Insights paper

A value-based tradeoff to explore AI Tools in the Twin Transition

Authors
Ilse Hellemans, Nick Oostervink

The case of the Horizon Europe DaCapo project

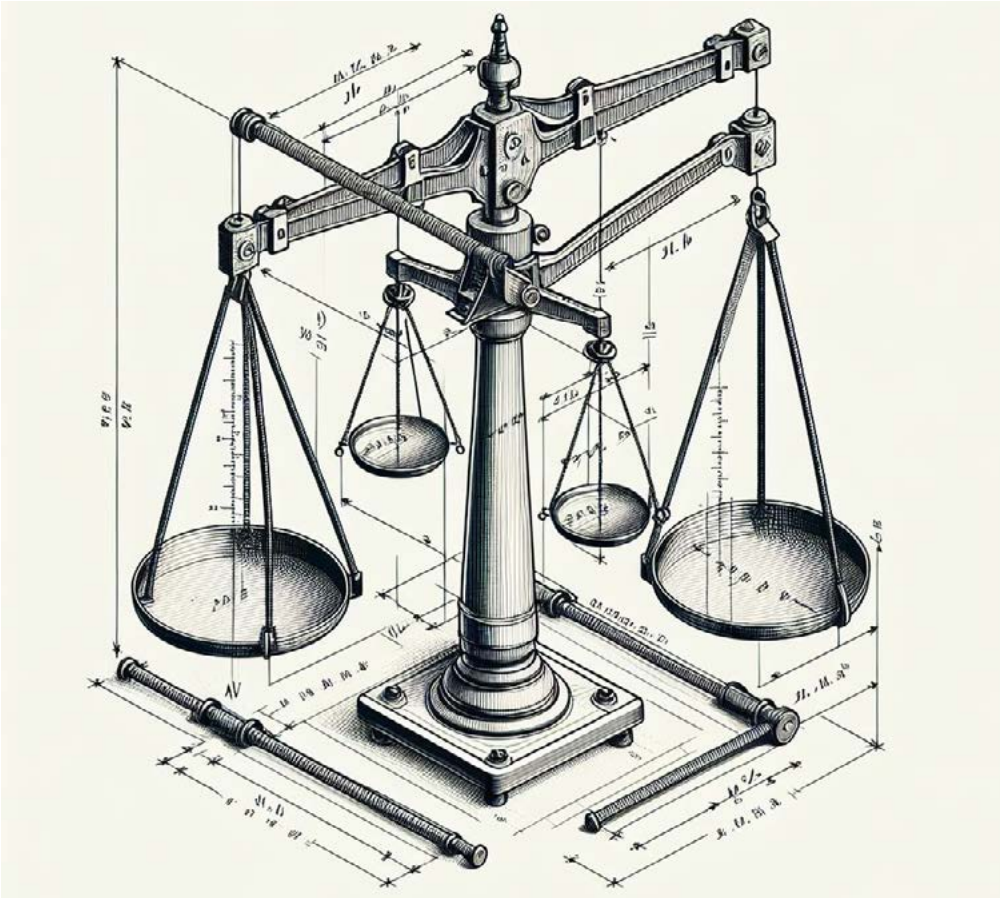
TNO innovation for life

Abstract

"While AI could change the world in many unforeseen ways, it's already having one massive impact: a voracious consumption of energy."

Times Magazine, 2024[1]

Popular AI tools such as ChatGPT, Copilot, and Claude are promising to address sustainability challenges and support Europe's Twin Transition (i.e. the transition to more digitalization and sustainability at the same time). With the leap in innovation and productivity these tools afford, a topic that is currently receiving increasing attention is the short term impact these tools may have in terms of sustainability (Khowaja et al., 2024; De Vries, 2023). Their innovation & productivity gains versus their requirements in terms of energy and water seem to present a paradox that requires attention: using these tools may help us speed up the Twin Transition in the long run, but at the same time may harm that very same transition in the short term. At TNO our vision is that "Our economy needs to foster innovation and competitiveness, while embracing sustainability, including circular practices."[2] In a recent Horizon Europe Project we encountered this seeming contradiction when developing a Digital Circularity Consultant with Popular AI Tools. In this article we reflect on our experiences on how to cope with these developments and provide initial considerations and suggestions on how to navigate this trade off. As new tools and use cases develop at record pace, there are no clear answers yet. To support Europe's SME's to stay innovative, competitive, and sustainable, we at TNO are currently working towards guidance for a Value-Based Tradeoff that may help future researchers, businesses and citizens in considering using the right Popular AI Tool for the right use case.



A Complex Balancing Act – Made by Microsoft CoPilot in 3 prompts

1 https://time.com/6987773/ai-data-centers-energy-usage-climate-change/
2 https://www.tno.nl/en/about-tno/mission-vision/

Contents

1 Introduction

1.1 Twin Transition in Europe

The Twin Transition in Europe is a powerful synergy of the green and digital transition. The green transition aims to reduce carbon emissions and promote sustainability, while the digital transition utilizes technologies like AI and IoT to enhance efficiency across sectors. Together, these efforts are crucial for achieving the EU's climate-neutral goal by 2050 (European Climate Law, 2021).

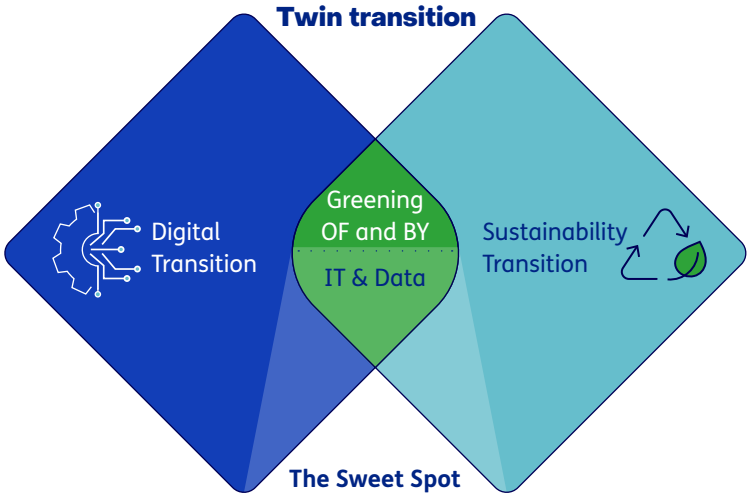
While digitalization offers numerous opportunities to promote sustainability, it also demands significant energy (Lange et al., 2019) and relies on scarce resources (OECD, 2019). Consequently, the sustainability of ICT has become an increasingly relevant topic, particularly since more problems are being addressed through digitalization (Seele & Lock, 2017). As we are moving towards a world with renewable energy in the long run with near zero marginal cost (think 2050), in the short term these technologies put significant pressure on Europe's sustainability goals. Striking a balance where digital technology supports sustainability is essential (Khowaja et al., 2024).

Generally put, digital technologies play a dual role in sustainability. They can drive sustainability by optimizing processes, reducing energy consumption, and enabling smarter resource management. For instance, smart grids and IoT devices can significantly enhance energy efficiency in various sectors (Hilty & Aebischer, 2014). Conversely, the sustainability of ICT itself is crucial, as the production, use, and disposal of digital devices can lead to significant environmental impacts, including e-waste and high energy consumption during operation (Defra, 2023). Therefore, ensuring that ICT solutions are both effective in promoting sustainability and environmentally friendly is essential for a holistic approach to the twin transition.

1.2 The impact of AI on Sustainability Goals

Although various technologies can be employed in the Twin Transition, this paper specifically focuses on popular Generative AI solutions such as ChatGPT, CoPilot, and Claude. These tools offer creative, innovative and fit-for-purpose solutions that can address both smaller day-to-day tasks (e.g., crafting emails and translating texts) and broader explorative issues (e.g., generating images and analyzing data and reports). And their use is increasing both in number of users and in types of use cases.

Artificial Intelligence (AI) enables advanced data analysis, predictive modeling, and automation, which can significantly enhance efficiency and sustainability in various sectors (Accenture, 2023). AI's ability to process vast amounts of data quickly allows organizations to gain insights that lead to more informed decision-making and optimized operations. For example, AI can help identify inefficiencies in supply chains, predict maintenance needs, and optimize resource allocation, all of which contribute to a more circular economy. Moreover, AI can assist organizations in transitioning to circular practices by identifying opportunities for resource recovery and waste reduction, making it a critical tool in the quest for sustainability (Ellen MacArthur Foundation, 2019). So the business case of using Popular AI Tools is clear.



At the same time, recent insights have shed light on the detrimental impact AI tools may have, for they require significant energy and scarce resources such as water for their computing power (World Economic Forum, 2024). In addition to pre-existing considerations on for instance ethical AI, this seeming contradiction is increasingly receiving attention: on the one hand, popular AI tools can support entrepreneurs in improving their efficiency, innovation, and sustainability efforts and circularity practices (or in their journey towards more circular practices). However, the substantial computational power and water required to run these AI tools seem conflicting with the environmental benefits they provide. For example, one prompt to ChatGPT-4 is estimated to consume around 0.001 to 0.01 kWh (Ten Tije, 2024; de Vries, 2023). A text query on ChatGPT can then be calculated as the equivalent amount of energy of running a 5W LED bulb for 1hr 20 min (Zodhyatech, 2024). This can be around 10 times more energy than using Google Search, depending on matters such as the model size and prompt (Ten Tije, 2024; de Vries, 2023). For an image this can be up to 60 times more energy use (Luccioni et al., 2024).

This creates a complex equation where the net impact on sustainability is not straightforward; highlighting the need for projects such as DaCapo to engage in more open discussions in what it is that we want to achieve, and what sustainability impact these efforts may have. As technologies and regulations change constantly, there is no stable permanent answer to this question, but it is a question that should be addressed nonetheless to make sure we as researchers, consultants, and practitioners are doing the right things to create a more sustainable and digital society. Another challenge, alongside changing technology and regulations, is that it is difficult to measure the environmental impacts of this transition due to the fact that measurable data about e.g. the number of parameters, architecture, and carbon emissions of certain tools is difficult to obtain and analyze. Furthermore, the energy usage also heavily depends on matters such as model size, prompts, embedding in a bigger system and interaction with other models. The energy source used by the provider of the model also has an impact on the carbon footprint.

At TNO, and undoubtedly at many other Research & Technology Organizations, our researchers and consultants want to use the state-of-the-art innovative technologies to solve societies' complex problems and we also champion responsible innovation. This focus on responsible innovation emphasizes the need for technological advancements to align with societal values and sustainability goals. Responsible innovation involves engaging stakeholders, considering ethical implications, and ensuring that innovations contribute positively to society (TNO, 2021). The value of innovation extends beyond economic growth; it also encompasses enhancing societal well-being and environmental sustainability.

We are currently working towards value-based frameworks on using AI that integrate societal considerations in to the innovation process, ensuring that technologies are developed and deployed in ways that are beneficial to society and the environment. We want to use new technologies to innovate and advance our long term (societal) goals, and at the same time also limit our short term environmental impact. In this insights paper we reflect on precisely this potential impactful but currently paradox of using powerful popular AI tools such as ChatGPT, CoPilot, Claude, etc: using these tools helps us speed up innovation and the twin transition, while knowing that these models have significant environmental impact and thereby may slow down the twin transition at the same time.

In this paper we explore this challenge through our experiences in the Horizon Europe Project called DaCapo. We provide three major insights based on our six-month exploration of the (im)possibilities of leveraging popular AI tools for this purpose that citizens, researchers and organizations may support in making decisions in using Popular AI Tools. Our suggestions aim to further the broader understanding of the complexity of the Twin Transition: how to make the transition to more digitalization sustainable at the same time.

2 Case Introduction

2.1 The DaCapo project

The **DaCapo project** is a large Horizon Europe project funded by the European Union (GA number: 101091780[3]) in which 8 top research institutes join forces with 6 industry partners, backed by 1 European Association, to stimulate the adoption of circular strategies, tools and technologies in the manufacturing industry in Europe. The word DaCapo is an abbreviation of the formal title of the project: **D**igital **A**ssets and tools for **C**ircul**A**r value chains and manufacturing **Pr**O**d**ucts

More specifically, the project aims to develop human-centric digital tools and services that facilitate the adoption of circular economy strategies across manufacturing value chains. This initiative involves collaboration among various stakeholders, including industry partners, research institutions, and governmental bodies, to create methodologies that enhance sustainability and efficiency in critical sectors such as aeronautics and electronics (DaCapo, 2023).

The project focuses on integrating digital technologies into traditional manufacturing processes to promote resource efficiency and minimize waste.

The tools and services developed within the DaCapo project focus on the creation of new digital assets, AI-based (support) systems, and application of new solutions such as digital twins and digital product passports. The goal is to improve the sustainability, efficiency and the use of critical raw materials in the manufacturing value chains. This can range from supply chains to production and recycling. In particular, Digital Product Passports and a Circular Economy Decision Support System will be developed as high-level tools, facilitating the trustful exchange of assets, the selection of optimum circular stock management strategies and tools, and the definition of informed and coordinated product-lifecycle management decisions in a safe, reliable and agile way.

There are three major commercial companies involved in the project to assure that the solutions developed in the project can be implemented in practice as best as possible. The three companies are (1) Fairphone, (2) GKN, and (3) PESMEL. Fairphone is on a mission to create a circular smartphone[4], GKN is a global multi-technology leader in the aerospace industry[5], and PESMEL is a global supplier of highly automated material handling systems[6].

2.2 TNO's role in the project

TNO is involved in all the work packages in the DaCapo project, but the focus from TNO is on Work Package 2 (WP2). In collaboration with all DaCapo partners, but predominantly with CEA from France and VTT from Finland, the goal of WP2 is to identify circularity indicators, create an agile methodology and to define a conceptualization regarding Digital Product Passports. CEA, VTT and TNO are all active in these field and collaboratively the different RTOs have worked the past 1,5 year to create deliverables that will ultimately support SMEs in their journey to become more circular.

2.3 A paradox or not? Do popular AI tools impede or actually augment the Twin Transition?

In the context of the Horizon Europe DaCapo Project: TNO developed an Agile Methodology to assist European manufacturing organizations in transitioning towards circular practices. This includes the creation of a tailored framework that guides organizations in assessing their current practices, identifying areas for improvement, and implementing circular strategies. Specifically, the TNO team has experimented with different popular AI tools such as OpenAI's ChatGPT and Microsoft's CoPilot to – in a way – create a circularity consultant through their chat technology. The idea was that end users (i.e. circularity champions and SME's in the manufacturing industry) could chat

3 https://www.dacapo-project.eu/
4 https://www.fairphone.com/
5 https://www.gknaerospace.com/
6 https://pesmel.com/

with the popular AI tool to find their way in the plethora of information that is now available to SMEs. The reasoning behind this experimentation was that currently, SMEs are basically overwhelmed with the amount of information, and this information is most often fairly generic. An AI tool such as ChatGPT or CoPilot could help in making the suggestions more tailored to the specific end user who is 'chatting' with the AI tool. The goal in mind was that using such tools could help SME's adopt circular practices easier, faster, and more practically. Providing tailored advice to organizations based on their specific needs and contexts would surely increase the Twin Transition. This dual approach not only enhances the effectiveness of the methodology but also empowers organizations to make informed decisions regarding their sustainability efforts.

More specifically, for this project, we experimented with popular AI tools such as **Copilot, ChatGPT**, and **Claude**, to enhance the capabilities of the sustainability consultant. These tools enable organizations to receive personalized recommendations and insights, facilitating a more effective transition to circular practices. By leveraging these popular AI tools, TNO aims to provide organizations with real-time data analysis, predictive insights, and tailored strategies that align with their unique operational contexts.

The considerations that emerged, however, were more in the context of "does using a tailored ChatGPT or CoPilot lead to a net positive or net negative effect on the climate transition?" as more and more research emerges that highlights the enormous energy and resource use by AI applications (Khowaja et al., 2024; De Vries, 2023), potentially undoing our intended impact on circular economy goals. Hence our experimentation with the different tools increasingly led to discussions and awareness about what we know, but also about what we don't know about the energy and resource requirements of these tools. And basically, we ended up with the fundamental question: Do the benefits of using AI tools offset their downsides? Are we speeding up the Twin Transition, or are we impeding it by using AI?

Aspect	Application
Application context	TNO developed a comprehensive agile methodology to assist manufacturing organizations in transitioning towards circular practices. This includes the creation of a tailored framework that guides organizations in assessing their current practices, identifying areas for improvement, and implementing circular strategies.
Application AI	The team experimented with different popular AI tools to – in a way – create a custom circularity consultant through their chat technology. The idea was that end users (i.e. SME's) could chat with the popular AI tool to find their way in the plethora of information that is now available to SMEs. The reasoning behind this experimentation was that currently, SMEs are basically overwhelmed with the amount of information, **and** this information is most often fairly generic. An AI tool such as ChatGPT or CoPilot could help in making the suggestions more tailored to the specific end user who is 'chatting' with the AI tool.
Intended usage and societal impact	The goal in mind was that using such tools could help SME's adopt circular practices easier, faster, and more practically. Providing tailored advice to organizations based on their specific needs and contexts would surely increase the Twin Transition.
Tools used	Various generative AI tools such as OpenAI's ChatGPT and Microsoft's CoPilot
Intended users	Circularity Consultants and Circularity professionals from SME's in the European Manufacturing industry: sustainability

3 Using popular AI tools through a value-based tradeoff

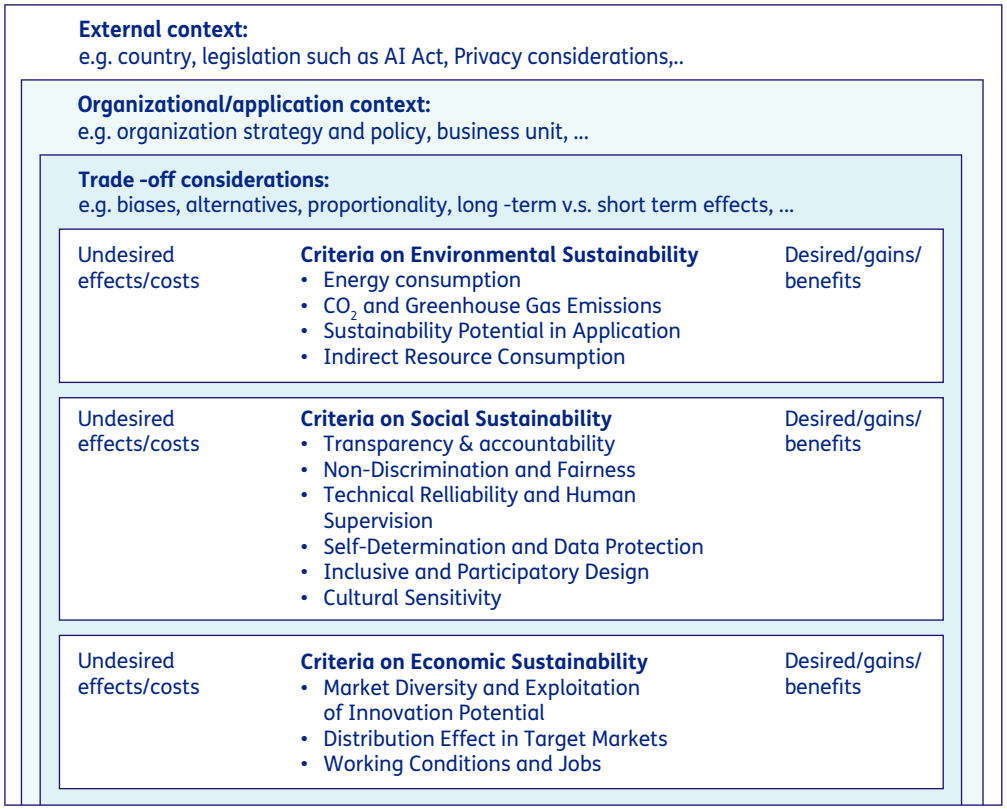
3.1 The value-based tradeoff

As developments in the AI field are developing at an unprecedented speed, at the time of experimentation (mid 2023) ChatGPT was the most easily accessible popular AI tool to "build" ones' own GPT. At the time of writing however (late 2024) the developments have led to a host of new AI tools that also provide the ability to build one's own personal AI assistant. Hence the reflection noted below show (1) an incremental learning path over time and (2) that experimentation is a key part of making a Value-Based Tradeoff: are the things I'm doing with the technology adding value to the overall end-goal of this project or not? You could use ChatGPT to write you a one paragraph email or a 4-page student-essay, or you can use the tool to give you tailored suggestions to improve your personal CO_2 footprint. Given that using such a tool requires a vast amount of energy and resources, the latter example seems to be delivering more value compared to the former examples. This is, however, how to actually make this Value-Based Equation in practice is not yet so straightforward. The jury is still out on how to quantify the different parts of the Value-Based Tradeoff. Currently we define the Value-Based Tradeoff in the context of IT development and deployment: in these processes tradeoffs are an inherent part of the decision-making process. Balancing economic benefits with sustainability and social impact often requires prioritizing certain values over others. For instance, investing in greener technologies might involve higher initial costs but lead to long-term environmental and social benefits. These tradeoffs ensure that IT initiatives align with broader organizational and societal goals and values, fostering a more holistic approach to technology development and deployment.

Rather than stating that using popular AI tools is not sustainable, the focus is on responsible AI usage to be able to utilize the innovative potential these tools have. The Twin Transition will need to happen and will also happen with popular AI tools. It is our responsibility, however, to use these new technologies responsibly. Building on the DaCapo project we conducted a high level literature scan as the research on the impact of popular AI tools has exploded in the past few months. We compiled a number of relevant insights to explore what guidance is already available and how future research can apply these frameworks (Appendix 1).

An example of a potential Value-Based Tradeoff is summarised in the visual below:

Example of operationalization of criteria to make a Value Based Tradeoff



The criteria described above are taken from SustAIn: The Sustainability Index for Artificial Intelligence (Algorithm Watch, 2022) and are used to serve as an example. Both in TNO and in the DaCapo project we are currently actively exploring possible relevant criteria that can also be measured as quantitative indicators are difficult to identify. The example highlighted in the figure shows how sustainability in the context of 'sustainable IT' is more than just energy consumption. Criteria related to social and economic sustainability may be equally relevant and also equally difficult to quantify and measure. However, the fact that some of these criteria are difficult (or even impossible to measure) does not mean that it can be useful to consider them in the process of considering the relevance of using IT solutions.

Working towards a value-based tradeoff approach may help future researchers and projects by going through the 3 steps that can support decisions makers in making the best use of Popular AI Tools. First of all, the intended goal of the application should be articulated. Is it just to use AI tools to experiment (which may be perfect argument if the goal is exploration) or is there a clear use case that the AI tool can support? Second, the context of the application of the AI tool should be considered. Is this a short-term exploration with limited impact or is this a multinational organization-wide implementation? The former has quite a different impact than the latter. And thirdly it can be part of the discussion to think about which tool is most appropriate. Are there relevant sustainable or even other alternatives available?

3.2 The value-based tradeoff in the DaCapo project

In the DaCapo project we focused specifically on the deployment: using Popular AI Tools to stimulate the adoption of circularity strategies and principles. We reflected on this application of AI tools to determine whether developing a Sustainability Consultant, and stimulating SMEs to use this ChatGPT based chatbot, would justify the environmental impact this solution would have.

First of all, we reasoned that ease of use combined with quality of outcome would be crucial factors. Considering that our overall goal is to stimulate SMEs to adopt more circular practices, it is already valuable if some initial experiments with such an AI tool help SMEs think about the possibilities and implications of circular strategies. Specifically, AI tools offer semi-tailored advice when prompts are customized well, which, while still somewhat generic, is already more specific and therefore valuable than general online resources. Though impossible to quantify at the time of experimenting, in the long run, we expected this will benefit the Twin Transition.

Second, and similarly, the focus on stimulating circular-thinking is of such importance to improve the circularity of Europe's manufacturing industry, the reasoning was that it is more important to start the discussion than to make the adoption of the tools 'perfect'. In other words: it is more important in the short term to stimulate entrepreneurs to become more circular than it is to make that start perfect in terms of sustainability. Perfect can be the enemy of perfection, was the reasoning.

Thirdly and finally, towards the end of this part of the DaCapo project we moved away from focusing on one specific popular AI tool. As the world of AI has changed so significantly over the past 1,5 year, it could be that in the meantime more sustainable initiatives have emerged. Hence our final deliverable – the Agile Methodology – contains cheat sheets with sustainability related considerations.

"It is more important to start the discussion than to make the adoption of the tools 'perfect'."

Horizon Europe project on Digital assets and tools for circular value chains and manufacturing products - DaCapo

Click here to view the DaCapo agile methodology for sustainability and circularity enhancement (open access)

4 Considerations on using popular AI tools from a sustainable IT perspective

Concluding, the field of AI is progressing at record pace and RTO's such as TNO are increasingly utilizing these tools while at the same time considering their sustainability impact. The Twin Transition will not happen without digitalization, but the Twin Transition also requires that attention is (increasingly) paid to the sustainability impact of these digital innovations. Based on our experiences with the DaCapo project and our brief literature review we outline three major recommendations for citizens, researchers, policy makers and organizations when considering using popular AI solutions for simple or complex challenges. The bottom line: make a value-based consideration whether your specific use case justifies the energy and resource consumption.

4.1 Balance innovation with responsibility in AI deployment

As you navigate the use of AI, whether personally or within your organization, you might feel the push to adopt new technologies quickly to stay competitive. This drive can be exciting, but it also brings a dilemma. On one side, rapid innovation can lead to significant advancements and personal or organizational growth. On the other side, moving too fast might mean neglecting important ethical and environmental considerations. There is a balance to strike as it is also clear that these new technologies may open up new opportunities.

At TNO, we have experienced this tension firsthand. Our ambition to lead in technological innovation may sometimes give friction with our commitment to responsible practices. The one doesn't need to exclude the other. But we need to strike a balance. Balancing these two strategic goals—innovating rapidly and ensuring our advancements are sustainable, transparent, and fair—has been an interesting journey. Through this journey, we have learned the importance of a thoughtful approach, where we embrace innovation while upholding our values of social responsibility and environmental care. Several important take aways are that using these popular AI Tools first of all in general help in making circularity more accessible, but also allow SME's to dive deeper into challenges that they specifically experience. In other words, popular AI tools may help SME's find more tailored answers.

4.2 Long term implications need our short term attention

There is an impact of using versus not-using popular AI tools. However, this decision often needs to be taken in the here and now when we are facing projects and or challenges that could benefit by the use of popular AI tools. In the DaCapo project we made the decision to explore these tools as the possible upside (or potential benefits) of these tools at least currently seem to outweigh the negatives in the long run. However, that is a temporal decision that may have significant consequences later on.

The discussions should emerge for example for what type of challenges we as citizens, researchers, and organizations may want to use these tools for. Is making funny pictures of cats in rainhats OK? Or should we reserve the intense power (and consumption of power) of popular AI tools for more complex challenges that may benefit society? These are questions we cannot answer at the moment but it is important to raise the awareness of these type of short term actions and their long term implications.

4.3 An open multidisciplinary conversation about an imperfect balancing act

The considerations we faced in the DaCapo project make it clear that conversations are crucial. As we do not have the answer to all the (sustainability) related questions yet, we should neither use these tools without restrictions nor should be stop using them all together just because we fear its sustainability impact. To achieve a truly integral perspective, it is essential to involve experts from various disciplines, including sustainability, technical, financial, and ethical domains. This multidisciplinary approach ensures that all relevant aspects are considered, leading to more balanced and informed decision-making. However, this is challenging as individuals from various disciplines need to understand and appreciate each other's perspectives and terminologies. Therefore, it is crucial to take this governance challenge seriously and foster an environment of mutual respect and open communication. There should be a balancing act and this balancing act is best established through constructive collective discussions with citizens, researchers, and organizations.

5 Conclusions for research and practice

5.1 Conclusions

Our conclusion here is that the goal of this discussion is to promote responsible use of new technologies, embrace these transformative AI Tools, and not to make people feel guilty about using Popular AI tools because of their environmental impact. We at TNO use them too as they have major benefits. The goal here is to create awareness and contribute to the discussion: how can we make the Twin Transition happen as best as possible. By increasing both digitalization and sustainability. The one doesn't need to exclude the other. By engaging in multidisciplinary discussions we can make best use of the newest technologies and be mindful of our sustainability impact.

An important note for the future: Agentic AI is expected to accelerate the growing AI footprint. Before the generative AI breakthrough with OpenAI's 3.5 generative AI model, the use and development of AI models were done for specific use cases on relatively small models, trained on a relatively small computation budget. In 2022, compared to many other industries, AI was estimated to cause a small part of global emissions, with about 1-1.3% of global electricity demand coming from data centers (International Energy Agency, 2023). Until then, data centers have only moderately increased their GHG emissions directly from electricity use, because efficiency gains have mostly offset the increasing electricity demand.

In the past years, it remained challenging to get accurate predictions of the overall footprint of AI, yet we've seen how AI's breakthrough caused Google to lose their 'net zero' status (Kerr, 2024). This coming year, in 2025, AI's footprint is expected to grow even faster due to the soon-to-be expected rise of Agentic AI, with trend watch agencies such as Gartner listing it as the number 1 technology trend for 2025[7], expecting it to grow from less than 1% to 33% embedding in enterprise software applications over the next 4 years, and companies such as Nvidia marketing for commercial applications[8] of this technology already. In contrast to current-day generative AI, where most applications get executed manually, agentic generative AI will act on a higher level of agency and coordination. The behavior of this technology inherently leads to higher use of the underlying models due to their automated nature. The exact (environmental) costs of these agentic applications will most likely be magnitudes higher than current LLM technology. These developments emphasize the importance of an ongoing conversation, including the state of the art on technologies and their impact.

5.2 Implications for research:

First, the literature field of sustainable AI is rapidly evolving, with a growing body of literature emphasizing the importance of integrating ethical and environmental considerations into AI development. Historically, social and ethical considerations have received more attention than environmental aspects. However, the focus on environmental sustainability is increasing as stakeholders recognize its critical importance. Second, to ensure responsible AI use in practice, it is essential to bridge the gap between theoretical knowledge and practical application. While literature offers valuable criteria for responsible AI, it often falls short in providing actionable steps for organizations to implement these criteria effectively. This gap can lead to inconsistencies in how AI is deployed, potentially overlooking critical ethical and environmental considerations.

In conclusion, literature on responsible AI often provides subsets of criteria and fragmented knowledge, making it challenging for organizations to comprehensively assess the responsibility of their AI systems. Organizations must integrate and balance various factors, including their own ambitions, environmental sustainability, and ethical considerations. This complexity can lead to difficulties in creating a holistic approach to responsible AI. Therefore, there is a pressing need for more integrated and applied knowledge that offers clear, actionable guidance. This would help organizations effectively navigate the multifaceted landscape of responsible AI, ensuring that their AI deployments are aligned with both ethical standards and sustainability goals.

7 https://www.gartner.com/en/articles/top-technology-trends-2025
8 Pounds, E. (2024, October 22). What is agentic AI? NVIDIA Blog. Retrieved from https://blogs.nvidia.com/blog/what-is-agentic-ai/

5.3 Implications for practice:

To effectively navigate the twin transition, which encompasses both digital and sustainability shifts, it's essential to transform the practices of key stakeholder groups. The following recommendations outline a few initial focus areas for incorporating sustainability in AI usage for main stakeholder types in the transition:

Research and Technology Organizations

- **Prioritize Environmental Impact**: Ensure AI models are designed with minimal environmental impact, considering energy efficiency and resource use.
- **Operationalize Sustainable Practices**: Develop practical tools and methodologies to apply sustainability guidelines in research projects, balancing intended societal impact and (environmental) costs of AI.

Policymakers (Dutch and EU Level)

- **Create Robust Environmental Regulations**: Develop and enforce regulations that ensure AI systems are environmentally sustainable, balancing innovation with ecological standards.
- **Facilitate Knowledge Application**: Provide clear guidelines and support for organizations to apply environmental principles in their specific contexts.

Organizations building/providing AI

- **Design for Environmental Sustainability**: Ensure AI technologies are developed with a focus on reducing environmental footprints, promoting energy efficiency, and using sustainable materials.
- **Implement Green Design Practices**: Create and follow design practices that incorporate environmental considerations into the product lifecycle.

Organizations Deploying AI

- **Implement Sustainable Practices**: Use AI tools in ways that are environmentally responsible, optimizing for energy efficiency and reducing waste. This includes company policy as well as guiding employees in their AI usage. For example, organizations can include guidelines for how an AI task is related to its energy use. To create these guidelines, consider these facts on AI usage in relation to its footprint:
  - Tasks involving images take more energy compared to tasks involving text.
  - Energy use for training a model goes linearly with the model's size.
  - The more input (your question to the AI tool) and output tokens (AI tool's response) there are, the less energy efficient the process becomes.
- **Monitor Environmental Impact**: Regularly audit AI systems for their environmental impact and take steps to mitigate any identified issues.

Consultancies

- **Advise on Sustainable AI Practices**: Provide guidance to organizations on how to implement environmentally sustainable AI solutions for their respective organizational and application contexts.
- **Develop Sustainability/IT strategies for clients**: Create frameworks and tools that help organizations integrate environmental considerations into their AI strategies. Collaborate and co-develop frameworks with research and technology organizations on complex, recurring challenges in sustainable AI.

Consumers Using AI

- **Stay Informed**: Educate yourself about the environmental impacts of AI technologies you use.
- **Make Sustainable Choices**: Choose AI products and services that prioritize environmental sustainability.

Role of Coalitions/NGO's on sustainable technology

- **Facilitate Collaboration for Sustainability**: Coalitions like the Nationale Coalitie Duurzame Digitalisering (NCDD) play a crucial role in bringing together various stakeholders to address the environmental challenges of digitalization. In a similar fashion, practitioner alliances such as the Green Software Foundation offer profession-specific guidance to incorporate sustainability in IT development.
- **Promote Best Environmental Practices**: These coalitions can help disseminate best practices and provide a platform for sharing knowledge and experiences, ensuring that responsible AI development is a collective effort focused on sustainability.

References

Accenture. (2023). What is Artificial Intelligence (AI) & Why is it Important? Retrieved from https://accenture.com

AlgorithmWatch. (2022). Assessing the sustainability of AI. sustAIn. Retrieved from https://sustain.algorithmwatch.org/en/assessing-the-sustainability-of-ai/

Chow, A. R. (2024, June 12). How AI is fueling a boom in data centers and energy demand. TIME. Retrieved from https://time.com/6987773/ai-data-centers-energy-usage-climate-change/

DaCapo. (2023). Digital assets and tools for Circular value chains and manufacturing products. Retrieved from https://www.dacapo-project.eu

Defra. (2023). Why sustainable ICT is vital. Retrieved from https://defradigital.blog.gov.uk

de Vries, A. (2023). The growing energy footprint of artificial intelligence. Joule, 7(10), 2191-2194.

Ellen MacArthur Foundation. (2019). Artificial intelligence and the circular economy: AI as a tool to accelerate the transition. Retrieved from https://www.ellenmacarthurfoundation.org/artificial-intelligence-and-the-circular-economy

European Commission. (2022). The twin green & digital transition: How sustainable digital technologies could enable a carbon-neutral EU by 2050. Retrieved from https://ec.europa.eu

European Union. (2021). European Climate Law. Retrieved from https://eur-lex.europa.eu/EN/legal-content/summary/european-climate-law.html

Henderson, P., Hu, J., Romoff, J., Brunskill, E., Jurafsky, D., & Pineau, J. (2020). Towards the systematic reporting of the energy and carbon footprints of machine learning. Journal of Machine Learning Research, 21, 1-43. Retrieved from https://jmlr.org/papers/volume21/20-312/20-312.pdf

Hilty, L. M., & Aebischer, B. (2014). Sustainability and ICT: A critical review. Sustainability, 6(8), 5110-5130. Retrieved from https://www.mdpi.com/2071-1050/6/8/5110

Kaack, L., Donti, P. L., Strubell, E., Kamiya, G., Creutzig, F., & Rolnick, D. (2022). Aligning artificial intelligence with climate change mitigation. Nature Climate Change. Retrieved from https://www.hertie-school.org/en/sustainability/news/detail/content/assessing-the-impact-of-ai-and-ml-on-greenhouse-gas-emissions

Kerr, D. (2024, July 12). AI brings soaring emissions for Google and Microsoft, a major contributor to climate change. NPR. Retrieved from https://www.npr.org/2024/07/12/g-s1-9545/ai-brings-soaring-emissions-for-google-and-microsoft-a-major-contributor-to-climate-change

Khowaja, S. A., Khuwaja, P., Dev, K., Wang, W., & Nkenyereye, L. (2024). Chatgpt needs spade (sustainability, privacy, digital divide, and ethics) evaluation: A review. Cognitive Computation, 1-23.

Lange, S., Pohl, J., & Santarius, T. (2020). Digitalization and energy consumption. Does ICT reduce energy demand? Ecological Economics, 176, 106760. https://doi.org/10.1016/j.ecolecon.2020.106760

Luccioni, S., Jernite, Y., & Strubell, E. (2024, June). Power hungry processing: Watts driving the cost of AI deployment?. In The 2024 ACM Conference on Fairness, Accountability, and Transparency (pp. 85-99).

OECD. (2019). Global Material Resources Outlook to 2060. Retrieved from https://www.oecd.org/en/publications/global-material-resources-outlook-to-2060_9789264307452-en.html

Pounds, E. (2024, October 22). What is agentic AI? NVIDIA Blog. Retrieved from https://blogs.nvidia.com/blog/what-is-agentic-ai/

Seele, P., & Lock, I. (2017). The game-changing potential of digitalization for sustainability: possibilities, perils, and pathways. Sustainability Science, 12(2), 183–185. https://doi.org/10.1007/s11625-017-0426-4

Ten Tije, M. (2024, Sep 11). LLMs Environmental Impact: Are LLMs bad for the environment?. Tilburg.ai. Retrieved from https://tilburg.ai/llms-environmental-impact-are-llms-bad-for-the-environment

TNO. (2021). Realising responsible impact. Retrieved from https://publications.tno.nl

UNEP. (n.d.). Risks of sustainability and digitalization. Retrieved from https://wesr.unep.org/sustainable-digitalization-and-the-triple-planetary-crisis-in-west-asia/risk-sustainability.html

Van Wynsberghe, A. (2021). Sustainable AI: AI for sustainability and the sustainability of AI. AI And Ethics, 1(3), 213–218. https://doi.org/10.1007/s43681-021-00043-6

World Economic Forum. (2024). AI and energy: Will AI reduce emissions or increase demand?. Retrieved from https://www.weforum.org/stories/2024/07/generative-ai-energy-emissions/

World Economic Forum. (2024). What is the “twin transition” - and how can it speed sustainable growth. Retrieved from https://www.weforum.org/stories/2022/10/twin-transition-playbook-3-phases-to-accelerate-sustainable-digitization/

Appendix

Appendix 1: Overview of resources to consider for environmental sustainability in AI

Balancing the intended value of AI with its environmental costs is crucial for responsible AI deployment. While no tool is perfect, utilizing the right tools and frameworks can significantly aid in this process. These resources can help stakeholders incorporate sustainability and environmental considerations into their AI practices. They provide structured approaches to assess and mitigate the environmental impacts of AI, ensuring that technological advancements contribute positively to sustainability goals. The following table offers a selection of such resources designed to support these efforts.

Tools/ Methods	Description	How can it be applied?
ESG-AI Framework Structured approach to help investors assess the materiality of AI use	This framework, developed based on insights from engagements with 28 companies, provides an overview of the environmental and social impacts of AI applications.	This framework helps evaluate AI projects using ESG criteria, ensuring responsible and sustainable investments. It is a robust, three-step framework co-developed by CSIRO and Alphinity, combining RAI and ESG criteria, and includes a sample assessment template.
Artificial Intelligence Impact Assessment (AIIA) (Framework) Tool for making considerations when deploying AI in a project	This is a structured method to map out the social benefits of an AI application while analyzing the reliability, safety, and transparency of the AI system. Provided by the Dutch Ministry of Infrastructure and Water Management.	This assessment can help review AI deployment risks and societal benefits in projects. The framework is only available in Dutch, provides clear steps and guiding questions for implementation.
Algoritmekader Framework with guiding principles on responsible AI deployment	Structured criteria including operationalization criteria on various domains, including sustainability. Provided by the Dutch Ministry of Interior and Kingdom Relations.	These criteria can help inform on laws and regulations and provide tips and tools for the responsible use of algorithms, including sustainability.
A Guiding Framework for Responsible AI Integration Into ESG Paradigms A framework that aligns AI development with ESG	It is a comprehensive tool developed by the Responsible AI Institute (RAI Institute) to address the intersection of Artificial Intelligence (AI) and Environmental, Social, and Governance (ESG) principles.	This framework offers organizations actionable strategies to embed AI ethics and sustainability into their governance structures. It includes selected criteria for impact evaluation and provides an example analysis. However, the output is less structured than the above framework, despite a similar focus on ESG and RAI.
SustainAI 13 criteria that organizations should consider to develop and use AI more sustainably	This project developed 13 criteria for assessing the sustainability of AI systems across environmental, economic, and social dimensions. It helps organizations develop and use AI more sustainably, addressing issues like energy consumption, CO_2 emissions, resource use, market diversity, and working conditions.	Organizations can use the 13 criteria in environment, economy, and society as guiding themes to evaluate their AI deployment. However, #3, while inclusive, lacks clear application in organizational decision-making and is only available in German

Tools/ Methods	Description	How can it be applied?
AI Kompass Administrative framework that help water boards make the right decisions applying AI	Developed by the Union of Water Boards in the Netherlands, this tool guides the responsible and effective use of AI in water management. It includes an administrative framework with five key principles and focuses on practical implementation.	This example shows how a water management authority adopts AI by addressing ethical issues, setting usage standards, and fostering transparent decision-making. The Kompass, available only in Dutch, lacks implementation steps but can inspire aspects to consider.
Framework for assessing the GHG emissions impacts of ML Systematic framework for describing the effects of ML on GHG emissions	This framework, introduced in a Nature Climate Change article, categorizes the impacts of machine learning (ML) on global GHG emissions into three main categories: computing-related impacts, immediate impacts of applying ML, and system-level impacts.	This framework helps organizations quantify ML's environmental impact and identify ways to reduce emissions. It is scientifically robust but focuses mainly on ML's environmental impacts and climate change mitigation.

Acknowlegements

This paper has been written based on the work in the DaCapo project and builds on the knowledge from a wide range of TNO domains: Smart Industry, Circularity and Sustainability Impacts, AI Governance and Data Science. The TNO DaCapo team that worked on the AI Circularity Consultant consists of Elmer Rietveld, Jisca van Bommel, Ilse Rietveld, and Nick Oostervink. Our colleagues Colette Wibaut, Jesse van Oort and Julia García Fernández have provided crucial details on their ongoing research into the actual energy expenditure of Popular AI Tools to illustrate its impact. With special thanks to the following TNO colleagues for their contribution: Gijs van Houwelingen, Miriam Veronesi, Marianne Schoenmakers, Herman Pals, Sjoerd Rongen

TNO innovation for life

Contact
Ilse Hellemans

Consultant
TNO Vector

ilse.hellemans@tno.nl
+31 6 2554 0392
https://www.linkedin.com/in/ilse-hellemans/

tno.nl