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Environment Takes a Backseat in EU Digital Push

A Case Study on the Energy Requirements of Generative AI and a Digital Euro

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Source: DALL-E 3 via ChatGPT.

The Commission's "twin transition", aimed at achieving both a greener and more digital society, suffers from a paradox: the impact of digital technology on sustainability is multifaceted and therefore difficult to predict. This cepStudy conducts two case studies; one on generative AI models and a second on the potential digital euro. It shows that their environmental impact may challenge their role as catalysts for the twin transition.

- ► Empirical evidence on the energy consumption of generative AI technologies suggests that they will lead to higher carbon emissions. Europeans could emit around 14,720 tonnes of CO2 per year from genAI-based web searches, equivalent to 38,272 flights between Amsterdam and Rome. Still, predictions of "rebound" effects are uncertain and overlook counterfactual scenarios and research on improving energy efficiency.
- ► While there is uncertainty about the sustainability of a digital euro, if properly designed, it could be one of the most environmentally friendly means of payment. However, many factors may challenge this potential, e.g., the fact that it is supposed to be an additional means of payment and will be issued in two variants.
- ► How can the "twins" become friends? To enable mutual mitigation and leverage, we make several horizontal policy recommendations that go beyond our case studies, focusing on improved transparency standards for carbon emissions, taxonomy criteria for sustainable digital infrastructure, and increased reliance on the European Emissions Trading System. Moreover, AI developers should leverage more energy-efficient hardware, develop small language models, and adopt "green coding" practices. Issuers of central bank digital currencies like the digital euro should prioritise centralised over decentralised Bitcoin-like technical solutions. Finally, it is essential to refer to renewable energy sources, develop a reliable e-waste strategy, and to include sustainability-related criteria in procurement processes for the digital euro infrastructure.

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1 Introduction: The Paradox of Green Digitalisation

Historically, the processes of digitisation and decarbonisation have been inextricably linked: relative to GDP, global economic production has been declining in energy use and increasing in information use since 1913.[1] Driven by increased usage of data centres, cryptocurrencies, and Artificial Intelligence (AI), however, global electricity demand is expected to double in the next three years.[2] Still, the key political project of the outgoing von der Leyen I Commission, and the European Union (EU) more generally, has been to initiate a "twin transition" aimed at achieving both a greener and more digital society *at the same time*. This is complicated by recent geopolitical shifts, triggered by Russia's attack on Ukraine and China's growing assertiveness on the international trade stage. These have led to calls for the EU to increase its "strategic autonomy" and "digital sovereignty",[3] for example by developing domestic AI models. **Can digitalisation play its promised role in the decarbonisation process**?

This paper aims to demystify the narrative of a twin transition: Digitalisation and sustainability are mostly independent phenomena, but one can support – or contradict – the other. **The Commission's use of the term refers to a range of legislative and non-legislative measures under the European Green Deal and the Digital Decade strategy**, including, for example, the Circular Economy Action Plan and the Digital Strategy.[4] Clearly, both policy domains are fundamental to fostering a European society that is both resilient and capable of sustainable growth. According to the State of the Climate in Europe 2022 report, Europe has been warming twice as much as the global average since the 1980s, with significant effects on the region's socio-economic fabric and ecosystems.[5] Similarly, the rapid spread of digital competencies, infrastructure, and services is becoming vital for maintaining the continent's industrial competitiveness, job creation, and resilience, especially in strategic sectors, like generative AI, where high-risk dependencies must be avoided amidst increasing global fragility. In fact, digitalisation is often seen as a "catalyst" not only for a competitive but also a sustainable European economy and society.[6] Several Commission documents note that the "digital transformation should contribute to a sustainable, climate-neutral and resource-efficient economy"[7], including also the Commission's White Paper on a future Digital Network Act.[8] The Council conclusions on the Future of EU Digital Policy, approved on 21 May 2024, underlined that the digital transformation should "go hand in hand" with the green transition.[9] Accelerating delivery of the twin transition is expected to play an important role in the next Commission mandate.[10]

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[1] Fouquet (2024), The digitalisation, dematerialisation and decarbonisation of the global economy in historical perspective: the relationship between energy and information since 1850, LSE Research Online Documents on Economics.

[2] According to a new IEA report: Electricity 2024 - Analysis and forecast to 2026 (windows.net).

[3] For a definition and discussion of this term, see: Steinbach (2023), EU's Turn to 'Strategic Autonomy': Leeway for Policy Action and Points of Conflict | European Journal of International Law | Oxford Academic (oup.com).

[4] European Commission (2019), Communication, The European Green Deal, COM/2019/640 final; Europe's Digital Decade | Shaping Europe's digital future (europa.eu).

[5] WMO (2023), State of the Climate in Europe 2022, WMO-No. 1320, download (wmo.int).

[6] EPC (2020), Towards a green, competitive and resilient EU economy: How can digitalisation help? (epc.eu).

[7] According to the summary by the European Parliamentary Research Service: EPRS (2024), The global reach of the EU's approach to digital transformation | Think Tank | European Parliament (europa.eu), p. 4.

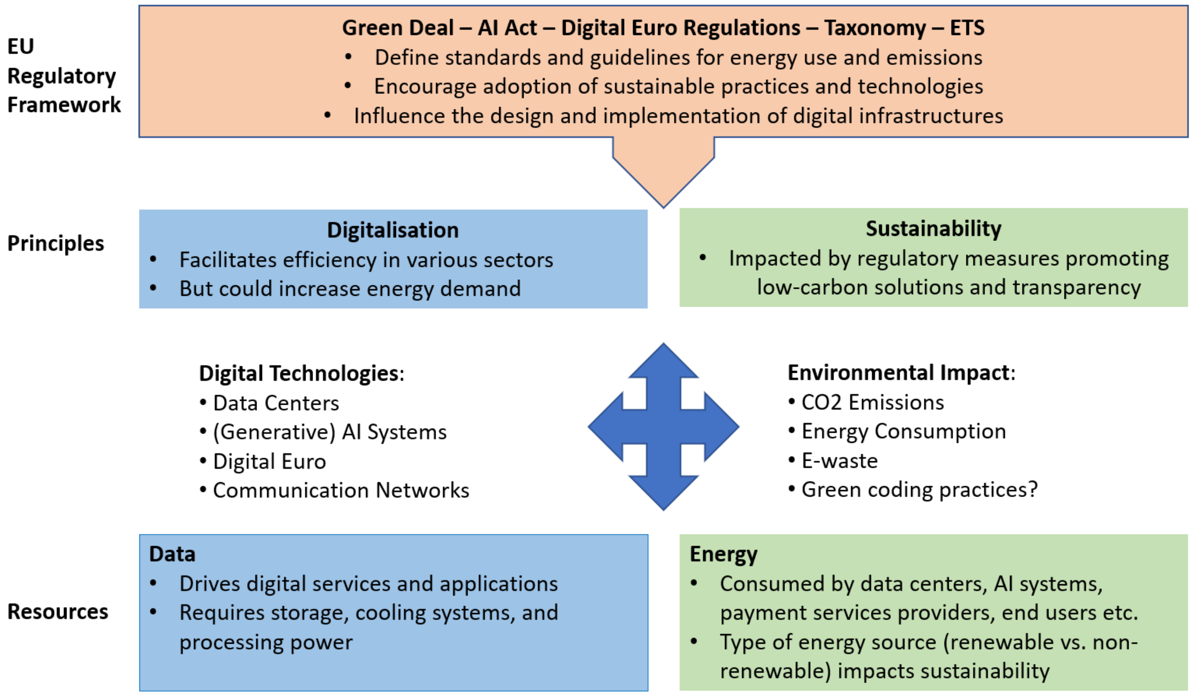
[8] See chapters 2.3.5 and 3.2.9 of the EU Commission's White Paper on "How to master Europe's digital infrastructure needs?" [COM(2024) 81, 21.2.2024, see cep**PolicyBrief**].

[9] Council (2024), The Future of EU Digital Policy, Council Conclusions (21 May 2024), No 9484/24, p. 15. The same sentiment was also contained in the Competitiveness Council conclusions approved three days later, which envisioned a "competitive European industry driving our green, digital and resilient future".

[10] EPRS (2024), Ten issues to watch in 2024, pp. 7f.

Crucially, however, there is an **underlying paradox at the heart of this strategy because the growing role of digital solutions presents a multifaceted impact on environmental sustainability whose channels are extremely difficult to predict and quantify**. On the one hand, technological advancements undeniably contribute to green objectives by optimizing resource use, better forecasting, and scheduling of energy supply and demand for renewables. For example, AI can make the power grid, on which digital technologies rely, faster and more resilient.[11] Scaling digital technologies across industries could account for up to 20% of the emission reductions required by 2050.[12] By addressing certain market failures that hinder the scaling up of circular activities, digital technologies help the public sector to deliver better circular economy policies, reshape government-citizen interaction, and improve implementation of those policies.[13] On the other hand, however, digital solutions have an intrinsic carbon footprint (in addition to more general risks related to security and privacy, which we omit in the following analysis). The energy consumption and electronic waste associated with digital infrastructure, including data centres, AI models, and digital payment options, necessitate a critical examination. Figure 1 outlines the relevant relationships in a diagram, focusing on data and energy as resources, digitalisation and sustainability as principles, and how infrastructures and regulatory frameworks might be inter-linked.

Fig. 1: Relationships between Digitalisation, Sustainability and Regulation



EU Regulatory Framework

Green Deal – AI Act – Digital Euro Regulations – Taxonomy – ETS
- Define standards and guidelines for energy use and emissions
- Encourage adoption of sustainable practices and technologies
- Influence the design and implementation of digital infrastructures

Principles

Digitalisation
- Facilitates efficiency in various sectors
- But could increase energy demand

Sustainability
- Impacted by regulatory measures promoting low-carbon solutions and transparency

Digital Technologies:
- Data Centers
- (Generative) AI Systems
- Digital Euro
- Communication Networks

Environmental Impact:
- CO2 Emissions
- Energy Consumption
- E-waste
- Green coding practices?

Resources

Data
- Drives digital services and applications
- Requires storage, cooling systems, and processing power

Energy
- Consumed by data centers, AI systems, payment services providers, end users etc.
- Type of energy source (renewable vs. non-renewable) impacts sustainability

Source: cep research.

Our examination is timely. Researchers have noted that “the role of AI in green industries remains relatively unexplored”, especially when it comes to the complementarity and “technical distance” between digital and green technologies.[14] Despite being optimistic regarding the potential benefits of

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[11] See: Kim (2023), Four ways AI is making the power grid faster and more resilient | MIT Technology Review.

[12] See: WEF (2022), Digital technologies can cut global emissions by 20% (weforum.org).

[13] Barteková and Börkey (2022), "Digitalisation for the transition to a resource efficient and circular economy", OECD Environment Working Papers, No. 192, OECD Publishing, Paris, https://doi.org/10.1787/6f6d18e7-en.

[14] Khunakornbodintr (2024), Examining the impact of green technological specialization and the integration of AI technologies on green innovation performance: evidence from China (frontiersin.org). However, the report “The Ethics of Advanced AI Assistants” published by Google includes a whole chapter (chapter 18) on environmental impact.

AI-driven tools to help combat climate change, UN advisors note that "[w]e also need to keep an eye on the potential negative impact of AI on climate change because of the associated energy and water consumption".[15] Within the machine learning literature, an often-quoted paper by Timnit Gebru and co-authors, which equates large language models with "stochastic parrots", even argues that the effect of deploying these digital innovations might amount to a new form of "environmental racism". The authors use this expression to highlight to the fact that the negative effects of climate change are affecting the world's most marginalized communities first, while those communities typically are not yet benefitting from the AI boom. They argue that policymakers and researchers should "prioritize energy efficiency and cost to reduce negative environmental impact and inequitable access to resources."[16] Overall, it is time to focus both on AI *for* sustainability (e.g. the Sustainable Development Goals), and on the sustainability *of* AI itself (i.e. the development and use of AI systems).[17]

The green and digital pillars of the Commission's twin transition strategy cover numerous and diverse projects, ranging from upgrading railways and enhancing the energy efficiency of buildings to e-government and digital services. By way of example, this cep**Study** conducts two detailed case studies focusing on digital technologies that have risen to particular prominence in recent months: generative AI models, as distributed by OpenAI with its "ChatGPT" service (Section 2), and Central Bank Digital Currencies (CBDCs), such as the plan for a "digital euro" advanced by the Commission and ECB (Section 3). Addressing the carbon footprint inherent in these prominent digital solutions is timely, as it poses a challenge to their role as catalysts for achieving sustainability targets. We thus derive several policy recommendations for the next Commission to ensure that the twin transition can be managed successfully and is not inherently contradictory (Section 4). Our conclusion then follows in Section 5.

Why did we choose these two technologies, genAI and digital euro, for our case studies? In the case of generative AI, this selection was due to the seemingly dominant belief among EU lawmakers that AI will lead to environmentally beneficial outcomes. This is reflected, for example, in Recital 4 of the EU AI Act, which states that AI can support "environmentally beneficial outcomes" including "resource and energy efficiency, environmental monitoring, the conservation and restoration of biodiversity and ecosystems and climate change mitigation and adaptation".[18] As our analysis shows, this optimism overlooks key empirical evidence and means that the AI Act may not adequately address the environmental impacts of AI. In the case of the digital euro, our choice is justified by the fact that both the legislator – the European Parliament and the Council – and the European Central Bank (ECB) are currently in the very process of deciding how to proceed with the project, and making several crucial design choices that will have an impact on the future ecological footprint of the (potential) new CBDC for the euro area. It is, thus, a timely moment to take a closer look at these decisions – e.g. technical design and market players involved – specifically from a sustainability perspective.

Overall, this **cepStudy** calls for a more holistic, standardised approach to measure and compare the ecological impact of different digital solutions, such as generative AI and CBDCs. The EU Taxonomy Regulation sets binding criteria for determining whether an economic activity can be considered environmentally sustainable, thus directing capital towards sustainable economic activities. The inclusion of the ICT sector in this taxonomy could promote sustainable transformation. Similarly, the European Emissions Trading Scheme (EU ETS) helps to steer economies towards carbon neutrality by

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[15] UN AI Advisory Body (2023), Governing AI for Humanity, interim_report.pdf (un.org), p. 4.

[16] Bender et al. (2021), On the Dangers of Stochastic Parrots | Proceedings of the 2021 ACM Conference.

[17] van Wynsberghe, A. (2021), Sustainable AI: AI for sustainability and the sustainability of AI, AI Ethics 1, pp .213–218.

[18] Final version, as of writing: CO_TA (europa.eu). For a critical discussion, see: Warso and Shrishak (2024), Hope: The AI Act's Approach to Address the Environmental Impact of AI | TechPolicy.Press.

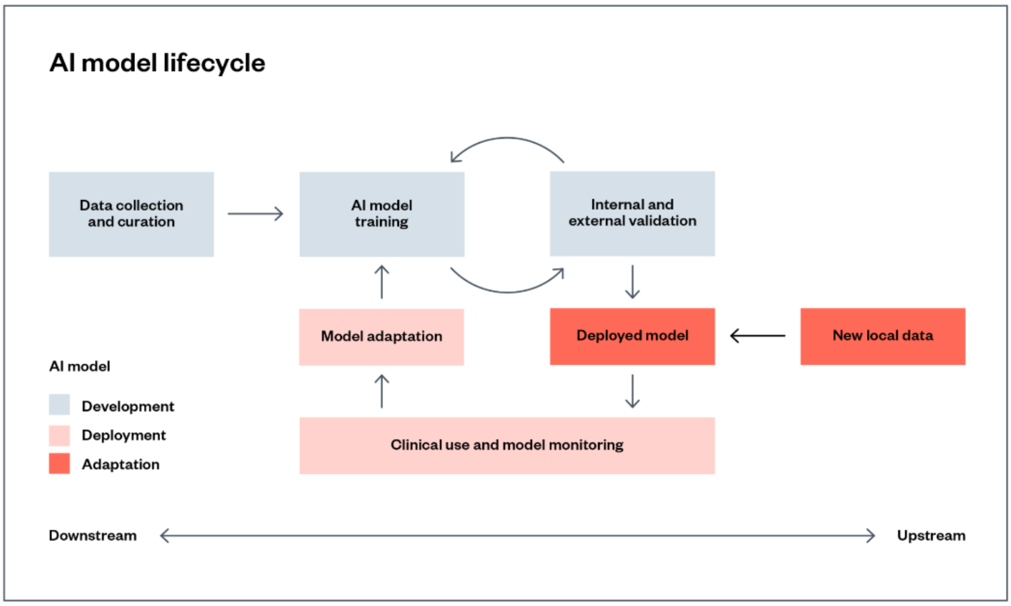
incentivising energy-efficient, low-carbon solutions without additional policy intervention. More specifically, however, the development of common terminology, standards, and protocols for measuring the carbon emissions of green digital technologies over their entire lifecycle is essential, including AI training, natural resource consumption, and addressing rebound effects. The EU Green Digital Coalition's Net Carbon Impact Assessment methodology should be extended, for instance through sector-specific guidelines on AI and CBDCs. Increased transparency by way of sustainability red-teaming and consumer-driven competition is crucial but requires improved systematic data collection and public reporting. Moreover, promoting green coding practices, providing financial incentives for efficient software development, and supporting research into energy-efficient AI hardware and small language models is essential, as is using AI to optimise the EU's internal operations. Meanwhile, the technical design of a digital euro should prioritise centralised solutions such as real-time gross settlement systems (RTGS) to minimise environmental impact. The choice of renewable energy sources for the digital euro ecosystem and the establishment of a reliable e-waste strategy are essential. Transparency on the environmental impact of the digital euro should be ensured, setting a standard for further disclosure and continuous monitoring. Lessons can be learnt from the Markets in Crypto Assets Regulation (MiCAR) regarding sustainability disclosures, ensuring that the environmental footprints of all payment instruments are transparent and comparable.

2 Case Study 1: Generative Artificial Intelligence

Over the past year, the increasing popularity of commercial AI products, such as OpenAI's ChatGPT, which utilize generative, multi-modal AI models, has marked a significant shift in the approach to integrating machine learning into technological applications. These general-purpose AI models, known as "foundation models", are designed to provide a unified solution for different tasks and therefore promise significant economic and social advances, similar to earlier general-purpose technologies such as the steam engine or electricity. Due to their prominent role in the current discourse on digitalisation, including the priorities of the European Commission, they are the focus of this section's case study.

Allocating responsibility for sustainable practices is difficult with respect to generative AI due to the multitude of actors and diverse knowledge sources engaged in the development and deployment of these models.[19] Irrespective of the model's complexity or the development approach – whether internally coded or outsourced – AI systems typically depend on elaborate supply chains (Figure 2). The spectrum of responsibilities borne by AI developers and implementers spans the entire lifecycle of the system, from initial problem formulation and data management (including data collection, labelling, and cleaning) to model training, testing, and eventual deployment. Although certain developers might manage these processes entirely within their organization, it is common for these tasks to be distributed among various entities. This structure of the genAI supply chain has led to some conceptual problems in the process of drafting the EU AI Act, which was initially based on an overly simplistic linear view of the AI value chain.[20]

Fig. 2: Abstract Lifecycle of an AI Model



Source: Brown (2023), Allocating accountability in AI supply chains.

To understand the environmental impact of modern AI models, which primarily results from the substantial energy consumption and associated carbon emissions during their training and operation, it is best to categorize this life cycle of generative AI systems into two stages: AI model training (2.1), and AI model usage (2.2), also known as "inference" since the model is inferring results based on a

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[19] Brown (2023), Allocating accountability in AI supply chains: a UK-centred regulatory perspective, Ada Lovelace Institute.

[20] Engler and Renda (2022), Reconciling the AI Value Chain with the EU's Artificial Intelligence Act – CEPS.

given input. To date, research and media attention has focused on the training phase of ML models, primarily because it is a more tangible part of the model lifecycle, typically occurring over a fixed period of time and on dedicated computing instances. However, recent papers have begun to look at the inference stage as well, which, as we will see, is crucial to understanding the impact of generative AI over its entire life cycle, as more and more people start to use generative AI applications in their daily life. Surveying this literature suggests that the EU's upcoming implementation of the AI Act, which includes environmental rules for systemically relevant models, should consider the entire operational span when addressing the environmental footprint of these AI systems (2.3). However, this may, in turn, pose problems for the EU's plan to increase its competitiveness and to attract AI start-ups and would also be burdened by methodological problems, given the current state of the literature. We thus propose a three-layered approach for incorporating sustainability benchmarking of genAI and advise the incorporation, for now, of only the first layer of any type of compulsory regulation (2.4).

When we focus on the carbon footprint of AI training and deployment in the following analysis, we deliberately leave out some other relevant elements in the lifecycle of this technology, from the collection of personal or copy-righted data, the mining of rare earth minerals, and the laborious labelling of training data by Kenyan workers[21] to the disposal of chips and the generation of toxic emissions. We also refrain from commenting on the negative trends of increasing market concentration along the generative AI value chain as we have already addressed this topic elsewhere.[22] While important, these factors would have been difficult to quantify to the same extent as model training and deployment, for which we already have some initial empirical results.

2.1 AI Training

Advancements in AI technologies, while beneficial, often entail substantial environmental implications. This is due to **the extensive computational power, energy, and resources necessary for training large models**. As an example, consider the carbon footprint associated with BLOOM, an early popular open-source language model with 176 billion parameters. Empirical findings suggest that the CO2eq emissions from BLOOM's comprehensive training phase are approximately 24.7 tonnes.[23] This figure even rises to 50.5 tonnes if all relevant aspects are taken into account, including equipment production and the total energy consumption during operations. Over time, the energy requirements of large language models have continued to rise. Estimated total emissions for Meta's newer model, known as Llama 3, were 2290 tCO2eq.[24] Training GPT-4 cost OpenAI $100 million and took 100 days, utilizing 25,000 NVIDIA A100 GPUs. Based on this information, it was estimated that GPT-4 consumed between 51,773 MWh and 62,319 MWh, i.e. more than 40 times the consumption of its predecessor, GPT-3.[25]

2.1.1 Growth in Computational Resources

For the purposes of this paper, we should highlight that the key element behind the current advances in AI performance and generality is the **exponential increase in the computational resources required**

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[21] Perrigo (2023), OpenAI Used Kenyan Workers on Less Than $2 Per Hour: Exclusive | TIME.

[22] See: Küsters and Kullas (2024), Competition in Generative Artificial Intelligence, cepInput No 6. The centralization of data, technology, and infrastructure in the hands of a few dominant companies further complicates these issues. See: Küsters and Vöpel (2024), Weniger KI-Risiken durch mehr Wettbewerb (cepInput), cep - Centrum für europäische Politik.

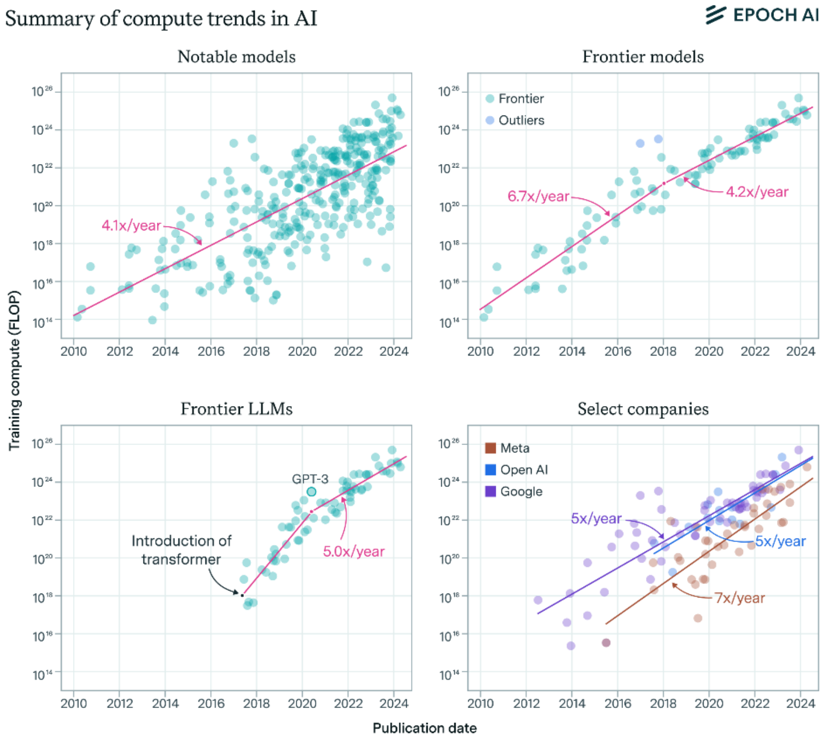
[23] Luccioni et al. (2022), [2211.02001] Estimating the Carbon Footprint of BLOOM, a 176B Parameter Language Model (arxiv.org).

[24] See the information on Hugging Face: meta-llama/Meta-Llama-3-70B · Hugging Face.

[25] Numenta (2023), AI is harming our planet: addressing AI's staggering energy cost (2023 update) (numenta.com).

to train state-of-the-art AI models. Estimates suggest that approximately two-thirds of the improvements in language model performance in recent years can be attributed to the scaling up of model sizes.[26] This trend highlights the critical importance of tracking growth in the computational resources, or “compute”, used to train these models. Recent analysis suggests that compute growth has quadrupled per year, reflecting a consistent pattern across the best performing models and leading AI organisations such as OpenAI, Google DeepMind, and Meta AI (Figure 3).[27]

Fig. 3: Compute Growth Trends



Source: Sevilla and Roldán (2024), “Training Compute”. For full reference, see footnote.

Some frontier language models experienced even faster growth of up to 9x per year between 2017 and 2024 (Figure 3). While there may be periods of slowdown due to technological or operational bottlenecks, the demand for computing power continues to escalate. Today’s largest models, such as GPT-4 and Gemini Ultra, exemplify the upper limits of current AI capabilities, being trained on a computational scale (FLOPS) far greater than that of their predecessors. Projections based on historical growth rates have closely matched the actual computational power of these models.[28] As these estimates make clear, the environmental costs associated with such extensive computational use require a balanced approach to future AI development, taking into account the need for sustainable practices in an empirical and structured way.

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[26] Ho et al. (2024), Algorithmic progress in language models. ArXiv [cs.CL], arXiv. https://arxiv.org/abs/2403.05812.

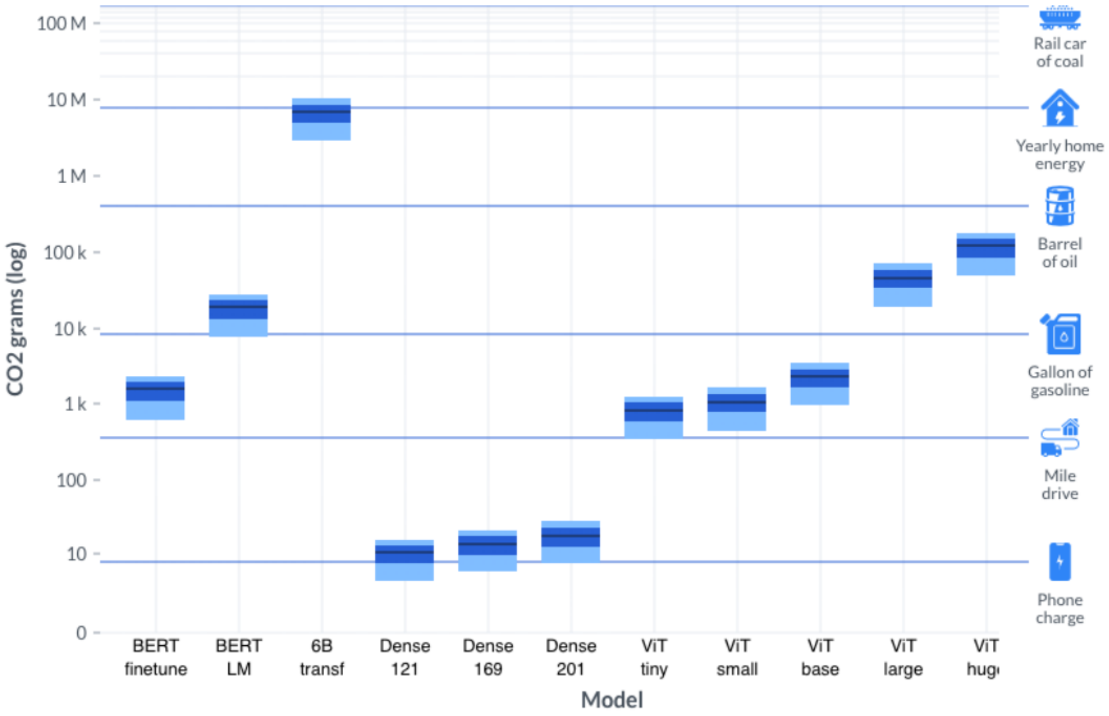
[27] Sevilla and Roldán (2024), Training Compute of Frontier AI Models Grows by 4-5x per Year. Retrieved from: https://epochai.org/blog/training-compute-of-frontier-ai-models-grows-by-4-5x-per-year [online resource].

[28] Sevilla et al. (2022), Compute Trends Across Three Eras of Machine Learning, 2022 International Joint Conference on Neural Networks (IJCNN), Padua, Italy, pp. 1-8.

2.1.2 Energy Implications

Empirical evidence for the energy implications of this scaling trend comes from a recent study by Dodge et al. (2022), who introduce a framework for assessing the carbon footprint of software operations, focusing on the use of real-time and geographically specific data to calculate the marginal emissions per unit of energy consumed.[29] It evaluates the operational carbon intensity of various modern AI models across a spectrum of sizes up to a partially trained 6.1 billion parameter language model. Additionally, the study contextualizes these emissions by comparing them to everyday activities and consumables. The results make clear that especially large-scale computational models – such as the one underpinning ChatGPT – have a substantial environmental impact (Figure 4).

Fig. 4: Emissions of Eleven AI Models



Source: Dodge et al. (2022), Measuring the Carbon Intensity of AI in Cloud Instances.

For instance, the partial training of a 6.1 billion parameter "transformer" (an AI architecture commonly used for today's large language models) is shown to potentially exceed the annual CO2 emissions of an average US household, even when only 13% trained. Similarly, Li et al. (2023) provide a methodology for estimating the water footprint of AI models, highlighting the need to consider water footprints holistically along with carbon footprints to enable truly sustainable AI training.[30] Overall, this empirical evidence suggests that energy-efficient practices should be incorporated into the training processes of large genAI models to mitigate their environmental impact as far as possible. However, as the role of data centres and chip manufacturing in this training shows, this is not as easy as it sounds.

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[29] Dodge et al. (2022), Measuring the Carbon Intensity of AI in Cloud Instances | Proceedings of the 2022 ACM Conference.

[30] Li et al. (2023), Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models (arxiv.org).

2.1.3 The Role of Data Centres and Chip Manufacturing

Despite significant investments in renewable energy, Big Tech companies like Meta, Google, and Microsoft – all of whom are known to train large language models – have continued to register rising overall emissions since the latest genAI boom started in 2022. From July 2022 to the end of June 2023, Microsoft's AI-related training resulted in 15.4 million metric tonnes of CO_2 equivalents, which runs counter to the company's plan to become carbon neutral by 2030.[31] The ongoing emissions rise is explained not least by the energy demands of data centres, which can consume up to 200 times the electricity of standard office spaces.[32] Much of Microsoft's electricity is used to power its data centres, with usage exploding from 11,284 to 24,008 gigawatt hours in three years.[33] Similarly, Google's emissions have increased by 48% in the last five years, largely due to the high energy demands of AI and data centres, putting its climate footprint reduction targets at risk.[34] Although Goldman Sachs' forecasts suggest that the data centre energy demand group is slowing down, from around 23.9% per annum to 9.8% per annum, **the data still suggests some rapid growth in the near future** (Figure 5).

Fig. 5: Energy Demand from Data Centres

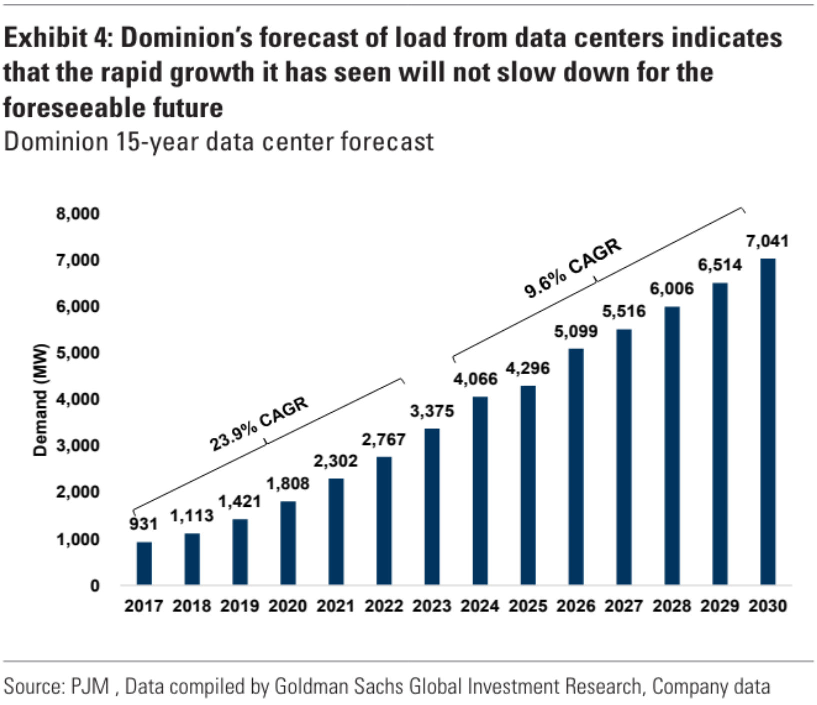
Exhibit 4: Dominion's forecast of load from data centers indicates that the rapid growth it has seen will not slow down for the foreseeable future

Dominion 15-year data center forecast

Source: PJM , Data compiled by Goldman Sachs Global Investment Research, Company data

Source: As indicated in the figure.

Moreover, **these data centres typically use significant amounts of water for cooling**. This demand is likewise expected to increase because AI technologies, which require powerful graphics processing units (GPUs) to operate, require more cooling compared to traditional servers. For instance, it is likely that training GPT-3 in Microsoft's state-of-the-art data centres caused the evaporation of 700,000 litres of clean freshwater.[35] In 2022, Microsoft experienced a 34% increase in water consumption,

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[31] Mantel (2024), Microsoft: KI lässt Emissionen um bis zu 40 Prozent steigen | heise online.

[32] Arcieri (2022), Datacenter demands push Amazon, Big Tech toward renewables, S&P Global Market Intelligence.

[33] Mantel (2024), Microsoft: KI lässt Emissionen um bis zu 40 Prozent steigen | heise online.

[34] Milmo (2024), Google's emissions climb nearly 50% in five years due to AI energy demand | The Guardian.

[35] Li et al. (2023), Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models (arxiv.org).

which has been attributed to the company's increased focus on genAI.[36] Overall, the company's water consumption has increased from just under 4.2 million to over 7.8 million cubic metres since 2020.[37] According to recent estimates, the global AI demand may be accountable for 4.2 to 6.6 billion cubic meters of water withdrawal in 2027, which is more than the total annual water withdrawal of half of the United Kingdom.[38]

Besides the energy and water costs of training AI models and hosting servers, chip manufacturing further increases the footprint of genAI, as the production of each successive generation of semiconductors also involves higher levels of energy and water consumption, and greenhouse gas emissions.[39] Despite advancements in algorithms, software, and hardware that improve energy efficiency and performance (see our discussion below), the total carbon footprint of computer systems is still increasing, primarily due to emissions from hardware manufacturing and infrastructure.[40] This issue has been overlooked in favour of security of supply, particularly in Europe, which currently has a small share of global production, but is set to increase its share under the EU Chips Act, potentially leading to a dramatic increase in emissions**. If the EU Chips Act achieves its target of 20% global production by 2030, emissions from semiconductor manufacturing are expected to at least quadruple**. According to a recent study, these emissions could range from 38.91 MMTCE (million metric tons of carbon equivalents) to over 100 MMTCE by 2030, even with increased use of renewable energy.[41]

2.1.4 Counter-effects

As a response to these developments, some start-ups are now reconsidering the dominance of conventional GPUs and seeking a paradigm shift in computational infrastructure. Here we would like to point to three promising areas of current research.[42] First, so-called stochastic processing units (SPUs) utilize thermodynamic properties to perform calculations through random fluctuations within circuits, offering a novel approach particularly suited to AI algorithms dealing with uncertainty. Secondly, some start-ups are ambitiously integrating so-called neural computing with analogue thermodynamic chips, drawing on insights from quantum computing. Finally, others hope to revolutionize the field by developing reversible computing chips, an energy-efficient technology that preserves information during calculations[43] Overall, this welcome shift towards alternative computational methods reflects a growing consensus on the necessity to transcend the limitations of Moore's law and conventional chip design, as AI models rapidly outgrow existing hardware capacities. This technological evolution, while challenging entrenched industry practices, promises significant rewards in terms of sustainability, but requires more funding and economic certainty to reach the market and will take a long time to mature.

Despite the apparently high figures and the long way that research still has to go, it is worth pointing out that **from a global perspective, AI as such is far away from significantly changing the**

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[36] Moss (2023), Microsoft's water consumption jumps 34 percent amid AI boom - DCD (datacenterdynamics.com).

[37] Mantel (2024), Microsoft: KI lässt Emissionen um bis zu 40 Prozent steigen | heise online.

[38] Li et al. (2023), Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models (arxiv.org).

[39] Crawford et al. (2021), The Chip Industry Has a Problem With Its Giant Carbon Footprint - Bloomberg.

[40] Gupta et al. (2020), Chasing Carbon: The Elusive Environmental Footprint of Computing, 2011.02839 (arxiv.org).

[41] Hess (2024), Chip Production's Ecological Footprint: Mapping Climate and Environmental Impact (interface-eu.org).

[42] See the overview provided by Knight (2024), ChatGPT's hunger for energy could trigger a GPU revolution (wired.com).

[43] On reversible computing, see also: Azhar and Galbraith (2024), Breaking the energy barrier with reversible computing (exponentialview.co).

environment. In recent years, cloud and hyperscale data centres have accounted for 0.1-0.2% of global greenhouse gas emissions, with an estimated quarter of their workloads and traffic currently related to AI.[44] In 2023, AI processors likely consumed between 7 and 11 terawatt-hours (TWh) of electricity per year, or about 0.04% of global electricity use, but for comparison, this consumption is significantly lower than cryptocurrency mining, which uses 100-150 TWh per year, and traditional data centres, which use 500-700 TWh.[45] It could therefore be argued that the energy cost of the initial training is basically negligible, especially if it is only used occasionally for very large and advanced models that are subsequently used by many people and firms around the world. In such a setting, the initial high fixed costs in terms of energy would be quickly recouped. What is alarming in this context, however, is the **fact that generative AI models are not only getting bigger and bigger, but that more and more such models are being trained each year**, rather than fewer and fewer: In 2023, a total of 149 foundation models were released, more than double the amount released in 2022.[46] Rather than concentrating on a single model, the number of vendors is increasing, and at the same time the half-life of the models in terms of their capabilities is decreasing, which means that new training has to be done faster and faster. Nevertheless, given the numbers cited above, current evidence and projections suggest that AI training *alone* is unlikely to lead directly to large, short-term increases in greenhouse gas emissions.

Finally, it must be emphasised that current predications might be erroneous. A report by the Center for Data Innovation pointed out that “as with past technologies, many of the early claims about the consumption of energy by AI have proven to be inflated and misleading”.[47] The report’s author points to **economic viability, technological advancement, and efficiency improvements as key factors explaining past inaccuracies of AI energy forecasts**. First, exaggerated predictions often overlook the significant financial implications of scaling AI infrastructure, such as the prohibitive costs associated with expanding data centres and procuring advanced computing hardware. Furthermore, the diminishing returns on AI performance enhancements indicate a shift towards optimization over raw computational growth, acknowledging the nearing plateau in certain domains of AI capability. Finally, current trends in data centre energy intensity, alongside advancements in hardware specialization and software techniques like so-called quantization,[48] suggest a sustainable path forward. While the future of technological innovation (and especially the rate of progress) is ultimately unknowable, it is important to keep these factors in mind when discussing the likely energy demands of generative AI.

A good example of how quickly **research progress in AI architecture might change current predictions about the energy requirements of generative AI training** is recent Microsoft research, which shows that 1-bit LLMs are more efficient than traditional systems.[49] These models, where each parameter is simplified to a ternary state (-1, 0, 1), illustrate that it is possible to drastically reduce energy consumption – by up to 98% – compared to traditional LLMs. In addition, these models improve latency by up to 310%, providing faster responses that are critical for real-time applications, and consume up to 85% less memory, thereby maintaining performance quality while being significantly more resource

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[44] Kaack et al. (2021), Aligning artificial intelligence with climate change mitigation (hal.science), p. 5.

[45] Data cited after: Luers et al. (2024), Will AI accelerate or delay the race to net-zero emissions? (nature.com).

[46] HAI (2024), HAI_2024_AI-Index-Report.pdf (stanford.edu).

[47] Castro (2024), Rethinking Concerns About AI’s Energy Use (datainnovation.org).

[48] The term quantization refers to techniques that reduce the precision of model weights and/or activations in order to improve computational efficiency and reduce memory requirements or usage. See: Jacob et al. (2017), Quantization and Training of Neural Networks for Efficient Integer-Arithmetic-Only Inference (arxiv.org).

[49] Ma et al. (2024), The Era of 1-bit LLMs: All Large Language Models are in 1.58 Bits (arxiv.org).

efficient. Moreover, the introduction of smaller but efficient language models such as Microsoft's Phi-3-mini and Apple's OpenELM show that this **trend towards smaller and "greener" but (roughly) equally efficient models** often goes hand in hand with the democratisation of AI technologies.[50] These models are designed to run efficiently on less powerful hardware such as smartphones and laptops. Phi-3-mini, with its 3.8 billion parameters, can run on consumer-grade GPU hardware, which is a leap towards bringing robust AI applications to everyday devices (such as iPhones) without relying on cloud connectivity.[51] OpenELM, meanwhile, not only advances the efficiency of language models, but also promotes transparency by making the entire training and evaluation framework available to the public.[52] This approach supports the open research community in replicating and improving existing work, which is certainly critical to fostering green innovation in AI technologies.

Taken together, these developments highlight the need to support AI research and development that prioritises efficiency and accessibility. Investing in technologies such as 1-bit LLMs and supporting open research initiatives are crucial to ensuring that AI advances do not lead to negative environmental impacts, especially as the push towards models that can run on consumer devices will lead to the integration of AI into various commercial sectors. For instance, AI-driven data collection, processing, and targeted advertising significantly contribute to energy consumption and greenhouse gas emissions, exacerbating the environmental footprint of the digital advertising ecosystem.[53] To mitigate these negative effects, research must develop **a new computing paradigm that allows companies to align their digitisation efforts with their environmental goals in a much better way than the current state of the art in AI training**.

2.2 AI Inference

Even after a model has been trained, it still has a daily carbon footprint due to the electricity required for running it (so-called "inference"). Due to the rapid success it experienced right after its launch, ChatGPT may have consumed as much electricity as 175,000 people in January 2023 alone.[54] According to recent research, ChatGPT requires 500 ml of water for every 20 to 50 questions answered.[55] As generative AI becomes more prominent, this problem will get worse. A study by Alex de Vries, a data scientist from the Dutch Central Bank, projects that by 2027, AI servers might use about 85 to 134 terawatt hours (TWh) of electricity each year under a moderate scenario.[56] This amount is roughly equivalent to 0.5% of the world's current total electricity consumption, or similar to the yearly power usage of smaller nations like the Netherlands, Argentina, or Sweden. De Vries bases his findings on the projected growth and energy efficiency of AI servers. He notes that the **energy demand of AI servers is escalating faster than the improvements in AI energy efficiency**. This increase is attributed to the escalating complexity of AI algorithms, which require more powerful and more energy-intensive hardware to function. As LLMs are increasingly embedded in products such as Microsoft computers or

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[50] See: Edwards (2024), Microsoft's Phi-3 shows the surprising power of small, locally run AI language models | Ars Technica.

[51] Abdin et al. (2024), Phi-3 Technical Report: A Highly Capable Language Model Locally on Your Phone (arxiv.org).

[52] Mehta et al. (2024), OpenELM: An Efficient Language Model Family with Open-source Training and Inference Framework (arxiv.org).

[53] Marken et al. (2024), The (Un-)Sustainability of Artificial Intelligence in Online Marketing (ioew.de).

[54] Ludvigsen (2023), ChatGPT's Electricity Consumption | Towards Data Science.

[55] Li et al. (2023), Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models (arxiv.org).

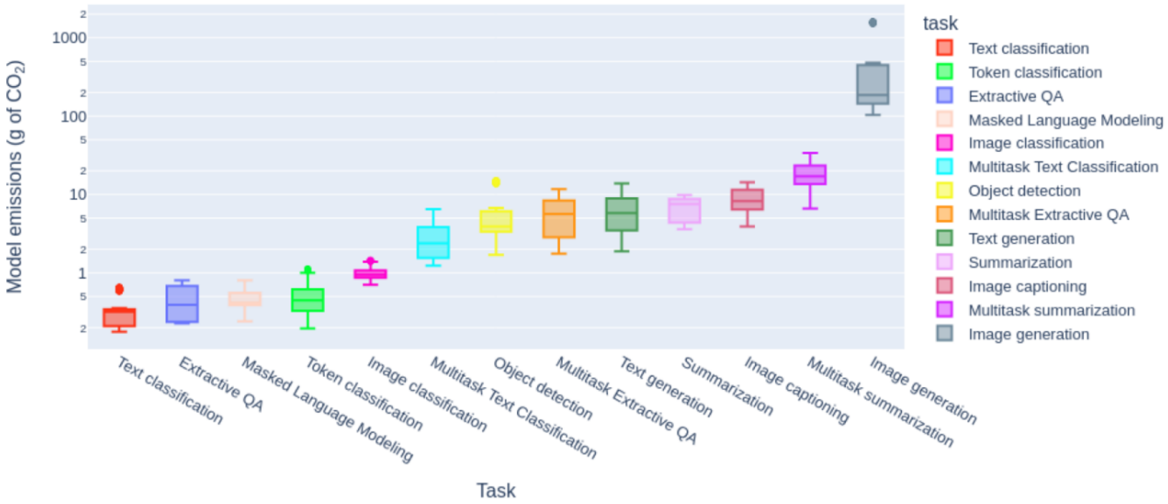
[56] de Vries (2023), The growing energy footprint of artificial intelligence: Joule (cell.co.m).

iPhones, it is therefore crucial to gain a more systematic understanding of the energy costs associated with inference.

2.2.1 Inference Costs for Different AI Tasks

A recent study by Luccioni et al. (2023) presents the first comprehensive comparison of the ongoing inference costs for different types of generative AI systems.[57] It includes both task-specific models (designed for a single task) and general-purpose models (capable of multiple tasks). The evaluation focuses on the energy and carbon footprint required to perform 1,000 inferences on a standard benchmark dataset. The findings reveal that multi-purpose, **generative models are significantly more resource-intensive than task-specific models across various tasks**, even when accounting for model size (Figure 6). Moreover, the analysis finds a substantial variability in resource use within and across tasks, particularly between tasks involving different data types (such as text and images). The study highlights that tasks combining image and text inputs in order to produce categorical outputs are less energy and carbon intensive than tasks generating text or images. This differentiation might be crucial, but the policy discourse on AI and sustainability has not yet reflected this finding.

Fig. 6: Average Quantity of Carbon Emissions produced by specific AI Rasks for 1,000 Queries



Source: Luccioni et al. (2023), Power Hungry Processing.

2.2.2 Benchmark Estimate for Europe

To gain a rough **estimate of the future emissions from using LLMs in Europe**, we conducted the following thought experiment: If millions of Europeans access services such as ChatGPT several times a day, this could easily add up to a large amount of energy consumption. How large? OpenAI does not have exact published figures on the number of queries it receives per day from European customers.[58] If the prediction of some experts is correct and LLMs do cause a "platform shift" by replacing search engines, then it makes sense to scale ChatGPT's current user numbers in Europe to those of Google. This is not an unreasonable assumption: Currently, 22% of people are already using ChatGPT as an

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[57] Luccioni et al. (2023), Power Hungry Processing: Watts Driving the Cost of AI Deployment? (arxiv.org).

[58] According to a statement from Sam Altman in February 2024, ChatGPT users are generating 100 billion words per day. See: Altman (2024), ChatGPT users are generating 100 billion words per day - Sam Altman : r/OpenAI (reddit.com).

alternative to Google.[59] A survey that included Europeans found that the vast majority of respondents use Google 3+ times a day to search for things online.[60] So if in the future, those questions are put to a genAI-based service, such as ChatGPT, instead of Google, this would translate to at least 490.56 billion queries in Europe per year (448 million people living in the EU × 365 days × 3 queries/day = 490.56 billion queries per year). We also do not know the exact energy consumption of ChatGPT per query. However, from the above-mentioned paper by Luccioni et al. (2023), we can see that BLOOM consumes about 20-30 gCO2 per 1000 queries. Since BLOOM is much smaller than GPT4, multiplying the energy costs of BLOOM queries with the likely figures for using ChatGPT leads to a very conservative estimate, even using the upper figures (Table 1). Based on this, we estimate that in an AI-driven future, Europeans could emit around **14,720 tonnes of CO2 per year from genAI-based web searches**. For comparison, this is equivalent to the emissions caused by 38,272 economy flights between Amsterdam and Rome.[61] Based on the latest data for 2022,[62] where the total CO2 emissions in Europe (EU-27) are 2,485,814.43 kilotonnes (or 2.485 billion tonnes), the CO2 emissions from genAI-based web search (14,720 tonnes per year) predicted by our estimate would account for at least 0.06% of the total CO2 emissions in Europe.

Tab. 1: Benchmark Estimate: Potential Generative AI Inference Footprint in Europe

Calculation Step	Value/Description
Total annual queries in Europe	448 million people living in Europe × 365 days × 3 queries/day = 490.56 billion queries/year
CO2 consumption per 1000 queries	Literature: 20-30 gCO2 per 1000 queries (BLOOM) Assumption: 30 gCO2 per 1000 queries (ChatGPT)
Total CO2 emissions per year	490.56 billion queries × estimated gCO2 per 1000 queries = **14,716.8 tonnes of CO2 per year**

Source: Own estimate. The methodology follows an idea proposed by: Lynn Kaack (2024),Presentation “Input und Q&A: Den ökologischen Fußabdruck von Basismodellen messen”, at: Conference “KI: Immer größer statt grüner”, Berlin (29.01.2024).

2.2.3 Counter-effects

Simply listing the energy requirements for using AI models on a day-to-day basis, however, overlooks the simultaneous potential of digital technologies to contribute to the decarbonization of the economy by replacing physical processes with digital ones. As Castro (2023) points out, one must also factor in the substitution effects that these technologies bring about.[63] Instances such as opting for email over traditional mail, streaming films instead of renting physical DVDs, and favouring video conferences over face-to-face meetings exemplify this effect. **While the substitution effect is theoretically clear, empirical evidence is scarce**. A rare example is a study by Tomlinson et al. (2023), who compare the emissions of several AI systems like ChatGPT, BLOOM, and Midjourney with those of humans completing the same tasks. They find that an AI writing a page of text emits 130 to 1500 times less CO2e than a human doing so, while an AI creating an image emits 310 to 2900 times less.[64] In general, AI is expected to amplify substitution shifts by means of improved video call quality and by enabling

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[59] See: SRI/PEARL (2024), New SRI/PEARL survey now published, reveals worldwide public opinion about AI.

[60] See: Ray (2019), We Surveyed 1,400 Searchers About Google - Here's What We Learned - Moz.

[61] See: Anthesis (n.d.), What exactly is 1 tonne of CO2? We make it tangible. - Anthesis-Climate Neutral Group.

[62] See: EEA greenhouse gases — data viewer — European Environment Agency (europa.eu).

[63] Castro (2024), Rethinking Concerns About AI’s Energy Use (datainnovation.org).

[64] Tomlinson et al. (2023), The Carbon Emissions of Writing and Illustrating Are Lower for AI than for Humans, arXiv.

the execution of tasks more efficiently than traditional human labour, thereby potentially reducing the overall energy consumption associated with these activities.

2.3 Legal Requirements and Measurement Criteria

Over the past year or so, a number of countries, including China, have begun to establish strict guidelines governing the deployment of AI technologies. However, **a significant gap exists in these frameworks regarding the explicit incorporation of environmental sustainability**. In cases where it is mentioned, it is often treated as an optional aspect of risk management rather than a mandatory criterion. At the municipal level, regulations scarcely address the environmental implications of AI computational processes. While regions like the EU, the US, and the UK have initiated strong rules for AI regulation, their primary emphasis is on safeguarding consumer and business interests, along with ensuring safety and open digital markets. This competition-centred approach might overlook the critical need to integrate environmental sustainability into AI laws and regulations. As one academic notes, "there is no guarantee that if we open up the market and have 10,000 Microsoft Azures instead of one that the industry's environmental footprint will somehow magically reduce".[65] Therefore, some observers have argued that the sustainability of AI systems should be included in AI regulations "to mitigate its environmental impact during the model design phase rather than being an afterthought".[66]

2.3.1 EU AI Act

In the case of the EU, the new **AI Act primarily aims to mitigate safety risks and uphold fundamental rights but also includes some form of high-level environmental protection**. As noted by researchers on AI ethics, "distal concerns related to upstream development activities are largely omitted from the AI Act's scope, such as the societal and environmental impacts of computing hardware and infrastructure".[67] The final proposal for the AI Act recognises environmental considerations, and mandates the Commission to work with European standardisation organisations to establish standards for reporting and documentation, with a focus on improving the resource efficiency of AI systems. This includes reducing energy and resource consumption throughout the lifecycle of high-risk AI systems and promoting the energy-efficient development of general-purpose AI models. So far, however, measures to reduce the environmental impact of AI systems are limited and inadequate, with some being voluntary, and key details rely on the standardisation process. In May 2023, ahead of finalising the AI Act, the Commission sent a standardisation request to the European standardisation bodies.[68] This request failed to include standards for the energy consumption of AI models and systems, so an updated request is needed immediately. The Commission should consult the EU AI Board, the Advisory Forum, and other relevant stakeholders before issuing this update. The timing for issuing the updated request is uncertain and the delivery date of these standards is also unclear.[69] Furthermore, **providers of general-purpose AI models, which typically involve substantial data processing and thus high energy consumption, are obliged to report their energy usage**. If the model's energy consumption is unknown, estimating it based on computational resource usage is adequate. Providers of high-risk AI

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[65] Cath (2024), Is "More Clouds" the Future We Want? A Dispatch from the FTC AI Tech Summit | TechPolicy.Press.

[66] OECD (2023), Will businesses or laws and regulations ever prioritise environmental sustainability for AI systems? - OECD.AI.

[67] Attard-Frost and Widder (2023), The Ethics of AI Value Chains, Proceedings Template - WORD (arxiv.org).

[68] See: Commission (2023), Decisions of 22.5.2023 on a standardisation request to the European Committee for Standardisation and the European Committee for Electrotechnical Standardisation in support of Union policy on artificial intelligence, eNorm Platform (europa.eu).

[69] Warso and Shrishak (2024), Hope: The AI Act's Approach to Address the Environmental Impact of AI | TechPolicy.Press.

systems must consider and report any direct or indirect environmental harm to the regulator as a serious incident. Our empirical survey above suggests that the current framework of the AI Act is inadequate and that additional approaches are needed to regulate the environmental impacts of generative AI. Crucially, **standards for the energy consumption of AI models should be requested and developed as soon as possible and should include reporting standards for the use phase of AI** (“inference”), such as by means of the definition of different standard use scenarios by AI vendors prior to market launch.

2.3.2 Different Ways of Measuring AI’s Environmental Impact

If one accepts this premise, the key question becomes how to measure these varying impacts of AI across the life cycle. So-called **direct emissions, related to computing, are relatively easy to measure**. By way of example, we point here to “CodeCarbon”, an open-source software package to estimate the location-dependent CO2 footprint of computing.[70] It calculates the carbon dioxide (CO2) emissions generated by the computing resources needed to run the code, encouraging developers to make their code more efficient. In particular, the tracker monitors the energy consumption of key cloud services and on-premises data centres. It uses accessible data to calculate CO2 emissions by considering the carbon footprint of the electricity used by the connected hardware. The tracker records the estimated CO2 equivalent for each project and compiles this data for individual projects as well as for entire organizations. Additionally, it offers guidance to developers on how to lower emissions by choosing cloud infrastructure in areas that rely on cleaner energy sources. In the section on policy recommendations below (section 4), we comment further on this potential for incentivising “green coding”.

However, these measurements related to coding quality do not extend to indirect effects beyond computing. A comprehensive three-year study found a significant gap in the reporting practices of LLM vendors, who traditionally disclose only the direct energy consumption and emissions associated with a model’s training cycle, thereby providing an incomplete picture of the actual environmental impact.[71] When considering the entire lifecycle of these models, including hardware production and operational energy, the total emissions could potentially double, with additional significant emissions incurred during the model’s usage phase. To address this, the researchers proposed a more fundamental set of criteria for the collection of energy consumption data throughout the system development and model training phases, including power usage effectiveness (PUE), a metric that offers a transparent measure of a data centre’s computational energy efficiency relative to its overall energy consumption.[72]

Going beyond the direct effects (training and deployment), there also **broader societal spill-overs of employing AI**. From this perspective, a recent Bitkom study estimates that digital technologies have an enablement factor of between 6 and 9, a metric that shows the ratio of CO2 savings to the carbon footprint of digital technologies. This illustrates the large role that digital innovation could, in theory, play in mitigating the effects of climate change, not only by increasing efficiency but also by fostering new sustainable practices.[73] Similarly, Bill Gates has suggested that AI could allow countries to

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[70] Code: GitHub - mlco2/codecarbon: Track emissions from Compute and recommend ways to reduce their impact on the environment. See also: BCG (2020), Top AI Experts Create CodeCarbon, a Tool to Track and Reduce Computing's CO2 Emissions (bcg.com).

[71] Rohde et al. (2024a), Taking (policy) action to enhance the sustainability of AI systems (ioew.de).

[72] Rohde et al. (2024b), Broadening the perspective for sustainable artificial intelligence - ScienceDirect.

[73] Bitkom (2024), Klimaeffekte der Digitalisierung 2.0 | Studie 2024 | Bitkom e. V.

consume less energy by improving the efficiency of technology and power grids, even though more data centres would be needed. However, critics argue that this view overlooks the environmental impact of building new data centres around the world, a process that is not yet feasible using only renewable energy. They also point out that new AI-powered devices, such as Copilot+ PCs and iPhones with “Apple Intelligence”, tend to use significantly more power than their predecessors.[74] In other words, any optimistic view of the spill-over effects of AI can be challenged based on the inherent unpredictability of an exponentially AI-driven future, particularly with the growing trend towards larger AI models as well as AI-enhanced devices and their associated resource consumption.

In fact, while quantifying current benefits provides a valuable snapshot, **forecasting future scenarios remains extremely challenging due to potential rebound effects and the escalating demand for computing power and data centres driven by AI expansion**. Researchers have argued that the impact of emissions at this societal level remains uncertain, in part because of the diverse mechanisms by which they occur, which make measurement and prediction difficult.[75] There is also speculation among industry observers as to whether the current generative AI boom will continue as expected, or whether it will soon plateau due to the diminishing returns of increasing the number of training data and model weights, adding to uncertainty about the long-term sustainability impact.[76] Tellingly, estimates of life-cycle greenhouse gas emissions from the global information technology sector for 2015 differ by a factor of 2, while projections for 2025 differ by up to 25 times.[77] In order to meaningfully address and estimate rebound and other societal effects, greater transparency across the product lifecycle is needed for better understanding and management of increased consumption. However, achieving this transparency could impose additional bureaucratic burdens on companies, suggesting that a balance between regulatory requirements and market-driven insights is needed to effectively integrate environmental protection efforts while minimising barriers to growth. To achieve such an optimal trade-off, the next section proposes a three-tiered, iterative approach for regulating the energy footprint of AI models.

2.4 How to Design genAI Transparency that Supports the Twin Transition

Based on the preceding discussion of the technical and computational requirements of genAI and their impact on energy consumption patterns, this section proposes a three-tiered approach to conceptualising and measuring the energy footprint of genAI models (Figure 7).[78] This schema can be used for future guidance aimed at operationalising the EU AI Act’s obligations on energy consumption transparency for developers of general-purpose foundation models, and it may help to align the EU’s twin goals of sustainability and digitalisation – as envisioned in the strategy of a “twin transition” for Europe.

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[74] See: Mantel (2024), Bill Gates rechnet den Stromverbrauch von KI-Rechenzentren schön, heise online; Ambrose and Hern (2024), AI will be help rather than hindrance in hitting climate targets, Bill Gates says, The Guardian.

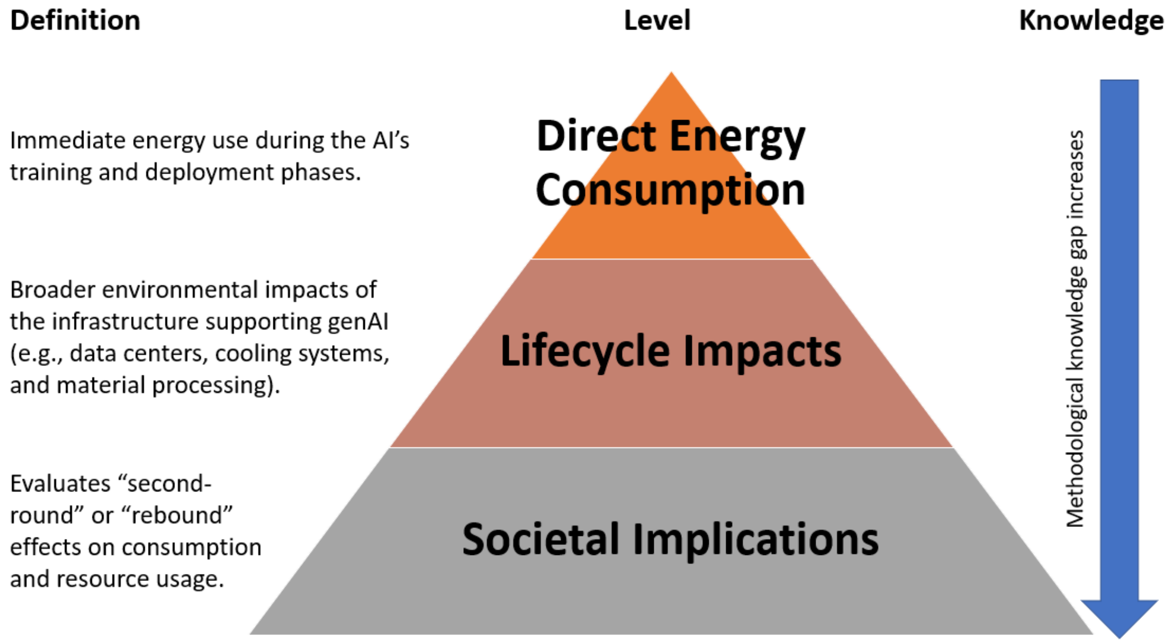
[75] Kaack et al. (2022), Aligning artificial intelligence with climate change mitigation. Nat. Clim. Chang. 12, pp. 518–527.

[76] Waugh (2024), The artificial intelligence experts who believe the AI boom could fizzle, Daily Mail Online.

[77] Quoted after: Bremer et al. (2023), Assessing Energy and Climate Effects of Digitalization: Methodological Challenges and Key Recommendations (May 25, 2023). nDEE Framing Paper Series, available at SSRN.

[78] This focus on three levels is inspired by a personal conversation with Verena Müller (TU Munich) at the 3rd Max Planck Law-Tech-Society Graduate Student Symposium, online, 26 April 2024.

Fig. 7: A Three-tiered Approach to Conceptualising/Measuring the Energy Footprint of genAI



Immediate energy use during the AI's training and deployment phases.

Broader environmental impacts of the infrastructure supporting genAI (e.g., data centers, cooling systems, and material processing).

Evaluates "second-round" or "rebound" effects on consumption and resource usage.

Source: Own figure, based on personal communication with Verena Müller (TU Munich).

2.4.1 Level 1

At the most basic level, one can capture the direct energy consumption of genAI during the training as well as the deployment (inference) phase of these models (level 1). As outlined above, both life-cycle phases are inherently energy intensive and require significant computational resources. Accurate, real-time measurement of the energy consumed by AI systems during these phases is critical for developers and regulators to effectively manage the immediate energy demands of genAI technologies. In line with the EU AI Act's reporting requirements, focusing on this most tangible level of genAI energy consumption should encourage the development of more energy-efficient AI algorithms and hardware.

2.4.2 Level 2

Beyond direct consumption, the second tier looks at the indirect impacts of the infrastructure that supports genAI, including data centres, cooling systems, the extraction and processing of raw materials such as rare earths, and potential recycling (level 2). These elements capture the broader environmental footprint of genAI but have so far rarely been considered in the debate and are not covered by the EU AI legislation. For instance, the availability of local energy and water resources has already emerged as a key factor in the economic and political feasibility of establishing domestic data centres.[79] To consider the impact of these indirect factors, life-cycle assessments would need to be extended beyond AI inference and carried out on all genAI infrastructure to capture the full environmental impact from construction to operation and decommissioning. If this were to become mandatory in the future, it could incentivise the adoption of advanced cooling technologies, waste heat recovery in data centres, and increased recycling of critical materials. Data centres can indeed improve their energy efficiency by adopting innovative cooling solutions and by locating in regions with abundant renewable energy sources, which is also in line with the economic incentives of Big Tech

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[79] Lazard (2023), The Geopolitics of Artificial Intelligence.

firms. As has been shown, “green” investments by Big Tech are closely aligned with the locations of their data centres, for instance in areas like Northern Virginia, a hub for Big Tech data centres and renewable energy projects.[80] Moreover, since data centres are increasingly required for training AI models and developing other digital products, often in the cloud, Big Tech firms are focusing on making them more energy efficient, e.g. by investigating better ways to cool them and to recycle their waste heat.[81]

2.4.3 Level 3

The third layer looks at the eventual societal implications of genAI, described above as “second-round” or “rebound” effects (level 3). In theory, these system-level effects could be both positive and negative and cancel each other out or even reinforce each other.[82] For example, while genAI could increase consumption by way of more efficient services, it also has the potential to significantly reduce resource use through optimisation of economic and social processes. Studies suggest that the integration of AI across industries could lead to significant reductions in resource use and emissions,[83] underlining the potential of genAI to contribute significantly to industrial sustainability. However, to showcase these impacts and leverage their potential (if the positive side indeed dominates), it is crucial that future research establishes standardised frameworks for assessing these second-round/rebound effects of genAI on society, considering both consumption patterns and resource savings.

Overall, such a structured, three-level approach to conceptualising the energy footprint of genAI is essential for achieving the EU’s twin transition goals. Starting with immediate impacts and progressively extending to life-cycle and societal impacts will allow for the comprehensive understanding and management of the environmental footprint of genAI. However, as we move from level 1 to level 3, the complexity of the data required for accurate measurement increases significantly. In other words, **our current methodological knowledge gap widens with each ascending level**, from direct energy consumption at level 1 to the more nuanced life cycle impacts and societal impacts at levels 2 and 3. Given the current limitations of our understanding and the evolving nature of genAI technology**, a pragmatic approach in the application of the EU AI Act and further guidance would be to prioritise the first level of direct measurement**. This avoids the error of “presumption of knowledge” (von Hayek) and will facilitate the establishment of robust baseline data and measurement methodologies. Over time, as methodological research progresses, policymakers can gradually broaden the focus of regulation and guidelines to include the more complex dimensions of levels two and three. We therefore suggest a phased approach.

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[80] Arcieri (2022), Datacenter demands push Amazon, Big Tech toward renewables | S&P Global Market Intelligence.
[81] Jones (2018), How to stop data centres from gobbling up the world’s electricity (nature.com).
[82] Kaack et al. (2022), Aligning artificial intelligence with climate change mitigation. Nat. Clim. Chang. 12, pp. 518–527.
[83] Bitkom (2024), Klimaeffekte der Digitalisierung 2.0 | Studie 2024 | Bitkom e. V.

3 Case Study 2: Digital Euro

For a couple of years now, central banks around the world have been considering establishing digital currencies to complement traditional forms of money, such as cash. While the reasons for these developments are manifold, the declining use of banknotes and coins for payments, the ongoing shift towards private digital means of payment and the uptake of cryptocurrencies and stablecoins are often mentioned as decisive factors. Also, the EU and especially the European Central Bank (ECB) are taking a closer look at establishing a Central Bank Digital Currency ("CBDC") for the general public ("retail CBDC") in the euro area ("digital euro"). The main objectives of this potential step are to ensure that central bank money with the status of legal tender remains available and that there exists a state-of-the art and cost-efficient means of payment for the general public, beyond any existing and future private means of payment. Furthermore, privacy related aspects, financial stability considerations and the promotion of financial inclusion are the main issues under discussion with regard to the potential introduction of a digital euro.

However, as with the adoption and implementation of many new technologies and innovations in the financial and payments sector - a prospective digital euro would be one of them – they often risk being out of line with the overarching global or European environmental goals as specified under the Paris Climate Agreement, which 195 countries worldwide agreed upon almost a decade ago,[84] and/or the "European Green Deal" initiated in 2019 and almost completed by the end of this legislative term.

In recent years, the media, academics and politicians have increasingly debated the sustainability-related problems of several privately issued and mined crypto currencies like Bitcoin. Their high energy consumption in particular sets alarm bells ringing, not to mention their impact on creating electronic waste. On the other hand, the sustainability of CBDCs, such as the digital euro, has received less attention, partly since they are still under development.

Against this backdrop, it seems crucial to incorporate sustainability considerations regarding CBDCs right from the start of the creation process and in good time before their market entry. In this section, we want to take a closer look both at the sustainability risks and sustainability benefits of a potential future digital euro and provide some recommendations on how such new digital currency could contribute to the transition to a climate-neutral eurozone.

3.1 The Digital Euro Project

The idea behind a digital euro is to establish a retail CBDC as a digital complement to banknotes and coins. Like cash, it would be an official form of central bank money directly accessible to the public, endowed with the status of legal tender and offered as public digital means of payment, coexisting with existing and future private digital means of payment.

The ECB has been working on the introduction of such a retail CBDC – the "digital euro" – since October 2020 when it issued a report on a digital euro and initiated a consultation on the project. Less than one year later, in July 2021, it launched a two-year "investigation phase". The investigation phase started in October 2021 with the "aim of addressing key issues regarding the design and distribution" of a digital euro.[85] In October 2023, the ECB concluded its investigation phase and launched a two year "realization phase", officially announcing the start of this phase in November 2023.[86] The main aims of

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[84] United Nations (2015), Paris Agreement.

[85] https://www.ecb.europa.eu/euro/digital_euro/timeline/html/index.en.html

[86] ECB (2023) Eurosystem proceeds to next phase of digital euro project, Press release, 18 October 2023.

this ongoing phase are to finalize the rules for the digital euro, select the infrastructure and platform providers and define the technical characteristics of the CBDC. Only after this phase, i.e. in November 2025, will the ECB decide whether to issue a digital euro at all, when[87], and what technical design to use.

In parallel to the work of the ECB, the European legislature started work on building a regulatory framework, which is to underpin the issuance of the digital euro by the ECB. In June 2023, the Commission proposed a Regulation on the digital euro (COM(2023) 369, see cep**PolicyBrief**).[88] The aim of the Regulation is to "ensure the effective use of the digital euro as a single currency throughout the euro area, meeting users' needs in the digital age and fostering competition, efficiency, innovation and resilience in the EU's digitalizing economy ".[89] The Regulation will establish the digital euro and regulate its main characteristics, while leaving the decision to authorise its issuance and the issuance itself to the ECB.[90] The ECB must abide by the rules and specifications of the Digital Euro Regulation. Nonetheless, it has a strong say on the technical details of the digital euro, as decisions on those aspects fall mostly within the purview of the ECB's Governing Council.[91] In the upcoming months and years, the European Parliament and the Council must finalise their work on the proposed Regulation. Only then can the ECB issue the digital euro.

3.2 The Ecological Impact of Various Means of Payment

Payment solutions and infrastructures are vital for the functioning of financial systems and the society at large. However, they may not always be ecologically friendly, can give rise to high energy costs and may have low energy efficiency levels. Predicting and quantifying the environmental impact of a potential future digital euro is challenging as it has not been introduced yet and, as indicated above, the final decision on its functionalities, the infrastructure(s) to be used and, ultimately, its technical design is still pending.

Nonetheless, in this section, we want to show that the digital euro , if properly designed, could contribute to a European payments landscape more closely in line with European and global sustainability goals. In this regard, we first want to take a closer look at existing payment solutions and their environmental impact, before drawing lessons for a potential future digital euro design.

3.2.1 Banknotes and Coins ("Cash")

Banknotes and coins ("cash") are still the most popular means of payment among Europeans when making purchases at the point of sale (POS).[92] Like any other payment solution, cash has a negative environmental footprint, attributable to its production, distribution and disposal. Furthermore, the powering of automated teller machines (ATMs), transportation and the authentication of banknotes

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[87] Burkhard Balz from the German central banks believes that the digital euro will not be issued before 2028 [„Der digitale Euro bietet große Chancen – auch für Banken", Interview with Börsen-Zeitung online, 7 May 2024]. Joachim Nagel from the German central bank even stated that "if we decide [to issue a digital euro], I would expect it to take four to five years' time until we have introduced a digital euro" [Joachim Nagel: Digital euro - vision, advances and challenges, Introductory remarks by Dr Joachim Nagel, President of the Deutsche Bundesbank, at the fireside chat with Massachusetts Institute of Technology students, Cambridge, Massachusetts, 16 April 2024].

[88] Proposal COM(2023) 369 of 28 June 2023 for a Regulation on the establishment of the digital euro, see cep**PolicyBrief**.

[89] COM(2023) 369, p. 2.

[90] COM(2023) 369, Recital 8.

[91] COM(2023) 369, Recital 8.

[92] ECB (2022), Study on the payment attitudes of consumers in the euro area (SPACE), Frankfurt am Main.

at the POS have an impact. However, several studies have shown that the environmental impact of cash payments is relatively modest.

In 2018, for instance, De Nederlandsche Bank (DNB) published a study on the ecological impact of the Dutch cash payment system using a life cycle assessment (LCA). It concluded that the impact of an average cash transaction was only 5.1 g CO2e, with the potential for further reductions, e.g. by investing in renewable energy sources for ATMs or less polluting vehicles to transport banknotes and coins. The study attributed the largest environmental impact to the operation (64%) and coin production phase (31%).[93]

In 2020, Ripple released a paper on the environmental impact of cryptocurrencies, which also included an estimate of the electricity consumption of a cash transaction (0,044 KWh in 2018). The estimate, however, only focused on the printing of banknotes and their circulation via ATMs, while not including the wider impacts of, e.g., paper money transportation.[94,95]

Tab. 2: Environmental Footprints of Euro Banknotes v. Other Common Products

	Value in micropoints (µPt).	Car journey equivalent
Average annual value of cash payments per EAC in 2019	101	8
Annual environmental impact of an EU citizen in 2019	1003686	79575
71 bottles of water per year	3429	272
Production and washing of a cotton t-shirt	697	55

Source: ECB (2023), Product Environmental Footprint study of euro banknotes as a payment instrument, December 2023.

Last year, the ECB released a paper on the environmental footprint of euro banknotes as a payment instrument. It showed that, in 2019, the environmental impact of euro banknote transactions by an average euro area citizen (EAC) constituted only a very small proportion of those citizens' total impact (0.01%). The overall score for the average annual value of cash payments per EAC was at a level of 101 micropoints (µPt).[96] This corresponded to a level of only one-seventh of that of the production and weekly washing of a t-shirt over a year or an average EAC driving a standard car for 8 kilometres (see Table 2).

Looking at the sources for the environmental footprint, the ECB attributed 37% to the powering of ATMs, 35% to transportation and 10% to processing activities in the distribution stage (10%). Paper manufacturing and banknotes authentication at the POS each only have a minor effect of 9% and 5% respectively. Focusing on the climate-change related impact of euro banknotes, this impact accounted for roughly 40% of the total environmental impact.[97]

3.2.2 Credit Card Payments

While the environmental impact of cash payments is rather low, it has been shown that the footprint of credit card payments is even lower. Those payments which represent most digital payment transactions in a global context need even less electricity than paper money. It has been estimated that each transaction with credit cards consumes only 0,0008 (Visa) or 0,0006 (MasterCard) kWh of

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[93] Hanegraaf, R. et al. (2018), Life cycle assessment of cash payments.

[94] Ripple (2020), Measuring the Environmental Impact of Cryptocurrency.

[95] Lee, S., & Park, J. (2022), Environmental implications of a central bank digital currency (CBDC).

[96] The ECB included 16 different environmental impact categories, including climate change. To quantify the overall environmental impact, those categories were converted into micropoints (µPt).

[97] ECB (2023), Product Environmental Footprint study of euro banknotes as a payment instrument, December 2023.

energy. Those amounts would be even lower if the card transactions relied on modern payment infrastructure instead of the less efficient legacy systems often in use.[98,99,100] In 2020, the combined electricity usage of credit cards transactions of Visa, MasterCard and American Express has been estimated at roughly 0.5 billion kWh.[101]

3.2.3 Cryptocurrencies

While cryptocurrencies do not play a major role in today's payments markets, the technologies they are based on are often referred to as potential building blocks for establishing CBDCs and, thus, also the digital euro.

However, many cryptocurrencies have not only been criticized for their high volatility in the past but also for their significant negative environmental impact. According to current estimates, the most popular private cryptocurrency worldwide – Bitcoin –, for instance, consumes as much as 139 terawatt hours (TWh) per year[102], which amounts to approximately 0,6% of total global electricity consumption[103] or the energy consumption levels of entire countries such as the Netherlands or Norway.[104] In 2020, electricity consumption per transaction of Bitcoin was estimated to be at 700 kWh[105] and, thus, outpaced that of cash and credit card payments significantly (see above). The fact that Bitcoin acts as a decentralized ledger, in which all transactions are visible to everyone, demands significant computing power. Furthermore, e-waste is often mentioned as a major issue with Bitcoin and Bitcoin-like cryptocurrencies because devices used for their production ("mining") need to be replaced regularly.[106]

Whether cryptocurrencies can be deemed ecologically sustainable or not, is, however, as matter of the technology that underpins them. The negative ecological footprint of the kind of cryptocurrencies mentioned above mainly stems from their decentralized consensus and validation mechanisms ("proof-of-work. POW") and the reference to permissionless distributed ledger technologies (DLTs). The problem of POW-permissionless DLTs is that much electricity is needed for the validation of transactions because, in complex mining processes, miners compete to be the first to solve complex mathematical problems.

However, other validation technologies and consensus mechanisms exist, such as proof-of-stake (POS) or directed acyclic graph protocols, that have gained momentum recently, also due to the criticism of the unsustainability of POW concepts. Ethereum, for example, changed to a POS consensus mechanism and decreased its energy consumption by roughly 99.9%. Also, other cryptocurrencies such as Solana and Cosmos use POS instead of POW. POS is deemed more eco-friendly as it does not require the same resource intensive computations as POW. Furthermore, switching from permissionless DLTs, which

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[98] Lee, S., & Park, J, (2022).

[99] Agur, M. I. et al. (2022), Digital currencies and energy consumption, International Monetary Fund.

[100] The energy consumption level would likely be even lower when using digital-only instead of physical credit cards.

[101] House, W. (2022), Climate and energy implications of crypto-assets in the united states. Accessed October, 21.

[102] See https://ccaf.io/cbnsi/cbeci (data retrieved on 3 July 2024).

[103] Agur, M. I. et al. (2022).

[104] Cristina Criddle, Bitcoin Consumes 'More Electricity than Argentina', BBC, (Feb. 10, 2021), https://www.bbc.com/news/technology-56012952.

[105] Rybski, R. (2024), Sustainability, Public Security, and Privacy Concerns Regarding Central Bank Digital Currency (CBDC). In Digital Transformation and the Economics of Banking. Taylor & Francis.

[106] Agur, M. I. et al. (2022).

allow anyone to validate transactions, to permissioned DLTs, which only have authorized and identified validators, provides further potential for energy savings.

As well as consuming less energy, studies also show that cryptocurrencies relying on permissioned DLTs profit from greater energy economies of scale than those relying on permissionless DLTs. Furthermore, it has been shown that the energy consumption per transaction of cryptocurrencies that use permissioned DLTs and non-POW consensus mechanisms may be even lower than for credit card transactions.[107,108,109]

As a result, cryptocurrencies are not ecologically unsustainable per se. In fact, their eco-friendliness differs widely and depends primarily on technological choices.

3.2.4 Comparison Between the Various Existing Means of Payment

In general, comparing the environmental impact of various existing means of payment is not an easy task and cannot usually be carried out in a straightforward and objective manner. There are many limitations that must be kept in mind.[110] Thus, the following estimates must be read with caution.

Ripple, for instance, tried to compare the electricity consumption of bitcoin, cash, Visa and Mastercard transactions, showing the highly negative impact of the former v. the latter (see Table 3).[111]

Tab. 3: Electricity Consumption per Transaction

	Electricity consumption per transaction	Year
Bitcoin	700	2020
Cash	0,044	2018
Visa	0,0008	2018
Mastercard	0,0006	2018

Source: Source: Ripple (2020) Measuring the Environmental Impact of Cryptocurrency.

And although Visa, Mastercard and American Express processed roughly 310 billion payment transactions together in 2020 compared to only 460 million for Bitcoin and Ethereum, the former consumed less than 1% of the electricity of the latter.[112]

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[107] Ibid.

[108] Lee, S., & Park, J. (2022).

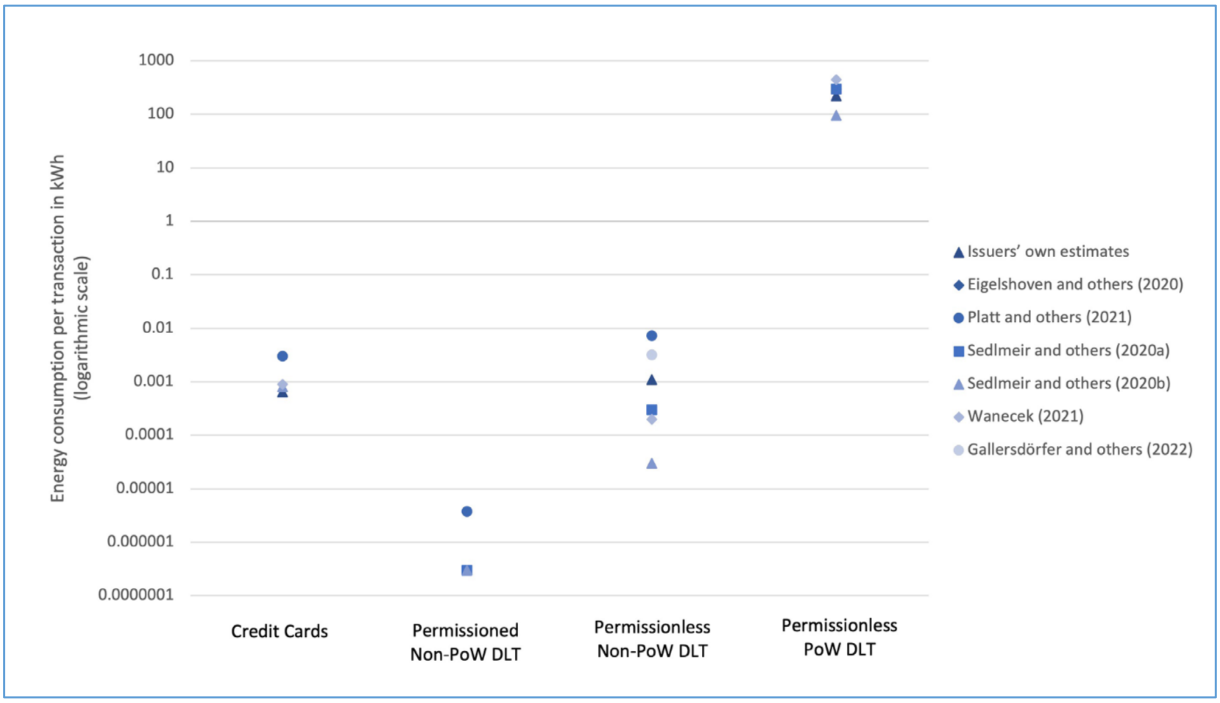
[109] Mary Pan (2024), Environmental Impact of Digital Currencies: A Closer Look at CBDCs, 24 January 2024.

[110] For example, a sound comparison between cash or credit card transactions with cryptocurrency transactions would necessitate similar amounts of transactions being made. However, there are much less transactions with cryptocurrencies. Also, calculation of the footprint of cards payments highly depends on the amount and types of actors, e.g. merchants' banks, involved and their (legacy) systems and infrastructures used. What is more, DLT systems offer the possibility to atch multiple payments in one transaction. [House, W. (2022); Agur, M. I. et al. (2022)].

[111] Ripple (2020), Measuring the Environmental Impact of Cryptocurrency.

[112] House, W. (2022).

Fig. 8: Energy Use (in kWh) per Transaction for the Core Processing of Some Payment Systems



Source: Agur, M. I. et al. (2022).

Another paper compared the per-transaction energy consumption levels of different DLT-based payments with credit card payment systems. It clearly shows the higher energy efficiency of the latter vis-a-vis permissionless POW-based cryptocurrencies. However, when compared to permissioned non-POW-based cryptocurrencies, credit card systems lose out (see Figure 8).[113]

3.3 Is Sustainability a Factor for the ECB/EU/G7 when Creating the Digital Euro?

3.3.1 The Intentions of the ECB

As stated above, in October 2020, the ECB released a report on a digital euro.[114] This laid down several core principles – e.g. convertibility at par, market neutrality –, scenario specific requirements – e.g. digital efficiency, cash-like features, competitive features –, and general requirements – e.g. regulatory compliance, easy accessibility – for a digital euro.[115] Those requirements and principles focus on ensuring ”the accessibility, robustness, safety, efficiency and privacy” of a digital euro.[116]

While sustainability considerations are certainly not the ECB's main priority when it comes to designing a digital euro, the ecological footprint is not completely under its radar. In the aforementioned report, the ECB states that a digital euro “could represent an option for reducing the overall costs and ecological footprint of the monetary and payment systems”[117] and that it wants to “proactively support improvements”[118] in this regard. The ECB claims that it not only wants to design the digital euro in a way that achieves cost reductions for the current payment ecosystem (Requirement 7a) but also to

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[113] Agur, M. I. et al. (2022).
[114] ECB (2020), Report on a digital euro, October 2020.
[115] Ibid, Annex 1.
[116] Lee, S., & Park, J. (2022).
[117] Ibid, p. 3.
[118] Ibid, p. 15.

base the retail CBDC on technological solutions that minimise its ecological footprint (Requirement 7b). Furthermore, if established, the ECB wants to focus on the "cost and energy efficiency of the digital euro as compared to existing means of payment", hinting that it wants to outdo the latter in this regard.[119,120]

What is more, at the end of January 2024, the ECB published a "Climate and nature plan" in which it postulates expanding its work on climate change in 2024 and 2025. This work will also include measures to achieve carbon reduction targets relating to the ECB's own operations. One element of the said climate and nature plan is also to "incorporate environmental footprint considerations" into the design of the digital euro. This will take place in the "preparation phase" that is currently underway.[121,122] Only recently, the ECB stated that, as part of this phase, it is considering several measures to minimize the environmental impact. It wants to optimize the entire digital euro value chain and advocates whenever possible for "avoiding energy-consuming protocols and re-using components". Furthermore, the ECB wants to adhere to "best practices in environmental performance and transparency".[123]

However, the technical configuration of a potential digital euro, which is crucial for determining whether or not the CBDC will be ecologically sustainable , currently remains open. The ECB has been testing a centralised solution based on the TARGET Instant Payment Settlement platform (TIPS)[124], as well as solutions based on decentralized ledger technology (DLT). In addition, a combination of both approaches has also been tested.[125] Basically, the ECB has not yet decided on the technology to be used for the issuance of a digital euro.[126]

3.3.2 The Intentions of the EU Commission

In June 2023, the EU Commission presented a proposal for a Regulation on the establishment of the digital euro. Beyond the proposal to establish it as a new retail CBDC for the euro area, the Regulation lays down rules concerning, in particular, its legal tender status, distribution, use, as well as its essential technical features.[127] While the ECB reserves the right to authorize the issuance of the digital euro[128], the proposed Regulation establishes the necessary regulatory framework on which such issuance is built. It "should ensure the effective use of the digital euro as a single currency throughout the euro area, meeting users' needs in the digital age and fostering competition, efficiency, innovation and

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[119] Ibid, S. 15.

[120] Rybski, R. (2024) concludes that the sustainability related requirements postulated by the ECB are "a clear declaration" that the ECB "intends to compete with private payment providers on the front of ecological footprint (including its energy efficiency)".

[121] ECB (2024a), ECB steps up climate work with focus on green transition, climate and nature-related risks, Press Release, 30 January 2024.

[122] ECB (2024b), Climate and nature plan 2024-2025, 30 January 2024.

[123] ECB (2024c), Progress on the preparation phase of a digital euro, First progress report, 24 June 2024.

[124] TIPS serves as the pan-European platform dedicated to settling instant payments in central bank currency. These instant payments refer to electronic retail transactions requiring settlement within seconds, aligning with the SEPA Instant Credit Transfer (SCT Inst) scheme.

[125] Martin Arnold, Interview with Fabio Panetta, Member of the Executive Board of the ECB, Financial Times, June 20, 2021, available here: https://www.ecb.europa.eu/press/inter/date/2021/html/ecb.in210620~c8acf4bc2b.en.html.

[126] Mooij, A. A. (2022), The Digital Euro and Energy Considerations: Can the ECB Introduce the Digital Euro Considering the Potential Energy Requirements?. German Law Journal, 23(9), pp. 1246-1265.

[127] EU Commission (2023), Proposal for a Regulation of the European Parliament and the Council on the establishment of the digital euro, COM(2023) 369, Art. 1.

[128] Ibid, Art. 4 (1).

resilience in the EU's digitalizing economy"[129]. While many of the functionalities and requirements, that the Commission wants the digital euro to fulfil, may have (considerable) ecological implications – e.g. the desire for both an offline and an online payment functionality –, the proposal does not stipulate any specific requirements on "greenness" to be fulfilled by the digital euro when it is implemented. Consequently, it is principally up to the ECB to incorporate such considerations in its reflections on the design of the digital euro.

Nevertheless, the Commission discusses the sustainability-related consequences of adopting a digital euro and, while concluding that – due to the absence of a concrete design for the digital euro – its environmental impact is currently difficult to estimate, it also believes it to be comparable to existing means of payment. The Commission reached this judgement because a digital euro is likely to be based on similar or identical payment infrastructure, at least in relation to its "online version".[130] In this regard, the Commission mainly has systems used for credit card payments in mind and believes that if such infrastructure is used, the digital euro will ultimately be more environmentally friendly than cash, i.e. banknotes and coins, and that, since the digital euro may to some extent replace cash, such a substitution effect may improve the sustainability of the current European payment ecosystem.[131]

Interestingly, while the Commission leaves the final decision on the technical design of the digital euro to the ECB, it seems to oppose the technological solutions used by several crypto currencies that are built upon energy-intensive consensus and mining procedures. It argues that those "unsustainable" procedures are not necessary for a digital euro, which is backed by the ECB's legitimacy.[132]

3.3.3 The Intentions of the G7

On 5 June 2021, the finance ministers and central bank governors of the Group of Seven (G7) released a communique in which they called for any future potential CBDC to support inter alia innovation, competition and inclusion. Furthermore, CBDCs should be both "resilient and energy-efficient".[133] Four months later, in October 2021, those calls were set out in greater detail when the G7 released a total of 13 public policy principles for retail CBDCs. These principles were issued in the spirit of ensuring international cooperation and coordination and with the ulterior motive of ensuring that any release of a CBDC in one jurisdiction, that has public policy implications for other jurisdictions, should be considered by central banks when deciding upon issuing a CBDC.[134]

While the established principles deal with several decisive questions related to CBDC issuance, like monetary and financial stability, data privacy, competition or cybersecurity-related considerations, the ministers and governors also presented some reflections related to energy and environment-related aspects of CBDC.[135] Ultimately, they call for "the energy usage of any CBDC infrastructure" [...] to "be as efficient as possible to support the international community's shared commitments to transition to

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[129] Ibid, p. 2.

[130] Ibid, p. 11.

[131] EU Commission (2023), Commission staff working document, impact assessment report, Proposal for a Regulation of the European Parliament and of the Council on the establishment of the digital euro and Proposal for a Regulation of the European Parliament and of the Council on the provision of digital euro services by payment services providers incorporated in Member States whose currency is not the euro and amending Regulation (EU) 2021/1230 of the European Parliament and the Council and Proposal for a Regulation of the European Parliament and of the Council on the legal tender of euro banknotes and coins, SWD(2023) 233 final, 28.6.2023, p. 86.

[132] Ibid, p. 86.

[133] G7 (2021), Finance Ministers and Central Bank Governors Communiqué, 5 June 2021.

[134] Sunak, R., & Bailey, A. (2021), Public Policy Principles for Retail Central Bank Digital Currencies (CBDCs). G7 UK.

[135] Ibid, p. 5.

a 'net zero' economy". In addition to factoring in the energy usage of CBDC, when designing and implementing them, they further recommend central banks to disclose, within their climate-related reporting, the environmental impact of CBDC operations (Principle 8).[136]

Clearly, those principles agreed upon by the G7 ministers and governors are non-binding and thus central banks are not required to incorporate them into their decisions regarding the issuance of CBDC. However, as "they reflect shared values", committing to them shows a willingness to think about the wider environmental implications of introducing CBDC.

3.4 Factors Influencing the Ecological Footprint of the Digital Euro

3.4.1 Technical Configuration

Clearly, the decision on which technical configuration will be used for the digital euro – decentralised, centralised or a combination of both / DLT based or not – will impact its ecological footprint.

Using a decentralised POW-solution would inevitably be the least attractive way from an energy consumption perspective. Implementing decentralized ecosystems with energy consumption levels similar to those of existing money or means of payment appears to be almost impossible.[137] Estimates have shown that implementing such a solution may require more energy than Hungary in the medium term as millions of digital euro transactions from millions of European citizens and companies would need to be processed each day.[138]

On the other hand, a centralized solution would allow for far simpler consensus algorithms to verify transactions. Validators could be selected and there would be no dependency on a large number of miners and the accompanying necessity for many computations to find consensus.[139] The Eurosystem would be able to choose (and adjust) which actors – e.g. the ECB, banks, other payment service providers – are allowed to verify digital euro transactions.[140] In this case, mining would remain unnecessary. Trust in the new digital currency would evolve from it being issued and supported by the ECB instead of referring to an anonymous crowd of miners.[141] Ultimately, a centralized option would, according to a study from 2020, mean approximately eight times less energy consumption than a decentralized one.[142]

When asking whether to opt for a DLT or non-DLT based[143] digital euro (not relying on POW), estimates show that, in principle, both variants can be as energy efficient or even more efficient than the current most efficient means of payment, i.e. credit cards. However, whether this is the case, and which of the two options would be preferable for a digital euro depends largely on the use of novel v. legacy systems and the choice of components (e.g. the hardware) required for them to function.[144,145]

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[136] Ibid, p. 11 and 12.

[137] Lee, S., & Park, J. (2022).

[138] Mooij, A. A. (2022).

[139] Lee, S., & Park, J. (2022).

[140] Giaglis, G. et al. (2021), Central Bank Digital Currencies and a Euro for the Future.

[141] Lee, S., & Park, J. (2022).

[142] Sedlmeir, J. et al. (2020), The energy consumption of blockchain technology: Beyond myth. Business & Information Systems Engineering, 62(6), pp. 599-608.

[143] One example of such a system is the TARGET Instant Payment Settlement (TIPS). More on it see below.

[144] Lee, S., & Park, J. (2022).

[145] Wang, H. (2023), Addressing Governance Challenges of Digitalisation and Sustainability: A Perspective of Central Bank Digital Currency.

While the technical design of the digital euro is certainly among the most decisive factors for the digital currency's ecological footprint, there are several other factors that will have an influence on its sustainability. We will now go on to present some of those factors (in a non-exhaustive manner):

3.4.2 Energy Source

One of the most important issues concerns the energy source on which the digital euro will be based. As Rybski (2024) points out, the ecological footprint is highly dependent on whether or not the source is carbon-neutral/renewable. This includes using solar or wind power to supply the data centres that process digital euro transactions. In contrast to a decentralized setting for the digital euro, in a centralized setting the ECB would be in a position to decide upon the energy mix and could, in principle, opt for a more ecologically sound one (if sufficiently available).[146]

3.4.3 The Digital Euro as an Additional Means of Payment and Substitution Effects

The ECB will probably issue the digital euro as a new means of payment, which will be added to a plethora of existing payment methods and which is not primarily intended to replace existing ones (at least not in their entirety). For instance, it is in the express interest of the Commission and the ECB that banknotes and coins can still be used in the future. Furthermore, it has been stated that a digital euro "should not lead to the crowding out of digital payment services in the private sector" and would merely be another payment option.[147] Nevertheless, the digital euro may become a competing means of payment both vis-a-vis cash and vis-a-vis the many private digital and non-digital payment solutions. The environmental impact of the digital euro is thus also dependent on whether there will be a substitution away from those other means of payment and their respective ecological footprints. If the digital euro is designed in a more sustainable manner than e.g. cash, credit card or mobile payments, a shift away from the latter payment methods may be a positive development from an ecological perspective.[148] However, the simple fact is that a new payment solution on the market, requiring a variety of new infrastructure, software and hardware elements, devices, cards and front-end interfaces, will inevitably have repercussions for the environment.

3.4.4 Two Tier v. One Tier Structure

Both the ECB and the Commission want payment service providers (PSPs) and especially banks to provide the digital euro by offering payment accounts for the digital euro as well as the corresponding payment services.[149] The digital euro will not be provided by the ECB itself but is to be made available via supervised intermediaries. Thus, both institutions want to keep a two-tier structure for the distribution of the digital euro, similar to the structure for the dissemination of cash. This is mainly to uphold innovation and competition in the payments markets and to avoid overburdening the ECB with tasks for which it has neither the capacity nor the experience. Nonetheless, opting for a two-tier rather than a one-tier system (where the ECB and/or national central banks would distribute the digital euro and offer payment services) has consequences from an ecological point of view. The main reason is

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[146] Rybski, R. (2024).

[147] https://www.bundesbank.de/de/aufgaben/unbarer-zahlungsverkehr/digitaler-euro/faq-digitaler-euro.

[148] When, for instance, the digital euro shows up as a substitute for cash, reducing the latter's usage, this may, on the hand, improve sustainability as less banknotes and coins must be printed and transported. On the other hand, even with less cash usage, the facilities to distribute banknotes and coins must be kept intact, e.g. ATMs still must be active, even when there are less withdrawals.

[149] COM(2023) 369, Recital 26.

that a one-tier system would involve fewer actors, whereas a two-tier system requires more computing capacity, duplicate infrastructure and processes. Thus, while there are good arguments for including authorized intermediaries in making the digital euro available, such a choice is likely to result in increased energy consumption.[150,151]

3.4.5 Universal v. Restricted Access

The ECB and the EU Commission want to grant the digital euro legal tender status. This means that, as in the case of the euro in physical form (banknotes and coins), it cannot be refused by a payee in settlement of a debt denominated in the same currency, it must be accepted at full face value and its use to make any payment discharges the payer from the payment obligation.[152] There are only minor derogations envisaged from this general rule.[153] Thus, it will be widely accessible, in contrast to private means of payment which are usually restricted to the customer base of their providers. This peculiarity of the digital euro may come with environmental costs as it potentially requires the provision of multiple “access solutions” to satisfy the particular needs of different customers (e.g., to allow for full financial inclusion).[154] In contrast, providers of private solutions are often able to opt for more specific approaches to address the needs of (potential) customers (e.g. one specific device, one specific wallet, one specific physical card etc.).

3.4.6 Online v. Offline Digital Euro

As envisaged by the ECB as well as the EU Commission, there will most likely be two variants of the digital euro, an online and an offline version.[155] Such a choice has environmental repercussions as well. While there are several non-sustainability related reasons for adopting both solutions – e.g. financial inclusion and privacy related considerations –, having them both not only adds complexity to the digital euro payments ecosystem, but also requires the running of two separate digital euro payment infrastructures and solutions in parallel, which, furthermore, must be synchronized with each other in a specific manner. Furthermore, it seems likely that many digital euro users will not stick to only one of the two variants but make use of both the offline and the online version. The online variant of the digital euro will most likely be based on currently available digital (hard-and software) solutions – like smartphones, wearable devices, mobile payment apps, web-based services – or the equivalent. By operating on devices already possessed by users, a digital euro would not require any new technical solution but simply, e.g., the installation of a specific mobile application. Thus, it will likely have similar energy consumption implications to current payment solutions.[156] Keeping the environmental footprint at a low level in this respect thus very much depends on whether it will be possible to use the existing and currently widely-used physical resources (“no new mobile phone”) and on whether the hardware and software deployed by users of the digital euro has been built with ecological considerations in mind. On the other hand, if new devices or additional front-end interfaces are necessary, this may increase the “brownness” of the digital euro in its online version.[157] Furthermore,

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[150] Mooij, A. A. (2022).

[151] Agur, M. I. et al. (2022).

[152] COM(2023) 369, Recital 14 and Art. 7 (2–5).

[153] COM(2023) 369, Art. 9 and 10.

[154] As an example, the Commission proposes that the digital euro must be accessible through a wide range of hardware devices [COM(2023) 369, Recital 54 and Art. 22 (1)].

[155] The Commission wants the users of the digital euro to be able to use it for offline as well as online payments (COM(2023) 369, Recital 34, Art. 23).

[156] Lee, S., & Park, J. (2022).

[157] Agur, M. I. et al. (2022).

an online version of the digital euro will probably require continuous connectivity to servers and the internet and depend on the availability of large data centres. Both factors might add up to a less favourable environmental footprint. The offline version of the digital euro could, instead of making use of web-based services and devices such as computers or smartphones, be based on interoperable and compatible physical cards, comparable to credit cards. If such cards are used, unlike the online version, they may not require constant connectivity to the internet or the intense usage of data centre storage facilities, thereby lowering their ecological impact. And even when specific devices are used for offline digital euro payments, transactions could be stored temporarily on the devices and synchronized later (when an internet connection becomes available). On the other hand, the production and distribution of such new physical cards could consume additional resources.

Both for the offline and the online digital euro, a decisive factor will also be whether existing infrastructure can be used by traders with respect to their point of sale (POS) facilities and by banks with respect to their ATMs. If those can be upgraded easily, no new infrastructure or hardware solutions will need to be implemented allowing for payments or withdrawals to be made based on common and interoperable standards, which may dampen any potential negative ecological impact.

3.4.7 Front-end Services for a Digital Euro

End users of the digital euro are supposed to be able to access and use it via front-end services. The Commission wants to oblige payment service providers (PSPs) to provide their customers with such a service. Any PSP will be able to decide whether to offer a front-end service which they develop themselves or to use a service developed by the ECB.[158] Consequently, it is very likely that there will be several different front-end services available which must be able to interact with each other. While referring to only one specific front-end interface might be problematic from a competition and innovation perspective, having several of them could add complexity to the digital euro payments ecosystem and, without proper safeguards, reduce the ability to keep it on a sustainable track.

3.4.8 Holding Limit and (Reverse) Waterfall Functionality

Another parameter that will influence the environmental impact of the digital euro will be the envisaged “instruments” to limit the use of the digital euro as a store of value. Both the Commission[159] and the ECB[160] want such instruments to be implemented for monetary policy and financial stability reasons. The most probable instrument would be that of (a) holding limit(s). If implemented, a digital euro user would only be allowed to hold digital euro up to a certain fixed amount, e.g. € 3,000 Euro.[161] If digital euro users receive online digital euro payments in excess of such (a) limit(s), they will be able to transfer the excess funds automatically to a non-digital euro payment account (“waterfall functionality”) and if their digital euro holdings are less than the amount of a payment, they can mobilize the missing funds from a non-digital euro payment account (“reverse waterfall functionality”).

Considering the two characteristics of a potential digital euro, clearly, the establishment of (a) holding limit(s) could, in practice, dampen its usability, lower the probability for significant substitution effects, and, ultimately, lower the volume of transactions made with the digital euro, compared to a situation without such limit(s). However, the ECB believes that there will still be hundreds of millions of

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[158] COM(2023) 369, Art. 28,.

[159] COM(2023) 369, Art. 15 und 16.

[160] ECB (2020), Report on a digital euro, October 2020.

[161] There are also discussions on having different such limits for the online and the offline digital euro.

transactions per day carried out by an estimated 400 million digital euro users.[162] Such volume will also have an impact on the digital euro's environmental footprint. Higher transaction volumes require more resource intensive processes to be conducted and, consequently, more energy consumption. Thus, the level of such (a) holding limit(s) will play an important role for the digital euro's ecological footprint.

The (reverse) waterfall functionality, which is to be established to allow for a smooth and uninterrupted payment experience for digital euro users, will inevitably increase the total number of transactions to be executed. This is because the function will trigger numerous additional transactions from digital euro to non-digital euro accounts and vice versa – on top of the initiated simple payment transaction – and, thus, will likely increase the energy consumption levels even further. In addition, the feature makes it necessary for a digital euro user to have at least one non-digital euro account. Thus, digital euro users would not normally be able to use only digital euro accounts and avoid using non-digital euro accounts completely. Thus, they would frequently be unable to substitute the latter with the former (even if they would prefer it), which is a more sustainable solution than being bound to use both.

3.4.9 Security and Resilience Aspects

ECB and EU legislators are unlikely to issue (allow the issuance of) a digital euro and allow for its dissemination by PSPs if the infrastructure, systems and technologies used by the ECB, national central banks and the PSPs are not reliable, failure-proof, (cyber-) secure and resilient. In order not to undermine trust in the new digital currency, they certainly will be eager to ensure the permanent and uninterrupted usability and functionality of the digital euro. This necessity will require recourse to highly sophisticated solutions to safeguard the stability of the digital euro ecosystem. Consequently, this imperative could lead to extra energy expenses, e.g. because there would be a need to maintain server backups, reserve extra hardware and software capacities, establish multiple data centres, guarantee the physical security of infrastructures and other means to ensure the digital euro's full integrity.[163,164] In this regard, the envisaged two-tier structure for the digital euro will also play a major role. As many actors will form part of the digital euro ecosystem, a lot of resource-intensive redundancy systems must be implemented to ensure the safety of the new means of payment. Limiting the number of ecosystem participants, while conflicting with other important objectives, may thus prove more sustainable.

3.4.10 Programmability of a Digital Euro

Both the ECB and the Commission envisage allowing for conditional payments ("programmability of payments") with the digital euro – i.e. transactions "automatically triggered by software on the basis of predetermined and agreed conditions"[165]. On the other hand, they are against having a "programmable" digital euro ("programme money") – i.e. allowing "units of digital euro" [...] "to be used for buying specific types of goods and/or services or only within a certain period/geography". The ECB and the Commission do not want the digital euro to be viewed as something like a voucher, limiting the full fungibility of each digital euro unit and restricting end users with respect to "where, when or with whom people and business could use it".[166,167] While the desire not to allow the programmability

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[162] https://www.ecb.europa.eu/press/inter/date/2021/html/ecb.in210620~c8acf4bc2b.en.html.
[163] Agur, M. I. et al. (2022).
[164] Wang, H. (2023).
[165] Conditional payments are interesting for e.g. recurring payments, such as paying gym fees every month.
[166] COM(2023) 369, Recital 55 and Art. 24.
[167] https://www.ecb.europa.eu/euro/digital_euro/how-it-works/html/index.en.html.

of the digital euro is understandable in many respects – i.e. because the functionality provides power to steer the spending behaviour of digital euro users, could tremendously limit their economic freedoms and undermine privacy – it may also restrict the digital euro's ability to support the transition to more sustainable European economies. As Ozili, P. K. (2022) pointed out, a CBDC and, thus, also the digital euro could be designed in such a way that it not only aims for goals like "payment efficiency, financial stability and financial inclusion", but could also support circular economy targets. If the digital euro were to allow for programmability features, it could be used as a (political) instrument to channel monies towards e.g. circular economic activities and away from brown linear economic activities.[168] As a result, although currently not envisaged either by the ECB or the Commission – and we strongly agree with this decision –, a digital euro that would incorporate programmability features could serve as a powerful tool for improving the transition towards an environmentally friendly continent.[169] Such a characteristic would also distinguish the digital euro from existing means of payment and could therefore make a difference.

3.4.11 Other Factors

In addition to all the issues and design choices mentioned above, there are many more aspects that could play a (minor) role with respect to ecological considerations. For instance, the ongoing development, research and testing phase is already leading to high energy consumption levels and costs, which means that, even before the first issuance of a digital euro, the preparation for it will leave a negative carbon footprint. Furthermore, decisions being taken concerning the level and strictness of financial inclusion measures, the degree of privacy and data protection to be conceded to digital euro users and the possibilities for non-euro-area citizens – both from third countries and from EU Member States not using the euro - to access and make use of the new means of payment, definitely need to be taken into account. Also, the question of how quickly digital euro transactions[170] should be settled is an important factor.

3.5 The Many Twin Transition Challenges and Trade-offs in Designing a Digital Euro

The Council strongly underlined the need to align the digital with the green transition and highlighted that the use of digital technologies can offer opportunities "to reduce the environmental footprint and to accelerate the green transition".[171] However, as shown above, mastering both the digital and the green transition with respect to the adoption and issuance of the digital euro is unlikely to be easy. There are multiple challenges ahead as well as trade-offs with other goals associated with the introduction of the digital euro that need to be properly addressed and managed. This is because the ECB and the Commission are also striving to achieve various other goals, including the desire [172]

- for widespread availability of the digital euro,
- to allow for competition among payment service providers in offering digital euro services,

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[168] Ozili, P. K. (2022), Circular economy and central bank digital currency. Circular Economy and Sustainability, 2(4), pp. 1501-1516.

[169] Clearly, such feature could not only be used to steer capital towards sustainable activities, but to the opposite as well. Thus, it would be a dangerous characteristic prone to be used for both laudable and doubtable political targets.

[170] Both the ECB and the Commission want digital euro payments to be settled instantaneously.

[171] EU Council (2024), The Future of EU Digital Policy, Council Conclusions, 21 May 2024.

[172] COM(2023) 369.

- to allow digital euro users to have multiple (online and offline) digital euro accounts, that, furthermore, can be linked with several non-digital euro accounts to allow for a seamless payments experience,
- to allow for multiple hardware and software as well as front-end solutions to access and use the digital euro in payments, which will enable competition and innovation in the digital euro payments market,
- to establish the digital euro as a complementary means of payment and not as a replacement for existing payment methods, be it cash or private solutions like credit cards,
- to ensure a high level of financial inclusion, allowing as many people as possible to make use of the digital euro, i.e., those with disabilities, functional limitations or the elderly,
- to establish two different digital euro versions for reasons related to privacy and financial inclusion, and
- to cope with the future payment needs of the wider economy, e.g. to allow for machine-to-machine payments in the context of Industry 4.0.

All of these “other goals” may, in some cases, conflict with the digital euro’s sustainability goals. Therefore, the ECB and the Commission should further reflect on whether all these other targets should be pursued fully or only partly, and how those aims can be achieved in a way not to undermine the EU’s ambitions to master the twin transition. In the following section, we will elaborate on how to manage this challenge in a proper manner.

4 Policy Recommendations

Based on our comparative analysis, we have come up with some more general policy recommendations for the new Commission, to ensure that the "twin transformation" is successful and not contradictory.

4.1 Horizontal Recommendations

4.1.1 Standards for Measuring Entire Life-cycle Carbon Emissions of AI and CBDCs

Develop common terminology, standards, and protocols for measuring carbon emissions in green-digital technologies over their entire life-cycle: Our analysis underscores the need for a comprehensive and standardized methodology to assess and compare the ecological impact of various digital solutions, specifically generative AI and different means of payment, including (prospectively) CBDCs, over their life-cycle.[173] For instance, one should not only report how much energy is spent on training an LLM but also estimate its later impact during inference/usage by modelling different usage scenarios. This approach would be akin to typical life cycle assessments of certain products, allowing for the evaluation of both the positive and negative effects of these technologies on sustainability, in line with the Commission's "Recommendation on the use of Environmental Footprint methods".[174] Such a form of **standardisation is ultimately also in the interest of the industry, as it will help to avoid duplication and excessive administrative burdens**, and should result in some form of international consensus on how to track the environmental impact of AI and payment methods, including CBDCs.[175] To improve consistency in methodology and data, it is also essential to develop common terminology[176] for key concepts such as "AI training" or "natural resources consumption" and to take stock of existing data gaps and methodological issues. This would probably necessitate developing better tools to assess the rebound effects of digitalisation and to identify measures to counteract undesirable effects. In this context, standards and protocols can greatly improve methodological consistency.[177] In particular, standards for AI-related data are needed to ensure quality and accessibility, and while recent EU regulations do not specifically require AI energy reporting, they could encourage the development of such standards through their focus on data centre transparency and efficiency.[178] In general, the EU Green Digital Coalition is already driving progress in measuring the environmental impact of digital technologies through the so-called "**Net Carbon Impact Assessment Methodology**",[179] whose deployment should be expanded and accelerated. Here, the net carbon

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[173] This is already being recognised in the US, where several Democratic Representatives recently introduced the "Artificial Intelligence Environmental Impacts Act of 2024", which calls for the Environmental Protection Authority to direct a study on the environmental impacts of AI across its lifecycle. Markey, Heinrich, Eshoo, Beyer Introduce Legislation to Investigate, Measure Environmental Impacts of Artificial Intelligence (senate.gov).

[174] Recommendation on the use of Environmental Footprint methods - European Commission (europa.eu).

[175] As the UN advisory body on AI has noted, "new global standards and indicators to measure and track the environmental impact of AI as well as its energy and natural resources consumption (i.e. electricity and water) could be defined to guide AI development and help achieve SDGs related to the protection of the environment". UN AI Advisory Body (2023), Governing AI for Humanity, interim_report.pdf (un.org), p. 19.

[176] Bremer et al. (2023), Assessing Energy and Climate Effects of Digitalization: Methodological Challenges and Key Recommendations (May 25, 2023), nDEE Framing Paper Series, Available at SSRN.

[177] Also argued by: Bremer et al. (2023), Assessing Energy and Climate Effects of Digitalization: Methodological Challenges and Key Recommendations (May 25, 2023), nDEE Framing Paper Series, Available at SSRN.

[178] Luers et al. (2024), Will AI accelerate or delay the race to net-zero emissions? (nature.com).

[179] The methodology can be downloaded here: EGDC - ICT Methodology (greendigitalcoalition.eu).

impact of a digital technology application is defined as “the comparison between the carbon impacts of a scenario with an ICT solution and a reference scenario without the ICT solution within the same boundary. The total positive and negative carbon impacts of each scenario are considered including all direct and indirect effects within the boundary of the assessment.” So far, the Coalition has conducted pilot projects related to six sectors, with the aim of developing methods to estimate the net environmental impact of real-life digital solutions.[180] These pilots covered energy/power, transport, construction/buildings, smart cities, manufacturing and agriculture, i.e. they did not cover generative AI or CBDC. Overall, the aim should be to cover these and other important areas through further case studies and sector-specific methodologies, in order to maximize their net positive impact (emission avoidance) while minimizing negative impacts (rebound effects).

4.1.2 Taxonomy-criteria for Sustainable Digital Infrastructure

In July 2020, the EU Taxonomy Regulation [Green Taxonomy, (EU) 2020/852, see cep**Adhoc**] came into force. The Regulation sets out binding criteria to be used in the future for determining whether an economic activity qualifies as “environmentally sustainable”. To qualify as environmentally sustainable, economic activities must contribute “significantly” to at least one of six environmental objectives and must not “substantially” harm any of these environmental objectives. While we are in general very critical of the Green Taxonomy, it is unlikely that the EU will abandon this central instrument for steering capital towards “sustainable” economic activities anytime soon. As the instrument is here to stay, the legislators may think of embedding the ICT sector in the green taxonomy, in a more stringent manner than currently.[181] The ICT sector could be a key enabler for sustainable transformation. In this regard, there is a need for closer examination of what kind of digital infrastructure, required for the operation of the digital euro ecosystem and AI solutions, should be included, as an enabling economic activity, in the climate taxonomy, and to what extent. Clearly, many types of digital infrastructure may not contribute directly to greenhouse gas reductions or lower energy consumption levels. However, if capital can be steered to the most efficient and most sustainable types, and based on robust and credible metrics, this may serve as a basis for the proliferation of more eco-friendly digital euro and AI end products and services.

4.1.3 Trust in the Power of Core EU Climate Policy Instruments

When trying to limit the ecological footprint of a future digital euro as well as that of AI solutions, the European policy makers should, furthermore, count on well-established climate policy instruments. The most suitable instrument to steer the European economies towards carbon neutrality is the European Emissions Trading System (EU ETS), which also includes emissions from the energy and heat generation industries. The EU ETS, as a market-based CO2-pricing instrument, contributes to a reduction in greenhouse gas emissions in an efficient, cost-minimizing and non-distorting manner. With its decreasing upper limit on CO2 emissions, it ensures a gradual reduction of said emissions, increases the costs for carbon-intensive activities relative to low-CO2 alternatives and, thus, fosters incentives for economic actors to opt for the latter. It does not require any additional political

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[180] See: Overview of EGDC methodologies - European Green Digital Coalition.

[181] Currently, the scope of the relevant delegated act on the climate taxonomy [Delegated Regulation (EU) 2021/2139] with regard to the ICT sector covers the economic activities (a) "data processing, hosting and related activities" as so-called transitional activities, and (b) "data-based solutions to reduce greenhouse gas emissions" - including the use of decentralised technologies (DLT), the Internet of Things (IoT), 5G and artificial intelligence - as so-called enabling activities.

intervention to achieve such a goal.[182] Thus, the EU ETS serves as a catalyst for all economic actors in a digital euro or AI ecosystem to choose energy efficient, carbon-friendly hardware / software solutions, digital infrastructures and data centres. In this regard, it will be more effective than other classic climate-related policy instruments like CO2 taxes, subsidies for climate-friendly solutions or strict bans on dirty economic activities, which are either less efficient at internalizing the negative environmental externalities or prove too-intrusive or disproportionate.[183]

4.2 Artificial Intelligence related Recommendations

4.2.1 Increased Transparency through Red-teaming, Disclosure Rules and Competition

Increase transparency through external "sustainability red-teaming", climate disclosure rules, and consumer-driven competition: As energy consumption is currently often untracked or data is kept private by major IT companies like Google, Facebook, and Amazon, one might also suggest implementing legal requirements for these companies to measure and disclose their energy and resource consumption data.[184] Companies involved in digital technologies as discussed in this paper should focus on improving the systematic collection and public reporting of current and high-quality data. Providing external researchers with access to data and using sustainability "red-teaming" of models is essential to validate the "green side" of new genAI models. This red-teaming could be done by experts from the climate community, such as the Energy Modeling Forum and the Integrated Assessment Modeling Consortium. Like the two recent climate disclosure laws signed by California Gov. Gavin Newsom,[185] the EU could consider ordering technology companies to become more transparent about their climate risks and impacts. A good example is the final draft of the EU AI Act, which includes such a provision for high-risk LLMs. However, we argue that these or similar requirements should not be too strict, as current methodological knowledge for reporting certain layers of digital sustainability is underdeveloped. Moreover, an overly strict approach would simply incentivise these firms to re-locate to other jurisdictions for AI training/interference, with no net benefits for the climate. Instead, the key will be to set a standard that is attractive for companies to fulfil (as a form of positive signalling) and may thus gain influence through conscious consumption decisions by consumers, who introduce sustainability as an additional competition feature into the market.

4.2.2 Analysing Interaction Data

Any transparency measures should include interaction data, i.e. information on user behaviour by developers of generative AI models: A better understanding of user behaviour by model developers can significantly improve the estimation of energy consumption during AI inference and throughout the lifecycle of AI systems. As discussed above, recent studies suggest that the energy costs associated with AI applications can quickly exceed the initial energy investment required for training, sometimes within weeks or months of widespread deployment. Better insights into how users interact with AI

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[182] More on the advantages of ETSs, see cep**Input Special** on Future EU Climate Policy: Challenges and Chances.

[183] Menner, Voßwinkel and Reichert (2023), Das Klimageld als Chance für einen klimapolitischen Neuanfang, Optionen für eine wirksame Ausgestaltung und EU-konforme Finanzierung, 28.11.2023.

[184] See the case study on AI-driven personalized online advertising: Marken et al. (2024), The (Un-)Sustainability of Artificial Intelligence in Online Marketing (ioew.de).

[185] Austin (2023), California Gov. Gavin Newsom signs law requiring big businesses to disclose emissions | AP News.

systems could not only optimise energy use, but also address security concerns and other critical issues associated with generative AI technologies, as discussed by academics such as Arvind Narayanan and Sayash Kapoor. They have argued that transparency reports on interaction data written by generative AI deployers are technically feasible and can be largely automated.[186] Integrating user behaviour analysis into the deployment of AI systems will help to create more energy-efficient and secure AI solutions, ultimately contributing to the broader goal of sustainability in the digital age.

4.2.3 Digital Interface for Consumer Comparisons

Create an easy-to-use web/app interface to allow for transparent comparisons by end-users: Once a common methodology and transparency about key data are established, the Commission could take inspiration from its recent procurement, through a competitive tender, of a calculator to assess the carbon footprint of audio-visual works.[187] Based on a common calculation methodology (see point 1 above) and similar to the EU's audio-visual works project, a user-friendly web application would allow all producers and consumers across the EU to easily calculate the carbon footprint arising from the use of specific large language models (for private reasons or as part of commercial products or services), this would facilitate comparability across Member States and allow Europeans to calculate, monitor, and reduce the carbon footprint of digital-green technologies.

In the future, this transparency mechanism could be further enhanced by or connected to the recently updated EU ecodesign approach in Regulation (EU) 2024/1781 of 13 June 2024.[188] This Regulation extends the ecodesign approach originally set out in Directive 2009/125/EC by making it applicable to the widest possible range of products. Its framework for setting ecodesign requirements for sustainable products includes the possibility of a digital product passport. This could be particularly relevant as generative AI is increasingly embedded into physical products from the outset, as anticipated by Microsoft's recent addition of a dedicated AI button to its Windows keyboards and Apple's planned integration of several generative AI models into iPhones. The new Ecodesign Regulation aims to cover the entire lifecycle of products, while also requiring transparency on carbon footprints. The introduction of digital product passports tailored to genAI-based products could make it easier for consumers, industry and authorities to access and understand the environmental impact of these products, in line with our suggestions above and the goals of the twin transition.

4.2.4 Shift to "Green Coding" Practices

Publicly encouraging and financially incentivizing a shift towards leaner "green coding" practices: Focusing on the physical aspects of digital technology's environmental impact, such as hardware and data centres, is both intuitive and visible, making it a primary focus of current environmental sustainability efforts. However, an area ripe for significant gains with potentially less effort is the realm of software optimisation, specifically through so-called "green coding". This approach advocates streamlining code bases, eliminating unnecessary lines of code, and avoiding the indiscriminate use of open-source packages when simpler, more efficient alternatives would suffice. Such strategies represent low-hanging fruit for reducing the carbon footprint of the digital sector, yet they receive

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[186] Narayanan and Kapoor (2023), Generative AI companies must publish transparency reports (aisnakeoil.com).

[187] See: Commission News (2024), A common carbon emissions calculator for the European audiovisual sector.

[188] European Parliament and of the Council (2024), Regulation (EU) 2024/1781 of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/ECText with EEA relevance, PE/106/2023/REV/1, OJ L, 2024/1781.

comparatively little attention from policymakers and the public. This oversight may be due to a general lack of programming expertise among policy observers and officials, leading to an underestimation of the impact that software optimisation can have on sustainability. Publicly encouraging and financially incentivizing a shift in focus towards more efficient and green coding practices (e.g. through changes to procurement rules) could thus unlock significant environmental benefits, highlight the need for broader educational efforts to demystify this potential and promote more sustainable software development practices. A great side effect of this shift towards lean, green coding would be to reduce the risk of cybersecurity incidents, as recent research and incidents show that the rise of low-quality, LLM-generated code has increased the potential for cyberattacks, e.g. through hallucinated libraries that are automatically downloaded.[189]

4.2.5 Research on Efficient Chips, Small Language Models, and Emissions Scenarios

Support for research on more energy-efficient AI hardware, "small language models", and AI-driven emissions scenarios: As the current rate of AI and cryptocurrency consumption may heavily burden the European energy grid, the EU should fund research and start-ups that promise to create more energy-efficient AI technologies and to adopt usage practices that reduce energy consumption. In this respect, promising areas, in terms of hardware that should be supported and whose progress should be closely tracked, are stochastic processing units (SPUs), quantum computing, and reversible computing chips. Similarly, research into AI architecture for language models is currently making significant strides towards developing models that are not only powerful, but also more energy efficient and suitable for a wider range of devices, including smartphones. This transition is evident in recent advances such as Microsoft's 1-bit LLMs and its new compact model, Phi-3, and Apple's OpenELM, which signal a shift towards greener, more accessible AI technologies. Finally, financial support should extend to research, both by academics and by companies active in this sector, on designing scenarios that assess the potential impact of AI expansion on the climate,[190] using quantitative modelling and expert consultation to explore different possible futures – a method commonly used by financial institutions to assess risk and to plan investments.

4.2.6 Using AI to Optimize EU Internal Processes

The EU itself should leverage AI to optimize its internal operations: In late January 2024, the Commission adopted a Communication outlining its own strategic approach to the use of AI, including concrete actions about how the Commission will build institutional and operational capacity to ensure the development and use of trustworthy, safe and ethical AI.[191] In addition, the Commission is also preparing to support EU public administrations in their own adoption of AI. This reform should be hastened and turned into more concrete action,[192] as well as ensuring that the environmental impact of AI systems deployed in the public sector is minimised.[193] For instance, by integrating AI into its energy management systems, the EU could employ predictive analytics to forecast energy demand across its facilities, enabling the dynamic adjustment of energy consumption to minimize waste. Additionally, AI-driven smart building technologies, ranging from automated lighting and heating,

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[189] Research: Coding on Copilot: 2023 Data Suggests Downward Pressure on Code Quality (incl 2024 projections) - GitClear; Incidents: AI hallucinates software packages and devs download them – The Register.

[190] For this proposal, see: Luers et al. (2024), Will AI accelerate or delay the race to net-zero emissions? (nature.com).

[191] European Commission (2024), Artificial Intelligence in the European Commission (AI@EC) Communication.

[192] See also: Küsters (2024), Anticipating AI Instead of Preventing It | cep - Centre for European Policy Network.

[193] See: Gabriel et al. (2024), the-ethics-of-advanced-ai-assistants-2024-i.pdf (storage.googleapis.com), chapter 18.

ventilation, and air conditioning systems to advanced insulation monitoring, could be deployed in EU-owned properties to ensure energy efficiency. Furthermore, AI could enhance the EU's procurement process by analysing vast datasets to identify the most sustainable suppliers and materials, thus reducing the environmental impact of its supply chain. This approach not only aligns with the EU's Green Deal objectives but also serves as a model for integrating digital technology into sustainability goals.

4.3 Digital Euro related Recommendations

4.3.1 Do we Need a Digital Euro at all?

Before deciding how to design a digital euro in a twin-transition-friendly manner, the first question to be answered is, whether there is a real need for a new public means of payment for the euro area at all or whether we should live with the many existing public and private payment solutions. For instance, in our cep**PolicyBrief** on the Commission's proposal on the digital euro, we concluded that the ECB and the Commission should refrain from introducing a digital euro at this stage since no market failure can be identified and many good payment alternatives to the digital euro are available. Furthermore, there is no immediate added value from the digital euro that could justify its expensive implementation, and, as of now, the feasibility and viability of the digital euro project is still unsatisfactory. Thus, even if a digital euro, in whatever form, would contribute to the EU's sustainability goals, it may not be worthwhile to promote its implementation. And issuing it purely for environmental purposes may be overblown as other policy measures could be adopted to encourage more eco-friendly payments markets.

4.3.2 Do we Need both an Online and an Offline Digital Euro?

The ECB and the Commission want to implement the digital euro in basically two different forms, online and offline. While the online version will mainly function like existing online and digital methods of payment, the offline version offers digital euro users a payment method replicating many of the features of cash. Not only, but also for environmental reasons, it should be discussed whether there is really the need for both variants. As the offline version basically replicates cash and we see no real added value of it vis-a-vis coins and banknotes, it might be worthwhile to focus only on an online version. This would reduce complexities and lower the need for the build-up of several infrastructures and systems at the level of central banks, commercial banks, payment services providers, merchants and end users. Furthermore, there have been many calls from politicians[194] and central bankers[195] that physical cash should have a future and should not - for many reasons[196] - be abandoned. Thus, for the

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[194] For example, in its Proposal for a Regulation on the legal tender of euro banknotes and coins [COM(2023) 364], the Commission warns that "the growth of electronic payments [...] has led to a general decline in cash payments and the reduction of automated teller machine (ATM) networks". Thus, it observes risks for citizens accessing cash and proposes granting cash the legal tender status, with the aim of ensuring that the physical form of central bank money remains present, available and accepted by all euro-area residents and enterprises.

[195] For instance, the German Bundesbank states that cash and the digital euro would co-exist and that it would complement but not replace cash [https://www.bundesbank.de/de/aufgaben/unbarer-zahlungsverkehr/digitaler-euro/faq-digitaler-euro].

[196] Even Sweden, an early promoter of digital public and private means of payment, slowly fears the disappearance of cash, and its central bank advocates for safeguards that ensure a basic supply of cash. This change in mind comes from several angles. These include financial inclusion and privacy considerations, but also aspects like having a payment system available that is secure and generally available and that would function in crisis times or when digital means of payment are, e.g. confronted with cyberattacks or power cuts. Thus, cash infrastructures could act as a fallback option, for instance

foreseeable future, it seems unlikely that there is an inherent need for a digital (offline) alternative to physical money. In addition to that, we are already seeing intensified efforts to improve the ecological footprint of cash. For example, the ECB already introduced (1) sustainable cotton sources into the manufacturing of euro banknotes, (2) gave a protective coating to lower-denomination banknotes to increase their lifetime and (3) implemented a ban on the disposal of banknote waste in landfill.[197,198] Furthermore, as early as 2013, the Commission published a Communication on issues related to the continued issuance of the 1 and 2 euro cent coins [COM(2013) 281, see cep**PolicyBrief**], which discussed, inter alia, a gradual withdrawal of small coins. First, the issuance of small coins would cease. Then, after some years, the legal tender status of those coins would be withdrawn. The recent inflation surge may be a good opportunity to think again about abolishing these small coins in the short or medium term (also for sustainability reasons).

4.3.3 Choose the Right Technical Design

If the Commission and the ECB nevertheless come to the conclusion that a digital euro is required as the new digital currency for the eurozone (in one or both versions), the technical design of the digital euro will be the most crucial factor for determining whether or not the CBDC can be considered sustainable in ecological terms. As shown above, centralized solutions have greater benefits than decentralized ones in this regard. Thus, experimentation and testing by the ECB should primarily focus on the former. With regard to centralized solutions, there are increasing discussions on the use of so called "Real Time Gross Settlement Systems (RTGS)" like the TARGET Instant Payment Settlement (TIPS).[199] TIPS, which was implemented by the Eurosystem in 2018, is a market infrastructure service enabling payments to take place in real time, within seconds, around the clock and every day of the year.[200,201] Evidence provided by the Bank of Italy shows that "a TIPS-based digital euro could mark an initial step towards a more general reduction of the environmental costs of payment solutions and instruments". In its examination, the Bank focused on a technological solution that is both cost-effective and has a low ecological footprint, and chose an option that, on the one hand, "reuses" existing Eurosystem infrastructure and, on the other, avoids mining mechanisms typical of many DLTs (see also Table 4).[202]

Tab. 4: Carbon Footprint of a Hypothetical TIPS-based Digital Euro

Carbon footprint of a hypothetical TIPS-based digital euro	
Total electrical power consumption per year	170687 kwh
Total emitted CO2 per year	86.367 kgCO2
Emitted CO2 per single payment	0,00027g CO2

Source: Urbinati, E. et al. (2021).

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in times of increasing geopolitical turmoil [Stefan Krempl (2024) Missing Link: Karten-Pionier Schweden entdeckt die Bedeutung von Bargeld neu, 5 May 2024].

[197] ECB (2023), Product Environmental Footprint study of euro banknotes as a payment instrument, December 2023.

[198] In May 2024, Piero Cipollone, Member of the Executive Board of the ECB reiterated the ECB's commitment to take measures to reduce the environmental footprint of banknotes and payment systems [ECB (2024), Europe's tragedy of the horizon: the green transition and the role of the ECB, Speech by Piero Cipollone at the Festival dell' Economia di Trento, 26 May 2024.

[199] Giaglis, G. et al. (2021), Central Bank Digital Currencies and a Euro for the Future.

[200] https://www.ecb.europa.eu/paym/target/tips/html/index.en.html.

[201] Wang, H. (2023).

[202] Urbinati, E. et al. (2021), A digital euro: a contribution to the discussion on technical design choices (No. 10), Bank of Italy, Directorate General for Markets and Payment System.

Also, a paper by Tiberi, P. (2021), which estimated the carbon footprint of the TIPS system in 2019 and compared it with other payment infrastructures, shows the environmental potential of TIPS. The author concluded, for instance, that the carbon footprint of Bitcoin was roughly 40,000 times larger than that of the TIPS system at the time[203] due to the energy-intensive decentralised consensus mechanism of the crypto currency. Furthermore, he stated that TIPS energy consumption levels outperformed many other payment infrastructures as well, albeit to a lesser degree.[204]

4.3.4 Choose the Right Energy Sources for Powering the Digital Euro Ecosystem

The decisions being taken by the ECB on a proper and eco-friendly technical design of a digital euro should go hand in hand with reflections on the right choice of energy sources to power the digital euro ecosystems. The - from a sustainability perspective - favourable centralized technical set-up would give the ECB and the national central banks of the eurozone the opportunity for a big say in lowering energy consumption levels and the wider environmental impact. The ECB has an opportunity to integrate environmental objectives into its CBDC development efforts, reducing greenhouse emissions and optimizing energy consumption. They should seize this opportunity. When

- opting for a DLT-based solution, they could and should steer the location of the participants ("nodes") of the digital euro infrastructures towards geographic locations where renewable energy sources are abundantly available or where there is an overproduction of non-renewable energy, which if not absorbed will be wasted.[205]
- choosing participants in the digital euro ecosystem, they should make the selection dependent on the participants' use of renewable energy sources and efforts to lower their carbon energy-related footprint, as well as including incentives to choose locations where such renewables can be produced most efficiently, e.g. in colder regions, or energy-efficiency criteria. This may involve incorporating related criteria within dedicated procurement processes. In this way, the ECB may trigger competition among interesting actors with the most sustainable solutions supporting the functioning of the digital euro. Ultimately, it should encompass players like hardware vendors producing devices, data centres and cloud service providers enabling payment transaction processing and storage, and software companies developing front-end services, digital euro wallets and application interfaces.[206,207]

When it is not in the ECB's direct competence or power to decide upon environmental factors because these decisions are taken by the companies in the digital euro ecosystem themselves – such as the many payment services providers (PSPs) that will distribute the digital euro and offer basic and advanced digital euro services – the legislators could consider issuing recommendations requiring those companies to incorporate similar energy consumption safeguards in their procurements and processes.

If these aspects are considered at an early stage, in all areas relevant to the development of the digital euro ecosystem, and used as a basis for developing innovative, sustainable ideas, solutions and

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[203] The author makes clear that the discrepancy would be somewhat smaller as there is no full acknowledgement of different transaction volumes of Bitcoin v. TIPS. However, the results would not change much "as the marginal increase in emissions per additional transaction [when using TIPS] is very small".

[204] Tiberi, P. (2021), The carbon footprint of the Target Instant Payment Settlement (TIPS) system: a comparative analysis with Bitcoin and other infrastructures. Bank of Italy Markets, Infrastructures, Payment Systems Working Paper, (5).

[205] Agur, M. I. et al. (2022).

[206] Agur, M. I. et al. (2022).

[207] This may include forcing any contractor to apply green software engineering principles.

standards, this could also provide a source of learning for existing means of payment. This would offer the potential for fruitful spill-over effects making the whole European payments markets more eco-friendly. Or as the G7 put it: “CBDCs present the opportunity to set a marker for how future payment [...] ecosystems are designed for optimal energy efficiency, including through utilizing carbon-neutral and sustainable energy sources, whilst achieving necessary functional, performance and resilience aims”[208].

4.3.5 Think of a Future-proof Electronic Waste Strategy

Any new means of payment is liable to produce new electronic waste (e-waste). A bad example in this regard is Bitcoin. De Vries and Stoll (2021) found out that devices needed to mine Bitcoin only have an average lifetime of 1.3 years before they are discarded and that the e-waste generated by only one Bitcoin transaction is comparable to throwing away two iPhone 13 Minis.[209] Thus, beyond pure energy source considerations, reflections must also focus on how to avoid e-waste. These reflections may include the possibility of using devices, e.g. smartphones, already utilized by digital euro users for other purposes, thereby avoiding the production of duplicate components or infrastructures. Furthermore, right from the outset, there must be a reliable and future-proof recycling strategy for both the digital euro payment instruments used by digital euro users as well as for the many digital infrastructure elements.

4.3.6 Be Transparent on a Digital euro’s Environmental Impact

If established, the digital euro would be a totally new public means of payment for the euro area. Thus, as yet no empirical values on its ecological footprint are available and information from other jurisdictions that have already issued retail central bank digital currencies is scarce. It therefore makes sense to establish a monitoring system on the sustainability of the digital euro ecosystem along the whole value chain, for the entire lifecycle and in a continuous and regular manner. In this regard, the ECB should act as a pioneer making its digital-euro-related carbon footprint transparent right from its first issuance, in a comprehensive manner, potentially setting a standard for further disclosures by PSPs and other market participants. Such disclosures/transparency could act as a catalyst for improvements over time, lowering the digital euro’s potential adverse environmental impact. Close monitoring could, furthermore, ensure the longstanding visibility of the topic at the political level and thus, in practice, provide an important control function. When establishing such transparency/disclosure recommendations or requirements, lessons could be drawn from the experiences gained in connection with similar requirements that have been or soon will be adopted under the Regulation on Markets in Crypto Assets [MICAR, (EU) 2023/1114, see cep**Input**] on level 2 (see Box 1).

Box 1: Disclosures on the Environmental Impact of Crypto-assets under MICA

Under the MICA Regulation (EU) 2023/1114, persons that draw up prospectus-like white papers on crypto-assets must include information in such white papers on “the principal adverse impacts on the climate and other environment-related adverse impacts of the consensus mechanism used to issue the crypto-asset". The European Securities and Markets Authority (ESMA) is mandated to specify the content, methodologies and presentation of this information and to delineate sustainability indicators by adopting draft regulatory technical standards. In doing so, the ESMA must, inter alia, consider the various consensus mechanisms, their

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[208] Sunak, R., & Bailey, A. (2021), Public Policy Principles for Retail Central Bank Digital Currencies (CBDCs), G7 UK.

[209] De Vries, A., & Stoll, C. (2021), Bitcoin's growing e-waste problem. Resources, Conservation and Recycling, 175, 105901.

incentive structures and their energy use, and the production of waste and greenhouse gas emissions.* In an early discussion paper, published in October 2023, the ESMA proposed**

- a targeted set of mandatory disclosures, including metrics on energy consumption, scope 1 and scope 2 GHG emissions and on waste production as well as on the impact on natural resources of the use of equipment by DLT network nodes,
- a set of additional, but (initially) optional indicators, that include granular information on the energy mix and the carbon intensity of the energy used or on scope 3 GHG emissions.

On 3 July 2024, ESMA published the draft technical standards. Those standards include mandatory disclosures on the adverse impacts on climate and other environment-related adverse impacts, encompassing

- general information on the crypto-asset and on the features of the consensus mechanisms,
- a mandatory key indicator on energy consumption, and, where relevant, supplementary key indicators on energy and greenhouse gas (GHG) emissions, and
- a section on the sources and methodologies used to calculate these key indicators.

In addition to that, the draft technical standards include, for crypto-assets with higher levels of yearly energy consumption, several supplementary key indicators, including

- the yearly ratio of consumption of renewable energy,
- the average energy consumption expressed per transaction,
- the greenhouse gas emissions production expressed per transaction, and
- the yearly GHG emissions linked to the use of direct and indirect energy sources.

Furthermore, persons drawing up white papers and the providers of crypto-asset services may voluntarily include several additional indicators on climate and other environment-related issues, e.g. on the production of waste or on the use of natural resources.***

Against this background, it is crucial for issuers of crypto-assets and crypto-assets service providers (CASPs) to both identify and reveal any potential adverse climate or environment impact.****

** Art. 6(12), 19(11), 51(15) and 66(6) MiCAR.*

*** ESMA (2023), Consultation Paper, Technical Standards specifying certain requirements of Markets in Crypto Assets Regulation (MiCA) - second consultation paper, ESMA75-453128700-438, 5 October 2023.*

**** ESMA (2024) Final Report Draft Technical Standards specifying certain requirements of the Markets in Crypto Assets Regulation (MiCA) – second package, ESMA75-453128700-1229, 3 July 2024, pp. 178 et seq.*

**** Recital 7 MiCAR.*

In this regard, it is to be welcomed that the G7 have already made a strong transparency commitment by stating that, when making climate-related disclosures in their reporting, central banks should also include disclosures on the environmental impact of operations with respect to their CBDCs.[210] In addition to that, it may be helpful to establish a common and well-founded methodology for calculating the environmental impact of all private and public means of payment, including a potential digital euro, to make their respective ecological footprint transparent and comparable.

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[210] Sunak, R., & Bailey, A. (2021).

5 Conclusion: Towards an Environmentally Conscious Digital Future

This paper’s examination of generative AI and the digital euro in the context of the EU’s twin transition strategy highlights the complex and ultimately unpredictable interplay between digitalisation and decarbonisation. While digital technologies hold great promise for optimising resource use, they also pose notable challenges in terms of energy consumption and e-waste. Our case studies show that the optimistic views of EU legislators on the environmental benefits of AI and the design of digital currencies often overlook critical empirical evidence. To ensure a successful transition between the two, policymakers must adopt a more holistic approach that balances technological progress with environmental safeguards. In this concluding section, we summarise the main findings from our two case studies and then situate them in the EU’s broader geopolitical battle for strategic autonomy, which necessitates reconciling the goals of a green and digital Europe.

To begin with, the first case study made clear that the environmental impact of modern generative AI models stems primarily from their significant energy consumption and carbon emissions during both the training and inference phases. To date, policymakers and most research has focused on the training phase due to its tangible and fixed duration and dedicated computing resources. The recent escalation in computational requirements is evident from the exponential growth in model sizes and the corresponding increase in energy consumption. The last wave of advances in AI performance are indeed mainly due to the scaling of computational resources. In addition, the role of data centres and chip manufacturing further amplifies the environmental footprint, as these infrastructures require significant energy and water resources, contributing to overall emissions. However, as generative AI becomes more integrated into everyday applications, such as updated computers or iPhones, the inference stage also now warrants attention. The forthcoming standards being developed for the implementation of the EU AI Act, which includes some minimum environmental requirements for AI models, should take into account the entire direct impact of these systems, i.e. in both training and inference.

However, it is important that these requirements do not hamper the EU’s ambitions to increase its competitiveness and attract AI start-ups, due to current methodological challenges in measuring environmental impacts comprehensively. To address these issues, this paper has proposed a three-layer approach for the sustainability benchmarking of generative AI. The first layer focuses on direct energy consumption during both the training and inference phases, promoting real-time measurement and the development of energy-efficient algorithms and hardware. The second layer considers the indirect environmental impact of supporting infrastructure, such as data centres and raw material extraction. The third layer examines broader societal implications and the potential rebound effects of genAI deployment. By initially targeting standards and policies at the first layer, and progressively incorporating more complex lifecycle and societal impacts as methodological understanding advances, this phased approach avoids the Hayekian “presumption of knowledge” and aligns the EU’s twin transition objectives.

The second case study on the digital euro has shown that comparing the environmental impact of the many existing means of payment available on EU’s payments markets is not an easy task and cannot usually be carried out in a straightforward and objective manner. It does show, however, that credit card systems usually perform much better, when considering electricity consumption levels, than cash and especially cryptocurrencies like Bitcoin. However, when compared to permissioned non-POW-based cryptocurrencies, credit card systems typically lose out. Then, the study considered whether the

ECB, the Commission and the G7 are keeping a proper eye on the development of a digital euro and of CBDCs in general with regard to sustainability. It shows that all three institutions do so. However, when comparing it to other incremental design factors, it is currently rather a marginal factor. For instance, the technical configuration of a potential digital euro, which is crucial for determining whether or not the CBDC will be sustainable in ecological terms, is still open and yet to be decided upon. The next section considered the factors that will determine the environmental impact of a digital euro. It pointed out that beyond its technical design other aspects also play a significant role, such as access universality, the question of whether the CBDC as a new means of payment will complement rather than replace others, the (reverse) waterfall feature or having two variants of the digital euro (online and offline).

Overall, our findings point to an uncomfortable dilemma. At a time when technology is the key element in a global geopolitical competition leading to protectionist measures and reshoring, Europe's competitiveness in leading technologies such as generative AI and digital currencies must be strengthened, and its foreign dependence reduced, if we want to preserve our sovereignty. However, as this paper has shown, large-scale adoption of both technologies also implies hard-to-quantify environmental spill-overs that could counteract the push for a green revolution, which is also necessary in the face of rapid climate change with its own dangers. As noted by former ECB Executive Board Member Fabio Panetta in a recent lecture, the EU's current tech strategy, which we have referred to as a "twin transition", creates "dilemmas for politics that are hard to solve", since, for example, "the green transition would be accelerated by focusing on rapidly adopting low-cost technologies, mainly produced in China, but at the cost of a growing strategic dependence".[211] This dilemma, and the underlying trade-offs of each policy measure adopted under the "twin transition" strategy, must be addressed much more directly by the incoming Commission. For instance, the latest report on the State of the Digital Decade still maintains that digital transformation and enhanced technology adoption by firms and citizens alike has the "potential to reduce total greenhouse emissions by 15% - 20% before 2030, across the whole economy".[212]

This ignores certain conflicts and trade-offs that can already be outlined today, despite all the uncertainties and the essentially unpredictable nature of rebound effects. In the case of AI, three simultaneous conflicts can be identified: between AI innovation and equitable resource distribution; between inter- and intra-generational equity; and between environment, society and economy.[213] In the case of CBDCs, there are also underlying trade-offs between the desire, on the one hand, for strong financial inclusion, a high privacy level, competition between PSPs for digital euro users, and widespread availability of the new means of payment, and, on the other, the achievement of sustainability goals. Our aim was not to predetermine these normative choices but to highlight the underlying conflict that is typically omitted from EU speeches and documents and acknowledge that there are environmental costs to AI and CBDCs, and, where possible, to estimate these costs on the basis of the initial empirical evidence that is emerging. Thus, it is hoped that the environment will no longer take a back seat in the EU's digital push, and that a fairer, more objective discussion can take place about the priorities of the next Commission and its likely continuation of the green-digital twin transition.

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[211] Fabio Panetta (2024), The future of Europe's economy amid geopolitical risks and global fragmentation, University of Roma, p. 11, fn. 53.

[212] The report can be found here: Second report on the State of the Digital Decade (europa.eu).

[213] See: van Wynsberghe, A. (2021), Sustainable AI: AI for sustainability and the sustainability of AI. AI Ethics 1, pp. 213–218.

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