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Driving AI-IoT design towards the UN sustainable development goals (SDGs)

ITU-T FG-AI4EE D.WG1-08

Driving AI-IoT design towards the UN sustainable development goals (SDGs)

Summary

In this Technical Report we discuss the need for integrating and harmonizing environmental and social models and sustainability needs when designing AI-IoT (artificial intelligence and Internet of things) based solutions (i.e., their algorithms, models and system architecture). In the first sections, we highlight current barriers hampering the adoption of a comprehensive path that addresses environmental, social and sustainability needs, and the risks stemming from single-path sustainability approaches. Suggestions are then provided for future work that can accelerate a transformation to a more comprehensive way of designing sustainable AI-IoT systems.

Keywords

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

Note

This is an informative ITU-T publication. Mandatory provisions, such as those found in ITU-T Recommendations, are outside the scope of this publication. This publication should only be referenced bibliographically in ITU-T Recommendations.

Change Log

This document contains Version 1.0 of the ITU-T Technical Report on "*Driving AI-IoT design towards the UN Sustainable Development Goals (SDGs)*" approved at FG-AI4EE sixth meeting held in Ålesund, Norway, 1-2 December 2022.

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Introduction

The acceleration of climate change and the limited time society has to meet sustainability milestones calls for a transformation in the way AI-IoT products and services are designed. While artificial intelligence (AI) and Internet of things (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 highlight current barriers hampering the adoption of a more comprehensive design approach; the risks stemming from single-path sustainability approaches; and sketch future design recommendations.

The document is structured as follows. Clause 5 discusses opportunities and adverse side-effects associated with approaching sustainability goals through common single-path approaches. Clause 6 stresses the need to embed issues from the environmental, social, and business dimensions of sustainability into the design of algorithms, AI models and system architecture. Clause 7 describes current barriers to a more comprehensive design approach. Clause 8 provides examples of AI-IoT systems' side effects stemming from a design driven by single-path approaches. In clause 9, we discuss future risks that can emerge from rebound effects that also need to be considered. Finally, clause 10, focuses on ways to facilitate a comprehensive approach to sustainable design, and outlines recommendations for future work.

ITU-T FG-AI4EE D.WG1-08

Driving AI-IoT design towards the UN sustainable development goals (SDGs)

1 Scope

This Technical Report is intended to raise awareness about the need for a comprehensive approach to AI-IoT product/service 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 on how best to embed all three sustainability requirements into the design process of AI-IoT services/products.

Although this Technical Report focuses on the design of artificial intelligence (AI) and Internet of things (IoT) systems, our discussion applies to digital technologies more broadly. It aims to highlight:

– 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.

– Elements that can facilitate the above, such as integration at design, including an outline of future work for recommendations.

2 References

[ITU-T L.1023]	Recommendation ITU-T L.1023 (2020), *Assessment method for circular scoring*.
[ITU-T L.1024]	Recommendation ITU-T L.1024 (2021), *The potential impact of selling services instead of equipment on waste creation and the environment – Effects on global information and communication technology*.
[ITU-T L.1470]	Recommendation ITU-T L.1470 (2020), *Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement.*
[ITU-T L-Sup.21]	ITU-T L-series Recommendations – Supplement 21 (2016), *Implementation guidance for small- and medium-sized enterprises on information and communication technology supply chain due diligence concerning conflict minerals*.
[IEEE 7000]	IEEE 7000-2021, *IEEE Standard Model Process for Addressing Ethical Concerns During System Design*.
[IEEE 7001]	IEEE 7001-2021, *IEEE Standard for Transparency of Autonomous Systems*.
[IEEE 7003]	IEEE 7003-2017, *IEEE P7003 Standard for Algorithmic Bias Considerations*.
[FG-AI4EE D.WG1-01]	ITU-T FG-AI4EE Technical report D.WG1-01 (2022), *Standardized glossary of terms*.

3 Definitions

3.1 Terms defined elsewhere

See [FG-AI4EE D.WG1-01].

3.2 Terms defined in this Technical Report

None.

4 Abbreviations and acronyms

This Technical Report uses the following abbreviations and acronyms:

AI	Artificial Intelligence
BFSI	Banking, Financial Services and Insurance
BSAT	Basic Sustainability Assessment
DPP	Digital Product Passport
EBIT	Earnings Before Interests and Taxes
IoT	Internet of Things
ML	Machine Learning
NLP	Natural Language Processing
SDG	Sustainable Development Goal
SME	Small and Medium Enterprise
STREAM	Science, Technology, Engineering and Mathematics, combined with Reading and Arts

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) [b-Vinuesa] [b-PwC]. 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), 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, poverty alleviation (e.g., SDG 1, SDG 2, SDG 5, SDG11, 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).

Figure 1 – UN sustainable development goals

However, these solutions are not exempt from costs and their expansion can have adverse environmental impacts. The impacts include heavy carbon dioxide emissions linked to the energy required to generate and process large amounts of data, as well as 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). E-waste, estimated at 53.6 Mt in 2019, is expected to reach 73.7 Mt by 2030. In addition, the rapid growth of digital devices has resulted in increased demand for rare materials that are mined and then (mainly) recycled in countries of the Global South, sometimes under hazardous and inhumane working conditions that do not comply with OECD regulations [ITU-T L-Sup.21]. 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 sources 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 [b-Hilty] [b-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 their augmented demand and pervasiveness that will lead to increased rebound effects. For instance, Coulombel et al. have shown how and to what extent changes in user behaviour such as switching from public transit to the car or travelling longer distances, may mitigate the environmental benefits of urban ridesharing [b-Coulombel]. Their analysis on several ridesharing scenarios in the Paris area showed that the overall rebound effect decreases by at least 68% of CO2 emission reduction.

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 clause 6). Recommendations that focus on sustainable solutions for AI-IoT must be contextualized 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 and consider medium-term product implications on users and communities, as well as business sustainability. This does not imply that engineers and product managers need to become experts in aspects of sustainability. Rather, they need to have awareness about the positive and negative impacts of their technical/business decisions on the environment and their stakeholders, and proactively engage with sustainability experts if required. Small organizations unable to afford the costs of hiring experts can explore partnership opportunities with a specialized business, research lab, sustainability initiative or with individual experts (see clause 10). Furthermore, moving to a more comprehensive design approach that encapsulates all aspects of sustainability is a complex task requiring support and guidance from policymakers.

A failure to embed environmental, social, and economic sustainability requirements into the design of AI-IoT solutions will hamper the efficacy of AI public/private financial investments for the implementation of sustainability roadmaps. As stressed during the 2022 Davos forum and the COP27, failure is not an option.

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) shown in Figure 1.

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 systems 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 grids 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] [IEEE 7001] [IEEE 7003]), guidelines (e.g., [ITU-T L.1023] on ecodesign to promote responsibility and durability of devices , [ITU-T L.1470] on GHG emission trajectory for ICT to align with Paris agreement, [ITU-T L.1024] focusing on business models) 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

This clause discusses 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) as a proxy for sustainability is widespread in computer research and high-tech business. While resource-efficiency plays a crucial role in designing sustainable systems and in reducing CO2 emissions, alone it is not sufficient to make them sustainable. For instance, in business, an organization moving from their own private data centre to the public cloud can save resources in terms of better electricity usage, cooling systems, load balance, memory storage, and more efficient infrastructures, thus lowering an organization's carbon footprint. However, these efficiency gains can trigger an increase in unnecessary resource consumption if not properly designed. For instance, wide availability of user-friendly packages within the cloud that implement complex AI models and data analytics techniques, have led to an escalation of massive data and computational-intensive solutions even in cases where they offer little significant benefits. Moreover, new data centres 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 [b-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 [b-Samuel]. Silo-type approaches such as this, which focus on specific technical issues, can lead to later 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 colour.

This business-centric approach has fuelled 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 perspectives of a limited group instead of the general interest.

In addition, promissory messages regarding AI and IoT can be particularly misleading for SMEs and organizations 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., CO2 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 quarter has experienced significant financial benefits [b-Kiron].

Moreover, this business drive means that digital businesses are pushing for the uptake of AI services/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 must be driven by a clear target and business strategy.

7.3 Barriers stemming from carbon-sole approach

Approaches focused on climate effects alone can marginalize the consideration of other adverse environmental impacts, as well as social aspects, such as justice, equality and 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, the carbon and energy efficiency of training new models for AI-IoT applications can be improved by moving them to newer hardware. However, doing so needs to also account for other environmental dimensions, such as the increasing amount of e-waste that will be produced from discarded hardware Even if the hardware is repurposed/recycled, it will ultimately become waste). According to the World Health Organization [b-WHO], 12.9 million women, often expectant mothers, work in the informal waste sector, which potentially exposes them and their unborn children to toxic e-waste. More than 18 million children and adolescents, some as young as 5-years-old, are actively engaged in the informal industrial sector of which e-waste processing is a sub-sector. Children are particularly vulnerable to toxic chemicals contained in e-waste due to less developed organs, rapid rate of growth, and ability to absorb more pollutants relative to their size.

Furthermore, focusing solely on energy and performance efficiency means less attention is focused 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, and whether associate income can fuel corruption. Moreover, as mentioned earlier, mining rare materials has a negative environmental impact through, for example, contaminated soils, rivers and water reservoirs, deforestation, and air pollution.

As a result, when designing AI-IoT solutions for CO2 reduction, engineers and product managers should also consider other environmental and social sustainability aspects (e.g., e-waste, impact on local communities, social justice issues) even if they are not a priority for that service/product, in order to evaluate pros and cons of viable technical options and to choose the option that best addresses sustainability requirements and provides more benefits.

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

This clause describes some examples of AI-IoT services/products that have had adverse environmental and social implications that 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 AI-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 devices 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. Embedded 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 each viable solutions. Engineers should then opt for the more sustainable system architectures, algorithms, and implementations. Moreover, they should ensure together with management and sales teams that infrastructures are (already) established to allow for recycling and keep a big picture across the entire value chain.

8.2 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 should be communicated to the user since 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, inappropriate medical treatments [b-Norori]). Data instability, failures, data biases, and other sources of instability can increase the uncertainty of the decisions and reduce the reliability of the system. Vulnerabilities of techniques such as deep learning and neural networks are usually not transparent to users who often delegate responsibilities to machines. AI explainability, the ability to express why the system reached a particular decision, recommendation, or prediction, can help address this issue, and explainable AI practices and tools should be accessible to all businesses, including SMEs and small organizations. A tool for making AI services transparent at design has been proposed by the IBM AI FactSheet Project [b-IBM]. A FactSheet is a collection of relevant information about the creation and deployment of an AI service and model (i.e., information regarding the purpose and criticality of the AI model, and measured characteristics of the dataset). According to a McKinsey study, organizations that establish digital trust among consumers through practices such as making AI explainable are more likely to see their annual revenue and earnings before interests and taxes (EBIT) grow at rates of 10 percent [b-McKinsey]. Furthermore, explainable AI practices lead to enhanced performance and maintenance of the AI models, increased productivity, and lower risks.

AI explainability applies not only to AI critical systems (e.g., industrial and utility AI control systems) but also to common consumer services, such as 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 for instance when maps are not updated, and the system relies on incorrect data. A better design could inform users, for instance, of outdated information. Furthermore, other individual, social, and cultural factors relevant for user decision-making should be also considered at design. The need to explore such social/behavioural issues (including ethical and cultural issues) at the beginning of the design process through an interdisciplinary approach is discussed in Recommendation 1 of clause 10.

8.3 NLP-based systems

Another domain where inaccurate AI decision systems can have a negative impact is in human resources (HR), for instance for screening candidates. Basic HR models relying on the occurrence or frequency of specific words are an example of how over-simplified models lead to biased decisions and candidate mismatches resulting in resource loss for companies, incorrect company investment, and unfair unemployment. Natural language processing (NLP) takes text analysis to the much higher level of details, granularity, and accuracy. NLP models can be applied in recruitment for classifying and ranking, identifying personal traits and/or fraud, removing human bias, improving competences, boosting SMART goals, and identifying and resolving potential conflicts. However, their limitations can lead to inappropriate decision-making, for instance in failing to recognize the contextualization of words, such as slang or irony. Moreover, their accuracy depends on the data they are trained/tested on, and incomplete training/testing data that are representative of a subset of cases can produce an AI model that can deepen discrimination. For instance, +70% digital corporate's leadership is male. These patterns are reinforced when AI models learn from historical data because the algorithm will predict that males are a key aspect of employees and therefore should be selected for. Furthermore, the well-established gender diversity crisis in the field of AI means that the ratio of people developing AI solutions is also skewed towards men. Because of data set incompleteness and biases, NLP-based systems should never replace HR decisions, but rather empower HR personnel within their organization.

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. However, cost cuts are often prioritized over these issues. Moreover, inaccurate models, which lead to low-quality automated customer service, have been sometimes 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. Similarly, to other AI-based technologies, they can be a powerful tool for sustainability and-in addition to marketing-they can be applied to raise awareness on sustainability issues and disseminate sustainable practices. However, their social and environmental risks need to be addressed at the design stage.

Social risks – AI-based adverts are more pervasive and subtle than regular adverts as they leverage heterogeneous data regarding our preferences, habits, and choices. As a result, the invitation for buying a product/service is camouflaged by a data-based solution to our perceived needs, with opportunities provided to match our perceived desires/expectations. Much social science research points to consumer concerns that are associated with businesses collecting, processing, and using their data in this way. Consumers usually "automatically" accept the terms and conditions when they use a particular webpage or software application-even when businesses provide a tick box choice for how data is handled-because they feel a lack of control or ability to choose a reasonable alternative.

Moreover, AI-based personalized experiences can lead to echo chambers of knowledge and ideas. This is when personalized experiences result in consumers encountering ideas, knowledge, and beliefs that only resonate with their own. If consumers are only receiving adverts associated with their interests/ideas, not only are these interests/ideas reinforced, but consumers are also not exposed to other ideas or concepts. In an extreme example, personalized adverts were used by *Cambridge Analytica* to swing election votes in several countries, including the election that brought Donald Trump to power in the US and the UK Brexit election. Personalized adverts can also have further negative social impacts on those who are more vulnerable. While not specifically related to sales, on Pinterest a person looking at posts/images that relate to, for example, suicide or body dysmorphia, will receive personal recommendations ('things you might love') related to how best to commit suicide, or how best to lose weight, etc. One example is searching for 'nothing tastes as good as skinny feels' and receiving recommendations such as 'be strong and don't eat' [b-Gerrard]. For those who already have concerns about, for example, their body, the targeting of this issue can amplify specific content producing echo chambers. This can exacerbate unhelpful feelings and ideas for someone who is already vulnerable and promote unhealthy and/or dangerous behaviour.

Environmental risks – Although AI-based personalized adverts are resource-efficient in theory, as discussed earlier their environmental impact can be negative because they lead to increased consumer demand beyond user needs, with a potential increase in resource consumption, externalities, waste and CO2 emissions related to production, global goods transport, and disposal. Such a trend can oversaturate the market in the medium term and increase rebound effects (see clause 9). Moreover, energy consumption and emissions related to AI development, production, and deployment can also induce adverse rebound effects. This is an example of the negative environmental impacts of a design driven only by business revenues growth rather than a careful consideration of users' best interests and environmental costs.

While personalized adverts are part of any business endeavour, and these side-effects are difficult to address, a more responsible design can help mitigate them as much as possible and therefore help with playing an active role towards sustainability goals (e.g., promote supply-and demand-side sustainability efforts and practices, highlight product sustainability features, and raise awareness among consumers). AI personalized adverts could be linked to the forthcoming digital product passport (DPP), providing information on resource utilization, repair, and recycle, as well as incentives for sustainable products. We discuss these opportunities more in depth in clause 10. This is an example of how a responsible design comprising all sustainability dimensions can not only reduce system's environmental and social costs but can play an active role in the path towards SDGs.

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 the lower costs lead to market segments expansion with additional environmental costs.

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 investments 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 computational power may outweigh any efficiency gain benefits in the sector, leading to increased consumption and e-waste, especially because of the additional electronic gear to participate, and the most likely constant need to upgrade hardware to more efficient models to allow for improvements in user experience. Furthermore, similarly 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 and amplifies 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 analyse the correct environmental and social costs associated to this technology.

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 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 'Other 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 and giving credits to those applications with higher sustainability gains. The forthcoming digital product passport can be a powerful tool to incentivize sustainable solutions.

10 Recommendations for a comprehensive AI-IoT design

Moving to sustainable AI-IoT systems calls for a plethora of actions, including assessment, reporting, designing, and governance, and all need to work in synergy. The benefits associated with the interlinkages between governance, design, and reporting are yet to be explored. The European AI Act is the first legal framework for trustworthy AI [b-AI-Act]; it harnesses opportunities and benefits of AI and ensures protection of ethical principles. In the future it could be extended to support the design of sustainable AI-based systems. At present the AI Act only encourages providers of non-high-risk AI systems to create codes of conduct and voluntary commitments associated with environmental and social aspects.

Extending 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 sustainability risks, and drive them in designing solutions attentive to the environment, users, and community wellbeing. For instance, such guidelines should help IT professionals to question the energy-, computational- and material-efficiency of their solution, its reparability and recyclability, as well as aspects associated with user self-determination, transparency, product misuse, and user rights.

Active collaboration among product stakeholders is crucial to gain a comprehensive view of sustainability costs and benefits of an AI-IoT product/service and evaluate its potential impact both in the short and medium term. Furthermore, embedding dynamic trade-offs into the underlying algorithms help to balance resources over the system's lifetime when the conditions change, and to adjust system priorities. Such an adaptive design takes into account variations of internal (system) and external factors and makes the system highly flexible and dynamic. 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 (but not simplistic), and easy to comply with for organizations with limited resources (e.g., time, budget, internal competences). Most guidelines and tools are too complex to be employed by SMEs and often are designed for businesses with an intermediate level of awareness and competences, and not for businesses with basic or no level of awareness and competences in sustainability.

Figure 2 summarizes the key steps associated with a sustainable design process, and a list of recommendations for future development is presented that should work in synergy with the ongoing digital product passport (DPP).

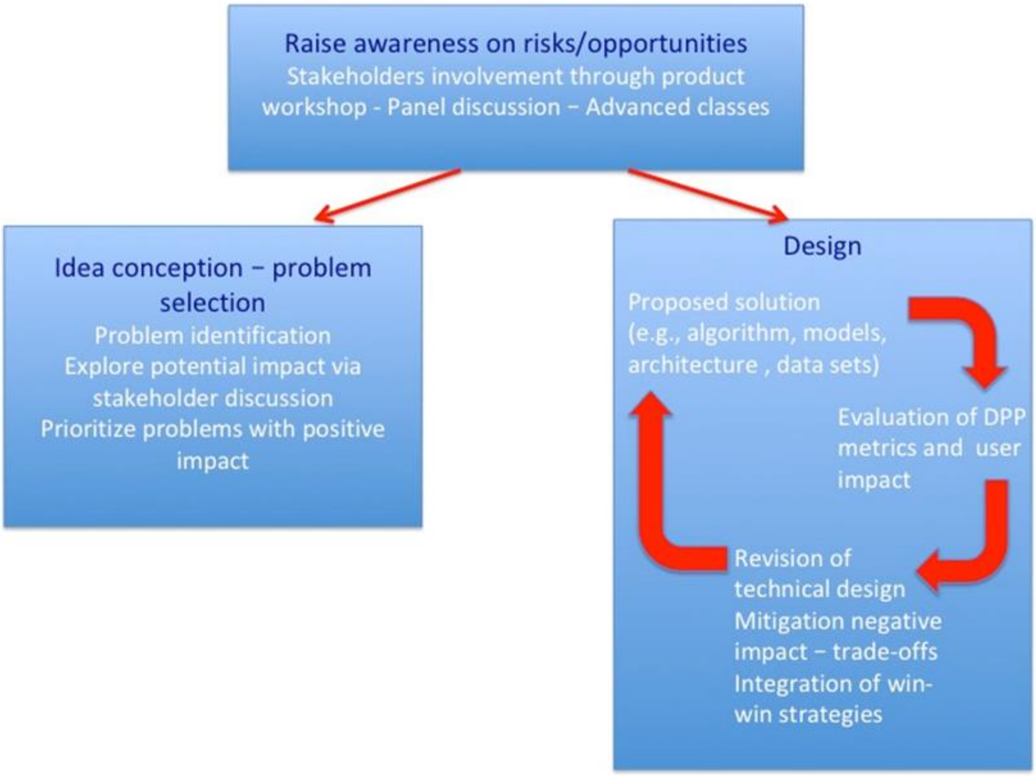

Figure 2 – Overview of a more comprehensive technical design process

10.1 Recommendation 1: Raising awareness

IT and business professionals (e.g., engineers, data scientists, product managers) must be aware of the environmental and social costs of their solution, as well as 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 businesses gain a comprehensive view of sustainability product implications on the environment, users, communities, and business, thus keeping the big picture and prioritizing issues. Startups and small organizations should have the opportunity to express their viewpoint and proposals at discussion tables, independently on their size. 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.

Social scientists can be useful in several domains. For example, they can help highlight the implicit assumptions associated with the categorization of data that is used to design and train AI models. Understanding this can help businesses and engineers better understand the limitations of their algorithms. If, for example, an AI model is trained to make decisions, but the training dataset contained data mainly from white individuals, it will unlikely make appropriate decisions for those who are not white. For instance, this occurred in the development of an AI model that was designed to detect skin cancer, which recognized cancer better for white rather than non-white people [b-Guo]. Understanding what categories are absent or reduced is also important (e.g., categories of male and female do not allow for those who are inter-sex). Finally, understanding how categories are formed is important. For instance, when developing datasets for a machine to learn about emotion, humans categorize faces and/or voices through subjective interpretation (e.g., humans decide whether a face looks happy or sad). This aspect is often not considered, and the outcome of the AI model is thought to be objective.

Furthermore, the role of a Chief Sustainability Officer can be beneficial also in small organizations – he/she oversees all sustainability issues and brings the necessary expertise to the small business to raise awareness within the organization. This person should be knowledgeable about the specific business value chain to estimate issues and propose solutions together with the IT team. Guidelines on sustainability issues for most common value chains and products would facilitate the work of designers, engineers, and sustainability specialists as they would follow a known path and could support them in enhancing their products/services.

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.

10.2 Recommendation 2: Idea conception – problem selection

Before launching the design process, it is crucial to analyse 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.

10.3 Recommendation 3. Environmental and social assessment at design aligned with the digital product passport metrics

During the design process it is crucial to test product hypotheses, as well as technical decisions related to the underlying algorithms and models, data choice and system architecture from the technical and sustainability perspective. That is, analyse not only the performance, reliability, privacy, or scalability of the prospective solution, but also its environmental implications (e.g., carbon footprint, materials, recyclability, reparability), and potential risks/opportunities for users. The forthcoming Digital Product Passport metrics can provide guidance in this analysis, which can leverage and extend previous assessment methodologies. Several tools have also been developed to help with this process. For example, the basic sustainability assessment (BSAT) tool offers businesses, particularly SMEs, a useful metric to assess environmental, community, and employee sustainability (BSAT).

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 hard to assess even for corporate, requires many resources, and is yet to be standardized [b-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 difficult to compare studies and fuels controversy.

To address this, we recommend using qualitative assessments alongside quantitative metrics. For example, conducting a societal impact assessment can help businesses understand the full societal implications of their work [b-Barnard]. The ASSERT model, while designed for the security sector, offers a useful approach for businesses to think about potential impacts that can emerge from their work. It considers societal dimensions from the beginning of the design process and resolves around six main areas: environment (e.g., quality of air, water and level of exposure to pollutants); health and well-being (physical and mental wellbeing); way of life and aspirations (e.g., how people live and interact with each other on a daily basis); culture and community (e.g., people's shared beliefs); political systems; and personal and property rights (e.g., economic effects, civil rights and personal disadvantage). For each of these categories, businesses should think about potential positive and negative impacts of their AI-IoT solution and try to mitigate the negative ones.

10.4 Recommendation 4: Transparency and self-determination

As discussed in clause 8, 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 should not be viewed as harming business reputability, but rather as a product feature that allows users to detain control when the machine's accuracy and reliability degrades due to noise, data instability, or failures, and a way to mitigate those side-effects described in clause 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 adaptable guarantees on the reliability of the service as proposed for instance in previous work [b-Tulone] thus allowing users to make more conscious decisions.

10.5 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. The petrochemical sector is a useful example. This industry is known for its negative impact on local ecosystems and people's health due to air and water pollution. Companies are subjected to pay expensive fines when emissions exceed a "tolerance threshold". Requests from local communities for upgrading the plant infrastructure with "green solutions" are often not aligned with business needs aimed at containing costs and growing production. This is an example where AI-based monitoring and forecasting can address those conflicts by allowing companies to adjust their production in order to contain pollutants and avoid expensive fines. Such a strategy could trigger additional opportunities such as strengthening the relationship with the local community who can be viewed as a valuable participatory stakeholder.

10.6 Recommendation 6: Fostering research on sustainable AI and IoT

Research on sustainable AI-IoT systems is still considered a niche in academia. Sustainability is often treated as an emerging topic in engineering and computer science Departments rather than a plethora of emerging issues that must permeate every single technical topic. This is often justified by the need for researchers to publish their results in well-known scientific arena and the lack of appreciation for these types of interdisciplinary contributions, which are often perceived as being of less valuable than hard-core technical contributions. Researchers are usually evaluated by their research production and the impact factor of their publications. Institutions should encourage such a transition in computer research and incentivize interdisciplinary technical contributions by supporting a new research arena for SDGs and giving visibility to interdisciplinary research results for sustainability.

10.7 Recommendation 7: 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. Currently, sustainability risks and opportunities of digital technologies are not usually taught in B.S. and M.S. computer and engineering programs or treated yet as a niche. Sustainability competences are often treated as "soft skills" although addressing sustainability challenges requires advanced hard-core skills.

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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