On the environmental sustainability of Ai art(s)

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ABSTRACT

A wide variety of creative practitioners are currently exploring the use of Ai in their work processes, for instance in poetry, music, performance, and visual arts. In this paper, we discuss the relationship between Ai and sustainability in general but focus on the relationship between the emerging area of Ai art and sustainability in particular. We highlight the importance of pursuing research concerning the sustainability of Ai art and take initial steps towards understanding how Ai art practices may influence how we save or waste resources. Developed through our online fieldwork by analyzing the environmental impact of three specific cases of Ai artworks, we provide a conceptual approach that can be used to map the environmental sustainability of Ai art. With this paper as a basis, we hope to elicit awareness among scientific and artistic communities about the environmental sustainability of Ai art.

KEYWORDS

Sustainable AI art, Sustainable AI, AI, Sustainability

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1 INTRODUCTION

Limits, scarcity, and abundance are all around us. Like with an optical illusion ("is it a duck or is it a rabbit?"), it is possible to have a perspective that focuses on scarcity [1–3] or a perspective that emphasizes nature's abundance [4–7]. In both cases it is still necessary to relate to planetary *limits* [8]. Irrespective of perspective chosen, sustainability and *exceeding* [9, 10] or *staying within* planetary limits/boundaries [11, 12] will be the major challenge facing humanity during this century.

Many of the specific problems that are related to sustainability and global climate change are neither easy to solve nor even easy to understand. Any one thing is related to something else, and that something else is yet again related to something else (and so on). Rittel and Webber [13] coined the term "*wicked problem*" to describe problems that can not be precisely formulated, that do not have a definitive solution, where it is not possible to know if a proposed solution is the best solution, where each solution leads to one or several new problems etc. Levin et. al. [14] believe that global sustainability challenges (climate change) are not only wicked but super wicked problems, and that these are characterized by situations where "traditional analytical techniques are ill equipped to identify solutions, even when it is well recognized that actions must take place soon to avoid catastrophic future impacts" [14, pp. 123]. We here ask, if Ai[1] technologies will help *solve* these complex sustainability problems or if Ai will further *aggravate* these problems? This relates to the question, whether Ai will *save* or *waste* resources? While these interesting and important questions that frame the paper are relevant for all Ai, our focus is specifically on Ai art - artists incorporating Ai in their creative practices. How are we to reason, from an ecological sustainability point of view, about Ai art in a world of sometimes scarcity, sometimes abundance, but always of limits?

Against a background of a more general discussion about the relationship between Ai and environmental sustainability, the more narrow focus of this exploratory paper will mainly answer two questions related to the environmental impact of Ai art: 1) what factors should be considered when assessing the environmental impact of Ai art, and 2) what approach could be used to assess Ai art? We argue, that developing this understanding is a step towards situating Ai art practices within the planetary limits thinking. Furthermore, we discuss how artists' practice can contribute to aggravating or solving sustainability problems. We have sought answers through an exploratory approach; online fieldwork of Ai artists and Ai arts technologies, as well as a literature review of methods to map and assess the environmental impact of Ai and art. We here introduce insights on a conceptual level and propose an initial approach for understanding Ai art in terms of two key dimensions, 1) the artistic practices and 2) artistic materials. We propose and discuss factors within these two key dimensions that can influence the environmental impact of Ai artistic practices.

While these findings contribute to an understanding of the potential environmental impact of Ai arts and provide directions for further studies, Ai arts practitioners in various fields can also benefit from the knowledge that we present here in order to address questions regarding the environmental impact of their own work. Furthermore, we would like to highlight the importance of including sustainability in Ai arts research agenda. By addressing these questions, we here take foundational steps towards understanding whether using Ai in artistic practices can save or waste resources, and how it could be practiced within the planetary limits. We hope that this paper will evoke further discussions regarding the environmental impact of Ai art within the research and artistic communities.

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[1]The "i" is lowercase in Ai to emphasize the fact that the intelligence of current systems is quite different from human intelligence and has not yet reached a level of HLAI (human level artificial intelligence)

2 AI ART(S) AND SUSTAINABILITY

In this section, we first describe the Ai juggernaut, move on to the emergence and development of Ai art (including presenting three cases of Ai art from our online fieldwork), shift to a discussion about the environmental sustainability of Ai, and discuss the importance of assessing the environmental impact of Ai art.

2.1 The Ai juggernaut

The use of Ai technologies has increased across different sectors of society during the last decade and immense efforts and resources are currently being invested in Ai research [15, 16] and development [17, 18], yet still to be overshadowed by the even greater hype around Ai. Only slightly adjusting the preface of Morozov's book "To save everything, click here: The folly of technological solutionism" [19], the gist of his prediction still stands: *"If Silicon Valley had a designated futurist, her bright vision of the near future - say, around 2020 [now: 2030] or so - would itself be easy to predict. It would go something like this: Humanity, equipped with powerful self-tracking devices [now: AI], finally conquers obesity, insomnia, and global warming as everyone eats less, sleeps better, and emits more appropriately"*. Following this current trajectory, Ai is expected to permeate various areas of society [15, 16, 20], including creative practices and creative industries. Current research into Ai and sustainability has on the other hand highlighted environmental impacts and other sustainability-related considerations that need to be taken into account concerning Ai technologies. While Ai is assumed to have many benefits, it has been suggested that we need to also think about and take stock of the negative consequences of Ai both in terms of social [21, 22] and environmental sustainability [23–25], ranging from algorithmic bias to the out-sized energy consumption of Ai algorithms. In an illustrative example, Devine [26] discusses the environmental impact of the creative industries and demonstrates that the carbon emissions of the music industry did not decrease with the paradigm shift from physical materials to digital music streaming (e.g. "dematerialization"). Devine's calculations exclude the increasing use of Ai technologies, which has the potential to further aggravate the situation. Thus emerges the concern of whether this trajectory of increasing environmental impact will continue with Ai arts.

2.2 Emerging Ai art practices

In recent years, there has been an increasing amount of online materials published about Ai art [27–30]. This ranges from informational websites to online communities, courses, interviews, and articles. Technology companies (*e.g.* [31]) have launched artist collaborations that have resulted in the advancement of Ai arts. Museums and cultural institutes [32–35] have started collaborating with artists who focus on Ai arts. Prominent media arts venues such as the LUMEN competition [36] and Ars Electronica [37] have also seen a rising number of contributions from Ai art practitioners. Conferences [38, 39] and research groups [40, 41] that focus on Ai art have appeared. Tools [42] and knowledge sources [27, 43] have been launched to make Ai more accessible to artists. It has even been argued that Ai art should be considered an independent art genre [44]. This is not a bold claim as we already recognize genres such as glitch art, computational art, and new media arts - and this kind of shift can presumably change how Ai art is perceived in the future: not only as a tool, but rather as a creative field in and of itself. These are a few of the factors highlighting the Ai art field's recent developments and it is thus reasonable to expect that it will continue to expand in the future.

2.3 Three cases of Ai art

Currently, there are a wide variety of creative practitioners exploring the use of Ai in their work processes (in poetry, music, performance, visual arts, etc.). We specifically focus on examining contemporary Ai artists in this paper. It provides an interesting perspective of the emerging Ai art field, as contemporary artists are usually at liberty to explore various directions of the use of Ai technologies in arts and in their artistic practices. Artists also often engage in critical reflection and societal discourses through their practices, as well as spearhead new ideas within the creative fields. Examining these practices can place us in a position to glean trends in the use of Ai in the arts that may become widespread in the future. For our exploratory fieldwork, we selected artists that are expressing diversity in their practices of using Ai, while also spearheading the development of the field. Below, we briefly describe the artistic practices of the three Ai artists selected for this study.

2.3.1 Artist 1 - Refik Anadol. Refik Anadol is a multimedia artist working with Ai-based installations [27]. We have focused on a specific art piece created in collaboration with Google Arts and Culture (Fig. 1). In this artwork, the historical archive of video footage from the LA Philharmonic was projected on the outer surface of the walls of the same building. The artwork uses "nearly 45 terabytes of data – 587,763 image files, 1,880 video files, 1,483 metadata files, and 17,773 audio files (the equivalent of 40,000 hours of audio from 16,471 performances)" and "42 large scale projectors, with 50K visual resolution, 8-channel sound, and 1.2M luminance in total" to realize the artwork [45].

Figure 1: Ai artwork by Refik Anadol: WDCH Dreams [45]

2.3.2 Artist 2 - Sougwen Chung. Sougwen Chung is a multidisciplinary artist working with performance and visual arts, exploring the communication between humans and machines. In the artist's well-known collaborative drawing piece *Drawing Operations* (Fig.

2), robotic arms are used to draw collaboratively, and the artist has trained an Ai algorithm with drawings from her past to produce a similar kind of style, but from her robotic collaborator [27]. It is stated online that technologies used include Markov chains and neural networks [46].

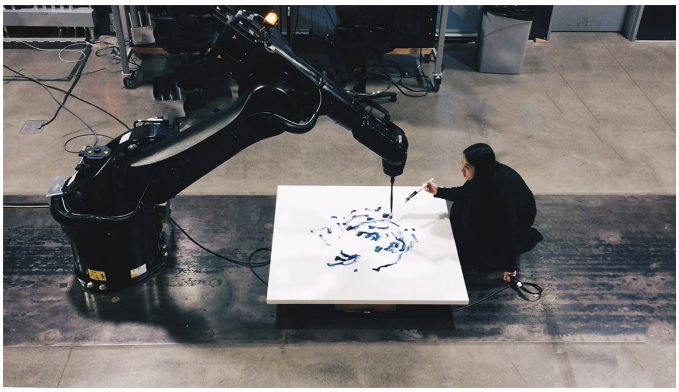

Figure 2: Ai artwork by Sougwen Chung: Drawing operations [27]

2.3.3 Artist 3 - Mario Klingemann. Mario Klingemann's *Memories of Passersby I* (Fig. 3) was the first Ai artwork that was sold in a traditional auction house [27]. It is stated that the artwork itself consists of the code and the system rather than of the visual representations created by them. The artwork generates neural network portraits in real-time, and the hardware is hidden in an old cabinet and a radio. The fact that Klingemann considers the technology itself to be the artwork (rather than the visual outcome that the technology generates) makes the artwork conceptually different from many other Ai artworks [27] and urges us to reflect on our understanding of what is considered to be art.

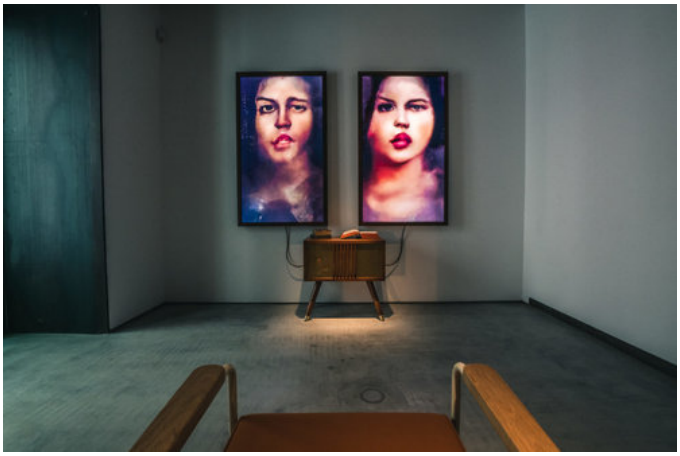

Figure 3: Ai artwork by Mario Klingemann: Memories of Passersby I [27]

2.4 Environmental sustainability of Ai

Several studies have examined and raised the topic of environmental sustainability concerning Ai in recent years. As a response to environmental challenges, Schwartz et al. (2020) suggested an "Ai for Green" approach [47]. Research has been conducted to understand and assess the energy use and CO^2 emissions of Ai use [23–25, 48]. Strubell et al. [23] have proposed energy and policy considerations for deep learning in general and Natural Language Processing (NLP) in particular. Others [24, 25] have instead focused on the impact of Ai on carbon emissions, for instance by estimating the carbon impact of different Graphics Processing Units (GPUs) [24]. Ligozat et al. [48] have highlighted the contradiction of Ai being seen as part of the solution to problems having to do with environmental sustainability, while Ai simultaneously uses significant amounts of energy and can thus be construed to be part of the problem. They also criticize the "Ai for green" approach for not considering the negative environmental impacts of Ai. Jang et al. [49] have also pointed to the challenge of measuring and quantifying the environmental impact of technology when the hardware is virtualized - which is often the case for Ai technologies.

As for the environmental sustainability of Ai, the first and easiest answer is to state that it depends on various factors, of which some are not well known. Ai technologies have a footprint and are thus born with a heavy weight of costs in terms of mined and utilized resources and energy use. But, perhaps, Ai can make up for it depending on how it is used? We will here reason by analogy and discuss also the environmental sustainability of ICT and digitization in general since those discussions are more mature than the discussions that specifically concern Ai. Hilty et al. [50] suggest that ICT in general can be part of the problem as well as part of the solution. Despite the environmental footprint of mining and manufacturing (and later disposal), ICT can be used to solve various problems that are related to sustainability and this could outweigh its environmental costs (see further Hilty et al.). Lange et al's [51] insightful observations repeat the same discussion, but in this case for "digitalization" in general. The conclusion is that while ICT, digitization and now Ai *could* be used "for good", without explicit (environmental) policies guiding research and development (and deployment), chances are that these technologies will be used to further support (rather than reverse or overturn) the current economic system. There is thus no particular reason to, in the absence of significantly different (economic and political) control mechanisms, believe that Ai in general will have beneficial rather than detrimental effects on environmental sustainability.

2.5 Assessing the environmental impact of Ai arts

If the outlook for environmentally benevolent Ai technologies to develop autonomously (in the absence of strong political steering) seems doubtful, what then is the case for Ai art? While the works cited earlier pave the way to an initial understanding of the environmental impact of Ai, no research specifically focuses on the use of Ai tools by the creative community, nor of Ai art practices. We argue that the environmental footprint of Ai art needs to be studied to better understand the environmental impacts produced by these artistic practices with their specific contexts of use and work

processes since these are likely to differ from other Ai application areas.

At this point in time, there is little understanding of the sustainability implications of adopting Ai technologies into creative practices. As with Ai in general, the creative fields have direct impacts in terms of resource use. Arts practices are diverse and can potentially have a significant environmental impact, particularly in contexts of large-scale use (such as media productions or music), when Ai is applied to their creation. There are indications of potential large-scale adoption of Ai tools in creative communities, as well-known companies are working on Ai-powered tools for digital artists. We would like to point out that the ongoing transformation in which Ai-based arts and media are used (deepfakes, image editing, film-making, music generation, non-fungible tokens (NFTs)) are largely focused on computationally demanding architectures, and the environmental impact of Ai arts will therefore become increasingly important to study. Several large corporations support our hypothesis that such Ai architectures will be increasingly infused into creative practices: Adobe is working on incorporating Ai technologies into Photoshop and other common tools for creative practitioners, and NVIDIA has launched an Ai-powered painting tool that has become popular among digital media artists and designers. Hence, are there any limits to these developments?

While at the same time, the potential environmental impacts of Ai art are currently for the most part uncharted. We argue, that the quick adaption of Ai technologies into creative practices highlights the urgency of discussing the environmental sustainability of emerging technologies and practices in Ai arts. Furthermore, we need to understand the potential environmental impact of Ai arts in order to identify if there is a need to set boundaries or guidelines for these practices. While we are not doing an exhaustive analysis or numerical predictions of environmental impacts in this paper, we consider it an important aspect of future research on Ai arts.

3 RESEARCH FOCUS AND METHODS

We have focused on analyzing one artwork of each one of the three Ai artists introduced in Section 2.2 through online fieldwork and by examining press publications, artist portfolios, technology manufacturers' websites, and other media content published on various online platforms. We used search engines to find articles and publications, searching with keywords of the artists' names and the titles of the artworks. We followed any traces we found to other websites; if media or the artists themselves had published images of hardware, we attempted to find specifics, e.g. what model and make and then technical specifications (energy use, etc.). While this process mainly revealed a lack of published information about hardware, software, materials, and algorithms used by the artists, we were able to identify factors that need to be analyzed when investigating the environmental impact of Ai art. Furthermore, during this process, we developed two perspectives – a material and a practice perspective – that can be used for understanding the environmental impact of Ai art (see Fig. 4). We have further divided the material perspective into the technology used (software, hardware) and other materials, but we focus exclusively on the Ai technology that is used since this is what materially differentiates Ai artistic practices from other artistic practices. The practice perspective in turn addresses the artists' creative process in terms of the different phases that the creative process consists of. Hence, whereas we acknowledge the limited specificity of the insights obtained from three artworks, we believe that the analysis of these artworks has helped to develop the perspectives that will be further described in the following section. As we also identified limitations in the information that is published online regarding the artworks, we are currently engaging in interview studies with Ai practitioners to gain further insights on the matters explored in this paper.

4 RESULTS

We here present our proposal of how to structure the assessment of the environmental impact of Ai art. We start by discussing the environmental impact of Ai technologies (hardware, software) in Ai art. We then discuss matters related to the artistic process and finally discuss how these two perspectives (materials and practices) come together in Ai artistic practices and how they potentially contribute to the environmental impact of Ai art. Fig. 4 summarizes the two perspectives.

4.1 Material perspective: Ai technologies

Ai technologies are (part of) the materials that artists use in their creative practices. These materials differentiate Ai artistic practice from other types of artistic practices and constitute the core of understanding the environmental impact of Ai art. Below we present what factors need to be considered (concerning Ai technologies) when we want to estimate the environmental impact of Ai artistic processes. We discuss the different choices that can be made in terms of using (and creating) Ai technologies, and their contribution to energy usage as a measure of their environmental impact. One important direction for future research is to quantify the environmental footprint of hardware and software use in Ai arts.

4.1.1 Hardware. The most central factor that influences the environmental impact of Ai arts concerns microprocessor chips (various types of GPUs and CPUs) used and their respective energy consumption. Furthermore, if the algorithms used are computed on a server, the environmental impact of Ai art will extend also to the server(s) used. This is the case with website tools that are popular among creative practitioners, such as Google CoLab and Huggingface[2]. This essentially means that the hardware of interest to us (e.g. that contributes to the environmental impact) can be located in various places, making it much harder to assess and quantify, as Jang et al. have also noted [49]. There have been attempts to account for additional factors of server-side energy use, for example by including Power Usage Effectiveness (PUE) which adds additional energy required for the supporting computing infrastructure. Such methods for accounting of the environmental impact of general (Ai) technologies need to also be mapped and applied in the context of Ai art to determine energy usage. For the three artworks that we studied, there was no information available in the artist portfolios regarding if the artists ran the Ai algorithms locally on their computers or if it was run on remote servers, nor of which exact hardware was used.

[2] https://huggingface.co/spaces/akhaliq/VQGAN_CLIP

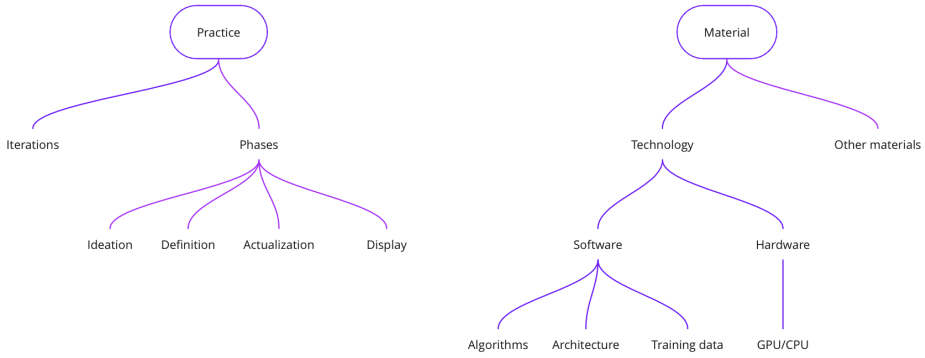

Figure 4: Material and practice perspectives to Ai art

4.1.2 Software. Besides the hardware used in Ai art, we need to consider the second material dimension (see Fig. 4) – e.g. the software that is employed. There is a variety of tools available that artists employ in Ai art practices and that differ in terms of their energy usage. These tools include Ai art tools that are available online, such as ArtBreeder[3], NightCafe[4], software tools that require installation, and plugins such as Wekinator[5], tools that require a deeper understanding of programming and code such as GitHub libraries[6], and Ai libraries such as Keras[7] and Tensorflow[8], and the Ai libraries provided by OpenAI[9]. Various factors within these tools (whether they run locally or in the cloud, the nature of the architecture of the tool, the type of used algorithms, etc.) will directly influence the energy consumption and the environmental impact of using these tools in the process of creating Ai artworks.

First, the chosen Ai *architecture* affects the energy consumption of training and inference with the model in question. VQGAN uses transformers and convolutional neural networks as architectures. However, there are many other architectures, and within each architecture, the number of parameters is a design choice that further affects the energy consumption. Energy expenditures are likely to be very different for various architectures as the Ai architecture has a direct impact on the energy costs of computation. Currently, there is no comprehensive evaluation of all architectures and tools used by Ai artists. *Algorithms* are a second influencing factor since they are used to train a model using a dataset and these algorithms are also used to compute the outputs of the trained model. The algorithms are closely related to the architecture, but they introduce an additional factor, e.g. how efficient they are (since different programmers/designers can create algorithms that produce the same output in more or less energy-efficient or wasteful ways). When training an Ai model, there are choices as to what kinds of parameters to include in regards to architecture and algorithms, but an important additional factor that influences energy consumption is what kind and size of *training data* are used to train the model. These three factors (architecture, algorithms, and training data) have a large influence on the energy use *during* the Ai artistic process.

The artists we studied seemed to base their artworks on varying kinds of data sets: from 45 terabytes of historical archive data that Anadol has assembled to more moderate amounts of data used by Chung, who trained the model using her previous artworks (e.g. drawings). In the process of studying the three artworks, it was observed that even if we would be able to obtain data on which specific Ai technologies the artists used, there is currently no research about the energy consumption of the specific Ai technologies (both hardware and software) used by the Ai artists. As there is no prior research that provides information on the environmental impact and energy consumption of Ai software used by Ai artists, we conducted an initial experiment where we measured the energy consumption of one of the most popular tools used by the Ai artistic community today (VQGAN+Clip) on a local terminal of an ordinary laptop. Through these measurements, we developed an initial understanding of how much electricity *one* inference iteration of VQGAN-Clip consumes within an Ai artistic process, a process that took around 3 hours and resulted in values in the range of 0.025-0.031 kWh. This is similar to the energy consumption of running a small household appliance (for example a table fan) for three hours. The numbers from our measurements of VQGAN+Clip are thus very low, but based on our insights from the three investigated artworks, it seems that there is potentially a very wide variation in the environmental impact of Ai art depending on how the Ai technologies are used within an Ai artistic process. Some artists use massive training data sets, such as the WDCH concert hall piece that utilized approximately 45 terabytes of data [45]. Furthermore, the estimates by [23] on training a neural network (in this case "BERT") can take as much electricity as one trans-American flight and Strubell et al. [23] have also provided energy consumption figures for training other models besides BERT (e.g. Transformer, ELMo, NAS, and GPT). We, therefore, plan to perform further studies where we compare energy usage in both inference and training of various technologies used by Ai artists.

4.2 Artistic practices

Here, we introduce an approach for structured analysis of Ai artistic processes which is informed by past research on (non-Ai artistic)

[3]https://www.artbreeder.com
[4]https://creator.nightcafe.studio
[5]http://www.wekinator.org
[6]https://github.com/justinjohn0306/VQGAN-CLIP
[7]https://keras.io
[8]https://www.tensorflow.org
[9]https://openai.com

creative practices. This is motivated by our assumption that the manner in *how* the Ai tools are used influences their environmental impact significantly. Within creative practices, there are different kinds of phases and these can vary depending on the project and artist. Botella et al. [52] have studied various kinds of creative processes and prior literature in the domain. From their paper, we can see that creative processes often contain these phases; ideation, definition, actualization, and reflection. These phases have been referred to with different names by various authors covered in the paper, and they may overlap or take place iteratively within the process (thus are non-linear).

In our model, we have changed the "reflection" phase into *display*, as we felt it was important to include the display of the artwork in the environmental impact assessment of Ai artworks. We also add that *iterations* are of particular importance to Ai artistic practices compared to non-AI practices, since it is possible to iterate repeatedly with small costs in terms of artists' time and effort, but with potentially large costs in terms of energy consumption and subsequent environmental footprint. Iterations also happen in traditional artistic processes, but the energy expenditures of such iterations are most likely relatively small (scrapping a paper and starting anew versus re-training a machine learning model many (many, many) times over). Running an algorithm 1 or 1000 times will have a significant impact in terms of the resulting environmental impact, albeit not on the artists' energy expenditures (food, coffee, etc.) required to engage in the artistic practice. We are currently planning further case studies with Ai artists to understand these practices in greater depth.

4.3 Materials and practices

The practice and the use of materials are intertwined in the sense that artistic practices (phases and iterations) may employ different materials within iterations, but the materials can also have an impact on how the phases and iterations emerge in the creative practice. The artistic practice is a dynamic process in which an artist adapts to the Ai materials and the prior phases of the process. Furthermore, with Ai artistic practices, we should keep in mind that Ai materials are not necessarily static materials as in other types of creative practices, but rather that the Ai may also adapt to the artist in the artistic process. For instance, in the work by [46], the robotic arm is participating in the creative process. That means we have to not only account for the practice and the agency of the artist but in some specific cases of Ai artistic practices also for the agency of the Ai technology. This emerging interaction between these two agents may influence the environmental sustainability outcomes of the creative practice. Therefore, we emphasize that the combination and relation of the materials and the practice are important to understand since they can reach particular complexity in Ai artistic practices. To develop an understanding of the environmental impact of Ai artistic practices, it is, therefore, necessary to understand both of these dimensions. This requires further studies of specific artists' concrete practices; e.g. to gain a deeper understanding of their processes and of how they are working with the (complex technological) materials in question.

Currently, we assume that Ai materials are primarily used in the "ideation", "actualization" and "display" phases of the creative process. In the three artworks that we studied, Anadol assumably used Ai materials in the ideation and actualization phases to develop and test the concept in a small-scale replica of the real artwork. Later, during the display phase, the artwork was displayed/ran in full size. Chung and Klingemann also used Ai materials in the display phases, and assumably in the ideation and actualization phases that proceeded the display phase. Especially Chung seemed to also use Ai technologies in ideation, by getting inspiration and trying out current developments, and by iterating them into new artworks (such as various versions of the artworks in her previous "Drawing Operations" series). In the ideation phase, artists generally seem to use Ai generators for inspiration and for helping ideas to emerge. In later stages like actualization, Ai is used by many artists to create the artwork itself. The Ai technologies can also be entangled with the display of the artwork: some artists are, together (or in "cooperation") with Ai tools *generating* interactive artworks in real-time together with the audience or environments. "Definition" and "disposal" are the two phases in the creative process where we could not find any examples of artists using Ai technologies.

5 DISCUSSION

In this paper, we have taken initial steps towards understanding and trying to estimate the environmental sustainability of Ai art. While we at present cannot provide a comprehensive analytical framework for the sustainability/environmental impact of Ai arts, we have taken the first steps towards defining the problem space. We have proposed a perspective (materials and practices) that can be used to map the environmental impact of Ai art in terms of their energy use (and subsequent carbon emissions), but also potentially other aspects of the environmental impact of Ai art such as the material life cycle. In the process, it has become evident that existing methods (such as Life Cycle Assessment (LCA) and methods for quantifying the carbon impact of Ai) can prove useful in the context of Ai arts. LCA has been used to assess the environmental impact of media production projects (Persson et al. [53]). However, such assessments have not yet been widely practiced in the arts. One possible reason for this is the difficulty to assess artistic processes due to their diversity, but another reason may be that artists lack awareness of (or worse, interest in) methods to assess the environmental impact of their practices and the resulting artworks. During the study, it became evident that to assess the full lifecycle of Ai art, it becomes important to draw boundaries in terms of what peripheral activities are to be included in an assessment. We also have to be mindful of how we draw these boundaries, as they may reflect our own preconceptions of what we as researchers think should be or should not be included in such processes.

In this paper, we simply addressed this problem by limiting the material scope to Ai technologies and accounting for the practices of the artists, but we find it important to highlight that measuring only the material aspects of an Ai artistic process is a reduction of the complexity of the problem of understanding the sustainability of Ai art. Artists are also working in dialogue with society, and their practices can have sustainability impacts on social and cultural levels. For example, their artwork can influence the behaviors of other artists or more widely the society (change the culture). In this way, Ai art could also have a positive sustainability impact

on a sociocultural level. Furthermore, cultural change is arguably one of the essential contributors to change towards sustainability. But it remains a challenge how to account for the various social and material factors, and if either one of them outweigh the other from a sustainability perspective in the context of Ai art? These questions should be studied further, and there is a wealth in future directions that can be pursued in the study of sustainability and Ai arts. Despite our critical view on reducing Ai art only to the material level, we would also like to highlight its importance - to have an understanding of how Ai art is situated within the *planetary limits and boundaries*, we need to develop knowledge on these material aspects.

5.1 The emerging Ai art ecosystem

When looking into the works of three Ai artists, we also became aware of aspects related to the Ai arts ecosystem. For example, we could identify potential sustainability issues related to the commercialization of Ai art concerning emerging technologies such as blockchain, cryptocurrencies, and non-fungible tokens (NFTs). An increasing number of Ai artists are exploring innovative high-tech pathways for selling (and reselling and reselling) their artworks - which in their turn will have environmental impacts. Whereas a "fair trade" art certificate [54] for artists who use NFTs and cryptocurrencies for their works indicates that a work of art has been produced in a socially sustainable manner, there are – to the best of our knowledge – no environmental sustainability certificates for Ai art. Such initiatives and technologies are constituent factors as emerging Ai art markets form. The value of art is co-created in society, and how more or less environmentally sustainable art is valued will be influenced by all relevant stakeholders. This highlights the importance of the socio-cultural landscape, mechanisms that concern Ai art practices, and how that landscape/ecosystem relates to matters of sustainability.

5.2 Artists' transparency

In our study, we found it challenging to gain insight into the stages of the process and the specific materials used in those stages since artists hardly provide any of this information in their portfolios. Most of them did not specify which hardware and software they had used, and they remained unclear about the existence of and the contribution of collaborators. Lack of such knowledge creates a challenge for assessing the environmental impact (and also social sustainability factors) of the artworks. On the other hand, considering transparency may also be in artists' interest in the context of the increasingly collaborative settings that seem to produce Ai art.

6 CONCLUSION

This study aimed to introduce the environmental sustainability of Ai art to the research agenda and propose methods and concepts to assess the environmental impact of Ai art. We have suggested that two key dimensions - materials and practices - can be used to approach this domain. We also discussed additional factors that could be relevant, as well as their interplay and relations to each other in the Ai artistic process. We lastly discussed some directions for future studies, including the lifecycle of an Ai artwork, the emerging Ai art ecosystem, and artists' transparency.

From an ecological sustainability point of view, we potentially need to break away from cultural values that assume "bigger is better". One pathway towards breaking away from these cultural values can be found from alternative aesthetics (including an appreciation of beautiful, efficient code [55–57] and from various movements that have worked with the notion that "small is possible" [58] and "small is beautiful" [59]. These approaches would for example include; appropriate technology ("about 'enoughness', robustness and sustainable living"), convivial computing ("as unpredictable, creative and lively as the people who use them"), permacomputing ("only does heavy computation if this saves resources elsewhere and uses automation to save humans from repetitive and time-consuming tasks"), small technology ("DIY-minded [...] often using limited CPU, memory, disk space and bandwidth by choice"), salvage computing ("with an eye to transforming what is exhausted and wasted into renewed resources") and low-tech ("techniques, technologies, services, and know-how that stick to three main principles: Useful. Accessible. Sustainable") [60]. Inspiration could naturally also come from Computing within Limits ("the design and development of computing systems in the abundant present for use in a future of limits"[10]). Other areas that could inspire for alternative, critical forms of Ai art that pay attention to resource use are slow tech [61, 62] and slow design [63, 64] - both tracing their way back to the slow food movement, manifesto and principles [65]. In terms of artistic sensibilities adapting and flourishing under harsh limits, we believe that contemporary Ai artists could also get inspiration from the (Nordic) demo scene of the 1980s and the 1990s [66–68] and from other artistic movements that have worked within self-imposed limits. We also think, that Ai artists from the global south can have a stake in developing these low-resource approaches to Ai art, and they should be actively included in the development of the field. However, many of the prominent Ai artists are located in the global north - including the ones we focused on in this case study.

Connecting back to the fundamental questions posed in the paper's introduction about the relationship between on the one hand sustainability and on the other hand Ai in general and Ai arts in particular, it is too early to draw any final conclusions. It is quite clear that in relation to non-Ai arts, Ai arts harbors the potential to "waste" immense amounts of resources (materials and energy) when applied on large scale. But also, it can be used to contribute in cultural change towards either saving or wasting resources. We believe these are perspectives on Ai art that few practitioners think about, but that they ought to. We hope that this paper elicits further interest in this direction. As to the question that we posed regarding whether Ai art could help us handle sustainability-related complex problems, the question is if art in general – including Ai art – could help us handle such problems? It could be that art, by having the potential to get people to reflect, think, and question anything and everything has a good chance to contribute to cultural change towards sustainability. But at the same time, the material costs of Ai art need to be addressed. Limiting the environmental footprint of Ai art would be a good first step in creating the credibility needed to convey critical and contrarian (and let's be honest, for the most

[10]From the 2017 Call for Papers for Computing within Limits, see further https://computingwithinlimits.org/2017/

part unwelcome) messages urging us to live *within* rather than to *exceed* the planetary limits/boundaries.

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REFERENCES

[1] T. R. Malthus, "An essay on the principle of population or a view of its past and present effects on human happiness, an inquiry into our prospects respecting the future removal or mitigation of the evils which it occasions," 1872.
[2] W. S. Jevons, "The coal question; an inquiry concerning the progress of the nation and the probable exhaustion of our coal-mines," 1865.
[3] P. Cafaro and E. Crist, *Life on the brink: environmentalists confront overpopulation*. University of Georgia Press, 2012.
[4] T. Jackson, *Prosperity without growth: Economics for a finite planet*. London, UK: Routledge, 2009.
[5] P. Mason, "Postcapitalism: A guide to our future," p. 365, 2015.
[6] B. McKibben, *Deep economy: the wealth of communities and the durable future*, 1st ed., ser. A Holt paperback. New York, NY: Times Books [u.a.], 2008.
[7] A. Bastani, "Fully automated luxury communism," 2019.
[8] G. Kallis, *Limits: Why Malthus was wrong and why environmentalists should care*. Stanford University Press, 2019.
[9] D. H. Meadows, J. Randers, and D. L. Meadows, "The limits to growth," in *The Future of Nature*. Yale University Press, 2013, pp. 101–116.
[10] W. R. Catton, *Overshoot: The ecological basis of revolutionary change*. University of Illinois Press, 1982.
[11] K. Raworth, *Doughnut economics: seven ways to think like a 21st-century economist*. Chelsea Green Publishing, 2017.
[12] J. Rockström, W. Steffen, K. Noone, F. S. C. Å. Persson, E. Lambin, and et al., "Planetary boundaries: exploring the safe operating space for humanity," *Ecology and society*, vol. 14, no. 2, 2009.
[13] H. W. J. Rittel and M. M. Webber, "Dilemmas in a general theory of planning," vol. 4, no. 2, pp. 155–169. [Online]. Available: https://doi.org/10.1007/BF01405730
[14] K. Levin, B. Cashore, S. Bernstein, and G. Auld, "Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change," vol. 45, no. 2, pp. 123–152. [Online]. Available: https://www.jstor.org/stable/41486859
[15] S. Makridakis, "The forthcoming Artificial Intelligence (AI) revolution: Its impact on society and firms," Apr. 2017.
[16] A. Bundy, "Preparing for the future of Artificial Intelligence," *AI & SOCIETY*, vol. 32, no. 2, pp. 285–287, May 2017. [Online]. Available: https://doi.org/10.1007/s00146-016-0685-0
[17] "The Week," *The Week.com*. [Online]. Available: https://theweek.com/speedreads/654463/google-more-than-1000-artificial-intelligence-projects-works
[18] "CBS News," *CBS News*. [Online]. Available: https://www.cbinsights.com/research/top-acquirers-ai-startups-ma-timeline/
[19] E. Morozov, *To save everything, click here: the folly of technological solutionism*. PublicAffairs.
[20] M. L. Minsky, *Future of AI Technology*, 1992.
[21] N. Turner Lee, "Detecting racial bias in algorithms and machine learning," *Journal of Information, Communication and Ethics in Society*, vol. 16, no. 3, pp. 252–260, Jan. 2018. [Online]. Available: https://doi.org/10.1108/JICES-06-2018-0056
[22] A. Howard and J. Borenstein, "The Ugly Truth About Ourselves and Our Robot Creations: The Problem of Bias and Social Inequity," *Science and Engineering Ethics*, vol. 24, no. 5, pp. 1521–1536, Oct. 2018. [Online]. Available: https://doi.org/10.1007/s11948-017-9975-2
[23] E. Strubell, A. Ganesh, and A. McCallum, "Energy and Policy Considerations for Deep Learning in NLP," in *arXiv:1906.02243 [cs]*, Jun. 2019, arXiv: 1906.02243. [Online]. Available: http://arxiv.org/abs/1906.02243
[24] A. Lacoste, A. Luccioni, V. Schmidt, and T. Dandres, "Quantifying the Carbon Emissions of Machine Learning," in *arXiv:1910.09700 [cs]*, Nov. 2019, arXiv: 1910.09700. [Online]. Available: http://arxiv.org/abs/1910.09700
[25] P. Dhar, "The carbon impact of artificial intelligence," in *Nature Machine Intelligence*, vol. 2, Aug. 2020, pp. 423–425. [Online]. Available: https://www.nature.com/articles/s42256-020-0219-9
[26] K. Devine, *Decomposed: the political ecology of music*. Cambridge, Massachusetts: The MIT Press, 2019.
[27] "AIArtists.org." [Online]. Available: https://aiartists.org
[28] "Creative AI.org." [Online]. Available: https://creative-ai.org
[29] "Udemy: AI Art Generation." [Online]. Available: https://www.udemy.com/course/complete-ai-art-generation/
[30] "Goldsmiths: Machine Learning for Musicians and Artists." [Online]. Available: https://www.kadenze.com/courses/machine-learning-for-musicians-and-artists/info
[31] "NVIDIA AI Art Gallery." [Online]. Available: https://www.nvidia.com/en-us/research/ai-art-gallery/
[32] "Daejeon Biennale 2020: A.I., Sunshine Misses Windows." [Online]. Available: https://www.daejeon.go.kr/
[33] "Somerset House Studios Residents." [Online]. Available: https://www.somersethouse.org.uk/residents/libby-heaney
[34] "Serpentine Galleries: Creative AI Lab." [Online]. Available: https://www.serpentinegalleries.org/whats-on/creative-ai-lab/
[35] "Los Angeles Philharmonic: WDCH Dreams." [Online]. Available: https://www.laphil.com/visit/when-youre-here/wdchdreams
[36] "LUMEN Prize." [Online]. Available: https://www.lumenprize.com/2019-winners/sougwen-chung
[37] "Ars Electronica: Artificial Intelligence & Life Art." [Online]. Available: https://ars.electronica.art/prix/en/categories/artificial-intelligence-life-art/
[38] "AIMC 2021 – 2nd Conference on AI Music Creativity." [Online]. Available: https://aimc2021.iem.at/
[39] "AI and Music Festival 2021 - 27.28 October 2021." [Online]. Available: https://aimusicfestival.eu/
[40] "University of Turku: LuotAI." [Online]. Available: https://sites.utu.fi/luotai/
[41] "King's College London." [Online]. Available: https://www.kcl.ac.uk/news/the-department-of-digital-humanities-and-the-serpentine-launch-creative-ai-lab-website
[42] "Wekinator." [Online]. Available: http://www.wekinator.org
[43] "creative-ai.org." [Online]. Available: https://creative-ai.org
[44] D. Kurt, "Artistic Creativity in Artificial Intelligence," Ph.D. dissertation, 2018.
[45] refikanadol.com. (Retrieved 1 Nov. 2021) refikanadol.com. [Online]. Available: "https://refikanadol.com/works/wdch-dreams/"
[46] S. Chung. Sougwen chung. [Online]. Available: "https://sougwen.com/project/exquisite-corpus"={Retrieved1Nov.2021},publisher={}
[47] R. Schwartz, J. Dodge, N. A. Smith, and O. Etzioni, "Green AI," in *Communications of the ACM*, vol. 63, Nov. 2020, pp. 54–63. [Online]. Available: https://doi.org/10.1145/3381831
[48] A.-L. Ligozat, J. Lefèvre, A. Bugeau, and J. Combaz, "Unraveling the hidden environmental impacts of AI solutions for environment," in *arXiv:2110.11822 [cs]*, Oct. 2021, arXiv: 2110.11822. [Online]. Available: http://arxiv.org/abs/2110.11822
[49] E. Jang, M. Johnson, E. Burnell, and K. Heimerl, "Unplanned Obsolescence: Hardware and Software After Collapse," in *Proceedings of the 2017 Workshop on Computing Within Limits*, ser. LIMITS '17. Santa Barbara, California, USA: Association for Computing Machinery, Jun. 2017, pp. 93–101. [Online]. Available: https://doi.org/10.1145/3080556.3080566
[50] L. M. Hilty and B. Aebischer, "ICT for sustainability: An emerging research field," *ICT innovations for Sustainability*, pp. 3–36, 2015.
[51] S. Lange and T. Santarius, *Smart green world? Making digitalization work for sustainability*. Basel, Switzerland: Springer International Publishing, 2020.
[52] M. Botella, F. Zenasni, and T. Lubart, "What are the stages of the creative process? what visual art students are saying." *Frontiers in Psychology*, vol. 9, p. 2266. [Online]. Available: https://www.frontiersin.org/article/10.3389/fpsyg.2018.02266
[53] L. Persson, K. Lagercrantz, and A. Björklund, "The climate footprint of the project climate-just worldings : Report of the life cycle asessment of the project climate-just worldings," *Stockholm: Stockholm konstnärliga högskol*, 2021.
[54] Verisart, "verisart: Fair trade art certificate," https://verisart.com/fair-trade-art, Retrieved 1 Apr 2022.
[55] S. Levy, *Hackers: Heroes of the computer revolution*, vol 14 ed. Garden City, NY: Anchor Press/Doubleday, 1984.
[56] D. E. Knuth, "Computer programming as an art," *Communications of the ACM 17 (12)*, pp. 667–673, 1974.
[57] E. Piñeiro, "The aesthetics of code: on excellence in instrumental action," Ph.D. dissertation, 2003.
[58] L. Estill, *Small is possible: Life in a local economy*. New Society Publishers, 2008.
[59] E. F. Schumacher, *Small is beautiful: A study of economics as if people mattered*. Random House, 2011 (original 1973).
[60] M. De Valk, "A pluriverse of local worlds: a review of computing within limits related terminology and practices," in *In LIMITS Workshop on Computing within Limits*, 2021.
[61] L. Hallnäs and J. Redström, "Slow technology–designing for reflection," *Personal and ubiquitous computing*, no. 5, pp. 201–212, 2001.
[62] N. Patrignani and D. Whitehouse, "Slow tech: a quest for good, clean and fair ICT," *Journal of Information, Communication and Ethics in Society*, 2014.
[63] C. Strauss and F.-L. Alastair, "The slow design principles," in *Proceedings of the Changing the Change 14*, 2008.
[64] B. Grosse-Hering, J. Mason, D. Aliakseyeu, C. Bakker, and P. Desmet, "Slow design for meaningful interactions," in *In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2013, pp. 3431–3440.
[65] C. Petrini, *Slow food*. Columbia University Press, 2003.

[66] N. B. Hansen, R. T. Nørgård, and K. Halskov, "Crafting code at the demo-scene," in *In Proceedings of the 2014 conference on Designing interactive systems*, 2014, pp. 35–38.
[67] G. Borzyskowski, "The hacker demo scene and its cultural artefacts," in *In Cybermind Conference*, 1996, pp. 1–23.
[68] V. Scheib, T. Engell-Nielsen, S. Lehtinen, E. Haines, and P. Taylor, "The demo scene," in *In ACM SIGGRAPH 2002 conference abstracts and applications*, 2002, pp. 96–97.