users and communities, as well as business sustainability. A failure to do so can hamper the efficacy of public and private financial investments for the sustainability roadmaps. As stressed during the 2022 Davos forum, failure is not an option.

Although this document focuses on the design of AI and IoT products our discussion applies to digital technologies more broadly. This document aims to highlight:

1. Current barriers to a comprehensive approach to AI-IoT sustainability, the risks of pursuing single-path approaches, and the need for a multi-dimensional approach during the technical design of new solutions.
2. Elements that can facilitate such an integration at design, including an outline future work for recommendations.

Document structure

Section 6 discusses adverse side-effects associated with approaching sustainability goals through common single-path approaches, and stresses the need to integrate and assess environmental, social, and business dimensions in the design of new products. Section 7 describes current barriers to considering all aspects of sustainability in the design process. Session 8 provides some examples of AI-IoT products' side effects stemming from a design driven by single-path approaches. In Section 9, we discuss future risks that can emerge from rebound effects that also need to be considered. The last section, Section 10, focuses on ways to facilitate such an approach to sustainable design, and outlines recommendations for future work.

6 Need for a multi-dimensional approach

Sustainability is a forward-looking concept for guiding a wide variety of choices that are grounded on the commitment to the well-being of both current and future populations. It calls for economic development to proceed with considerations of social justice (social sustainability), as well as with assurances that the natural environment remains in equilibrium and that natural resources are not harvested faster than they can be regenerated (environmental sustainability). The three components of sustainability (economic, social, environmental) are embodied in the 17 UN sustainable development goals (SDGs).

Historically, the AI-IoT sector has focused its attention on meeting just one aspect of sustainability. For example, the economic dimension of sustainability has historically prevailed over the environmental and social dimensions. AI-IoT have been regarded as an opportunity to accelerate the path towards SDGs, with much less attention being paid to the sustainability *of* these technologies, nor risks that could emerge from AI-IoT uptake. Over the past two decades calls for action to address climate change have changed this, propelling the importance of environmental sustainability in the AI-IoT and other sectors, in some instances, at the expense of economic or social dimensions.

Focusing attention to just one aspect of sustainability is problematic. For example, on-demand courier services that deliver goods ordered through mobile apps by bicycles have short-term environmental gains related to CO2 reductions and offer new business opportunities, particularly to startups. However, they have negative social implications. Bicycle couriers often operate under low-paid, stressful, and unsafe conditions. Their tasks are driven by algorithms and AI models designed for maximizing company revenues with little consideration to humans and the real urban conditions in which they operate. We can find similar biases driven by a design focused only on efficiency gains and business profits in other domains such as warehouse management and industrial production.

Similarly, the lack of a solid business case for an AI-IoT solution will likely be unsuccessful because its **economic and financial sustainability** is key for impact and scalability. In the private and public sector there are many examples of unsuccessful AI-IoT products and collaborative innovative projects designed for environmental and social issues that have failed because of the unsustainability of their business model or lack of clear business value (e.g., pilots for smart water and microgrids management).

The lack of a multi-dimensional approach to sustainability has been motivated by the complexity of sustainability issues and resources required, and by the need to divide these issues into sub-problems. Single-path approaches have been viewed as more convenient. However, their adverse side-effects, along with the time pressure for meeting all of the sustainability milestones means that we need to move away from them to a more multi-dimensional approach

Institutional initiatives and alliances (e.g., EU and the Global Digital Product Passport, EU DIGIT, EU AI Alliance), directives such as the EU AI Act, standards (i.e., IEEE 7000, 7001, 7003 [IEEE-7000][IEEE-7001][IEEE-7003]), guidelines (e.g., ITU L.1023 on ecodesign to promote responsibility and durability of devices [ITU-L.1023], ITU L.1470 on GHG emission trajectory for ICT to align with Paris agreement [ITU-L.1470], ITU L. 1024 focusing on business models [ITU-L.1024]) certification programmes (e.g., IEEE CertifAIEd) show how the multi-dimensional approach to sustainability is slowly gaining attention in the digital sector.

7 Barriers to multi-dimensional approaches

In this section, we discuss barriers that impede the adoption of a comprehensive approach to sustainability during AI-IoT product design. We focus on three barriers: ecosystems that promote (a) techno-, (b) business-, and (c) carbon- centric approaches.

7.1 Barriers stemming from a techno-centric approach

The tendency to measure **efficiency gains** (i.e., energy-efficiency and material-efficiency) as a proxy for sustainability is a common example of a technocentric approach. While resource-efficiency plays an important role in designing sustainable systems, it is not sufficient to make them sustainable. For instance, in business, an organization moving from their own private data center to the public cloud can save resources in terms of electricity usage and lower an organizations' carbon footprint. However, little attention is paid to the offset of these benefits in terms of increasing compute power (i.e. rare materials used in processors) and the energy needed to train a Machine Learning (ML) model on terabytes of data. Single-path approaches targeting efficiency gains also dominate **computer research**. Moreover, new data centers that may on the one hand be more efficient, are sometimes located in desertic areas to reduce management costs, thus increasing local water stress that damages local communities [Solon].

The techno-centric mentality, which dominates **high-tech businesses** (large companies, small/medium sized enterprises (SMEs) and tech startups) is also evident in other ways. For example, the analysis of the sustainability implications of a given solution (i.e., algorithm, model, data choice, or system architecture) is often considered out-of-scope by engineers/data scientists and often left to sustainability experts for later stages. In most cases IT professionals are unaware of the environmental and social costs, and consequently their technical choices follow technical-only criteria such as system performance, scalability, security, and accuracy. Experiences show the drawbacks and additional costs of this techno-centric approach. For example, in the fixing of products already in the market that were developed through techno-centric approaches but have had negative consequences. These costs can show up in the form of legal judgments and financial settlements when the company is found to have damaged a marginalized group in their hurry to launch a new product or service.

Furthermore, work on sustainability often focuses on the analysis and solution of sub-problems, with little time spent inter-connecting these analyses through a systems approach that takes into account the **big picture** [Samuel]. Silo-type approaches such as this, which focus on specific technical issues can later arise challenges when combining heterogeneous results to solve multi-dimensional problems. Silos can also emerge in university programs where computer subjects are often not interlinked with sustainability issues and students are often unaware of the environmental and social costs of AI and IoT technologies, and ways to mitigate those costs.

7.2 Barriers stemming from a business-centric approach

Business decisions are often driven by the hyper-competitive and global market that creates **time pressure on product development** for its rapid go-to-market, often at the expense of critical and responsible design and development, cautious testing of vulnerabilities, user misuse, as well as of social and possible environmental negative consequences. For example, in the effort to roll out a new mortgage product, a financial service company may overlook the bias inherent in its data set that might eventually impact marginalized communities like women or people of color.

This business-centric approach has fueled **hype around the benefits of AI, IoT, and massive data** as businesses try to sell their products/services. Over-optimistic communication around AI and IoT and the widespread use of **buzzwords** in non-technical communities can contribute to inappropriate decision-making at different levels (e.g., business, governmental). Moreover, the asymmetry between AI experts who fully understand the capabilities of AI algorithms, compared with non-experts who have less understanding and may buy into the hype, suggests a risk of **manipulation** and asymmetric influence that can affect decisions about, for example, investments that promote the interests and perspective of a limited group instead of the general interest.

In addition, promissory messages regarding AI and IoT can be particularly misleading for SMEs and organisations with no technical competences and can pose **unneeded pressure** on businesses to embark in AI-IoT investments without technical and business support, thus hampering their business benefits at additional environmental costs (e.g., CO_2 emissions, e-waste). Research conducted by MIT Sloan and BCG showed that among 40% of companies interviewed that are working on adopting AI in their business, only one fourth has actually experienced significant financial benefits [Kiron].

Moreover, this business drive means that digital businesses are pushing for the uptake of AI products, including in contexts where AI benefits are not clear or could be achieved through less resource-consuming and cheaper techniques to implement. Complex AI models requiring massive training should be used only when producing substantial benefits that cannot be achieved by resource-efficient techniques. While data analytics is an enabler for a wide variety of functionalities and automatic tasks with potential benefits for all sustainability dimensions, massive data collection does not add value by itself, but it has to be driven by a clear target and business strategy.

7.3 Barriers stemming from carbon-sole approach

Approaches focused only on climate effects can marginalize the consideration of other adverse environmental impacts; social aspects, such as justice, equality, self-determination; and business sustainability. As such, it is incorrect to assume that by addressing carbon emissions, other aspects of sustainability will follow. Efficiency gains and carbon reduction as a proxy for sustainability may neglect other important aspects such as increased e-waste, depletion of rare materials, toxic emissions, issues related to social justice and people's autonomy and wellbeing. For example, focusing solely on energy and performance efficiency, means less attention on where the metals and minerals that comprise the technologies are sourced from, whether people mining these minerals are treated fairly and have an adequate quality of life hides these issues, and whether associate income can fuel corruption.

8 Examples of AI-IoT side-effects driven by single-path approaches

Below we describe some examples of AI-IoT products that have had adverse environmental and social implications, which could have been mitigated by a more responsible design and analysis of medium-term product impact on the environment and users.

8.1 E-waste of IoT wearables

Increasingly, sensors are being placed in IoT-based products, and so their recycling is becoming a cause of concern. In the case of **smart textile products,** sensors are used to monitor bodily functions such as heart rate and body temperature, and the associated data is transferred to a smartphone or other digital device for visualization and/or analysis. Smart textile products can be useful in, for instance, monitoring health conditions, but are also increasingly used for recreational purposes. The sensors are difficult and expensive to recycle. This issue could be mitigated at design by an analysis of the environmental implications of sensors' end-of-life, and by an evaluation of costs/impacts and benefits of the IoT product. Engineers should then opt for the more sustainable architectures and implementations. Engineers should also ensure infrastructures are (already) established to allow for recycling.

8.2 Transparency and dependency of AI decision-support systems

AI decision-support systems offer a wide range of sustainability opportunities ranging from energy and resource savings to the mitigation of climate change effects and the enhancement of the safety/control of critical systems through the detection/prediction of anomalies. However, high-level information regarding inherent limitations of their models/algorithms or failures should be communicated to the user; an unconditioned reliance on AI systems can be problematic, and in worse case scenarios, lead to damages (e.g., identification of criminals via facial recognition, fraud detection). Transient data instability, failures, data biases, and other sources of instability can increase the uncertainty of the decisions and reduce the reliability of the system. AI vulnerabilities are often not clear to users who sometimes delegate responsibilities to machines. This applies not only to AI-based **critical systems** (e.g., industrial and utility AI control systems) but also to **consumer services**, like car navigation systems. While they provide excellent support for drivers, they can also cause car accidents if users are not aware of system limitations and over rely on it. This can occur when the GPS signal is lost and the system relies on incorrect data. A better design could inform users, for instance, of a poor connection or outdated information. Furthermore, a better design would recognize that technological solutions to problems (such as providing information to users) may obscure the fact that other factors are also important in user decision-making. For example, providing information on its own may not lead to behavioural change, and other individual, social, and/or cultural factors may be important. There is a need to explore such social/behaviour (and also ethical and cultural) issues at the beginning of the design process through social science methods, and through interdisciplinary approaches.

8.3 NLP-based systems

Another domain where inaccurate AI decision systems can have a negative impact is in Human Resources, for instance for screening candidates. Inaccurate models relying on the occurrence or frequency of specific words, for instance, lead to biased decisions and candidate mismatches resulting in resource loss for companies, incorrect company investment, and also unfair unemployment. Furthermore, the widespread adoption of NLP-based systems for customer service and cost optimization have sometimes had a negative impact on customers and employees in terms of job losses. Moreover, inaccurate models lower the quality of AI automated systems and customer service, and sometimes they have been used to weaken customer rights (e.g., make it harder for customers to claim their rights or unsubscribe to automatic costly services).

8.4 AI-based personalized advertisements

AI-based advertisements are designed to create more personalized experiences, to better target the appropriate audience, to select the relevant thought leaders and influencers, and to help clients make decisions faster. They are commonly employed by streaming, e-commerce, and digital content platforms, and are designed to increase company sales. All of that has a negative environmental impact since personalized advertisements foster consumer demand, with a potential consequential increase of waste, packaging and also CO2 emissions related to global goods transport. This is an example of negative environmental impacts of a design driven only by business revenues growth and not careful of users' best interest and environmental costs. Furthermore, social scientists have shown how personalized experiences can have negative social impacts. For example, the personalized adverts for those users who search topics associated with mental health (e.g., searches about pro-anorexia, self-harm, or suicide) will be adverts related to how best to harm themselves (via not eating or hurting themselves in other ways).

9 Rebound effects

Efficiency gains will likely lead to increased resource consumption (i.e., demand for data storage and analyses) rather than a reduction. Parts of the technical savings can therefore be "eaten up" by the increased demand for energy and resources. If rebound effects are high, the contribution that energy efficiency improvements make to decreasing resource consumption is limited. Moreover, the reduction of production costs can also rebound, as lower server costs paired with global interconnection and lower energy costs in developing countries lead to server farms, empowering global blockchains. The

Metaverse is one likely example of this. While not omnipresent, companies promise that its emergence- through technologies such as Virtual Reality and AI-will shift spend from social media and other web applications towards this platform. Gartner predicts that by 2026, 25% of the global population will spend at least one hour per day in the Metaverse participating in education, work, and leisure activities. 30% of the world's organizations will offer products and services in and around the Metaverse, according to the same Gartner report. The potential increase in compute power may out-weigh any efficiency gain benefits in the sector, leading to increased consumption and e-waste, especially because of the additional electronic gear to participate. Furthermore, similar to what has been seen with the increased use of social media, and given its predicted 3D environment, there will likely be both positive *and* negative social implications, including issues associated with inequity, discrimination, bullying, increases in predators. Evidence from social media research shows how it reflects, distorts, amplifies, and shapes issues already present in society. Most likely the metaverse will have similar affects, and will also likely be addictive, meaning that it could become an equally toxic environment (if used as a substitute rather than a tool for social life).

To avoid such effects, institutions must analyze the correct environmental and social costs for the usage of technology. In the case of rebound effects, technology usage should be aligned with a steering tax that constrains growth once efficiency gains have been met [Widdicks]. The risk of rebound effects will increase if AI-IoT applications are not focused on being aligned with sustainability goals. Despite the emphasis on AI and IoT as a way to accelerate sustainability targets, only a **small percentage of commercial AI systems address sustainability issues**. As shown by the last Grand View Research report 2022-2030, the largest AI market segment refers to "Advertising & Media", followed by "BFSI" (Banking, financial services and insurance) and by "Others Sectors", which includes gaming and entertainment. Sectors like health, manufacturing, supply chains and agriculture that are linked to the SDGs follow behind though are growing. It is crucial to incentivize those applications in support of SDGs. One possible way to help change this landscape is by treating AI-IoT products/services differently according to their impact on users and the environment, for instance through the forthcoming Digital Product Passports, and giving credits to those applications with higher sustainability gains.

10 Recommendations for a comprehensive AI-IoT design

The expansion of the design process through the integration of environmental, social, and business needs is a complex task requiring **new tools and methodologies** to assess the environmental and social impact of a product, but also active collaboration among stakeholders. Guidelines should help engineers, data scientists and product managers identify product's risks for the environment and users, and drive them in designing more resource-efficient solutions attentive to user and communities wellbeing. More specifically, guidelines should help IT professionals question the environmental aspects of their prospective solutions (e.g., energy-efficiency, computational-efficiency, material-efficiency, reparability, and recyclability) and its potential impact on users and communities involved (e.g., user self-determination, product misuse, user rights, social justice).

Active collaboration among product stakeholders is crucial to gain a comprehensive view of sustainability costs and benefits of a product, and evaluate its potential impact both in the short and medium term. Embedding dynamic trade-offs into the underlying algorithms help to balance resources over the system lifetime when the conditions change, and to adjust system priorities. Similarly, business win-win strategies can help find a suitable compromise among stakeholders when conflicting requirements and perspectives arise. When tensions arise, or some forms of sustainability are prioritized at the expense of others, we need to carefully balance decision-making to ensure all aspects of sustainability are taken into consideration.

To effectively support the design process, design guidelines must be **flexible**, **simple, and easy to comply** for organizations with limited resources (e.g., time, budget, internal competences). In the below, Figure 1 summarizes the key steps associated with a sustainable design process, and then we provide a list of recommendations for future development that should work in synergy with ongoing Digital Product Passport.

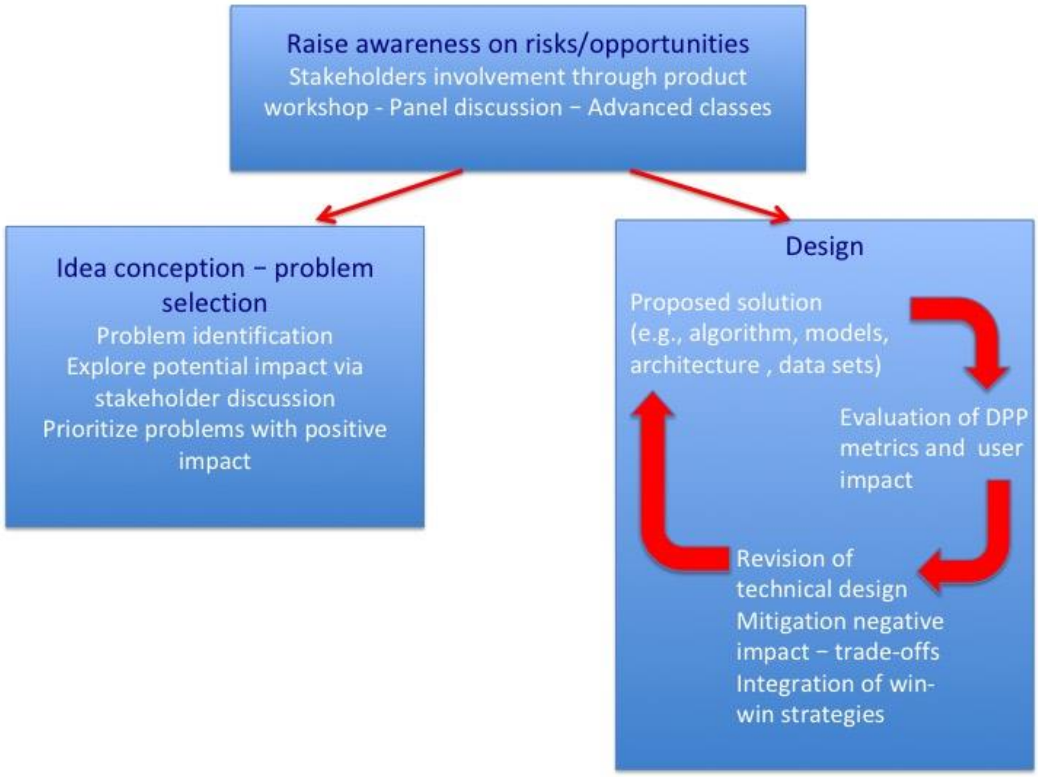

Figure 1: Overview of a more comprehensive technical design process

Recommendation 1: Raising awareness.
It is paramount that IT and business professionals (e.g., engineers, data scientists, product managers) are aware not only of the environmental and social costs of their solution, but also of sustainability opportunities to be able to "map" sustainability criteria into day-to-day business. Stakeholder workshops to discuss product requirements, costs, and benefits can help gain a comprehensive view of sustainability product implications on the environment, users, communities, and business, thus keeping the big picture and prioritizing issues. Stakeholder workshops should be conducted in collaboration with social scientists using responsible innovation approaches, and through co-design processes. Such approaches make explicit the range of value sets that inform stakeholder and engineers' decision-making during design processes, and help ensure that a range of values are incorporated into responsible design solutions. Moreover, organizations should offer their employees the opportunity to dive deeper into the sustainability risks and

opportunities associated with their work through participation in advanced classes, panel discussions, and workshops.

Recommendation 2: Idea conception – problem selection.
Before launching the design process, it is crucial to analyze the problem of interest from different angles beyond business/research opportunities, and assess its potential positive/negative sustainability impact on the environment, people and business growth. A revised SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) of the problem under analysis geared towards environmental, social and business sustainability can help. Sustainability dimensions are interlinked - problems with high positive environmental and social impact will likely result in business growth in the medium term.

Recommendation 3. Environmental and social assessment aligned with the Digital Product Passport.
During the design process it is crucial to test product hypothesis, and technical decisions related to the underlying algorithms and models, data choice and system architecture from the technical and sustainability perspective. That is, analyze not only the performance, reliability, privacy, or scalability of the prospective solution but also its environmental implications via the forthcoming Digital Product Passport metrics (e.g., carbon footprint, materials, recyclability, reparability), and their potential risks/opportunities for the environment and users. At the same time, while metrics provide useful insights on many environmental aspects and are key for assessment and future improvements, they are not the only answer. In fact, some indicators are unmeasurable (e.g., related to human impact) and there is a risk that because of this they will be ignored. Furthermore, some indicators are complex and resource-intensive to compute, especially for SMEs and startups. For instance, the computation of CO2 emissions of an AI-IoT system is difficult to assess, requires many resources, and is yet to be standardized [Samuel]. Studies reporting carbon calculations and/or footprints often use different metrics and rely on different assumptions, parameters, and data sets (e.g., public outdated vs. private but unavailable) that makes it hard to compare studies and fuels controversy. It would be more useful to focus on roughly estimating CO2 emissions and then categorizing them into a standardized scale similar to the A-G scale used for energy efficiency.

Recommendation 4: Transparency and self-determination. The inherent limitations of AI solutions should be made transparent to the user by providing high-level information on the accuracy, validity and reliability of the machine outcomes. This can be seen as a product feature that allows users to detain control when the machine's accuracy and reliability degrades for instance due to noise, data instability or failures, and that mitigate those side-effects of automatic systems described in Session 8.2. As the internal and external sources of system uncertainty varies over the time depending for instance on data instability, noise, or failures, it would be convenient to provide users with guarantees on the reliability of the service as proposed for instance in previous work [Tulone] thus allowing users to make more conscious decisions.

Recommendation 5: Harmonizing conflicting requirements through win-win strategies. When two or more priorities conflict new technical and business options must be explored. Stakeholders should work to identify win-win strategies providing each of them with reasonable benefits. On the technical side tunable trade-offs that automatically adapt to evolving system conditions (e.g., noise triggered by an external event, low battery, unstable communication) and to variations in user needs, can help the system

meet user needs under dynamic conditions while ensuring guarantees. Tunable trade-offs and business win-win strategies can offer benefits in a wide range of applications.
For instance, petrochemical industrial areas are known for their negative impact on air and water pollution for local communities and their health. For this reasons companies whose emissions exceed "tolerance threshold" are subjected to pay expensive fines. The needs of local communities aiming at new investments to make the plant greener and the respect of pollution limits, are usually not aligned with business needs aimed at containing costs and growing their business (production). This is an example where real-time monitoring and forecasting with built-in AI-based trade-offs can mitigate those conflicts, by helping companies adjust their production in such a way that air/water pollution is contained, thus avoiding the risk of incurring in expensive fines. Moreover, that could trigger additional win-win opportunities that can help strengthen the relationship with the local community and make it turn into as a valuable stakeholder/partner.

Recommendation 6: **Education.** Although education does not directly relate to the design of new AI-IoT products, it is crucial for the realization of such a transformation. It is important for universities to integrate sustainability implications and new techniques to their computer B.S. and M.S. programs and help their students get educated in STREAM (Science, Technology, Engineering and Mathematics, combined with Reading and Arts), This can help overcome silos by acquiring not only the competences needed for the sustainability transition, but a system-thinking mentality capable of harmonizing technical skills with the analysis of environmental and social impact of digital technologies (see W. Edward Deming's System of Profound Knowledge). Systems-thinking will enable students of all subject matters to understand direct primary impacts, but also secondary effects. Education plays a key role in preparing the young generation for future work requirements and providing them with the proper bases and critical thinking to question assumptions and discern information.

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