# *THE PHYSICALITY OF AI AND ITS MEANING FOR SUSTAINABLE AI*

## A Discussion of Sustainable AI for Sustainable Fashion and how to Approach it

Master Thesis
Melissa-Kim Petrasch
20th of September 2022

Master Philosophy of Science, Technology and Society
University of Twente, Faculty of Behavioural, Management and Social Sciences (BMS)
Enschede, the Netherlands

First Supervisor: Dr. Alexandria Poole
Second Supervisor: Prof. Dr. Fokko Jan Dijksterhuis

# Abstract

Artificial Intelligence (AI) is often perceived and portrayed as a magical solution to all problems, including climate change, due to its ability to work more efficiently and quickly than most humans. For industries such as fashion, which have a significant environmental impact, AIs are potential tools to achieve more sustainable practices. But the portrayal of AI as having minimal environmental impacts ignores the necessary infrastructure, its physicality, which can negatively affect the environment and people. To ensure AIs are not detrimental to these goals it is important to define sustainable AI for specific contexts.

The primary goal of this thesis is to find a definition of sustainable AI in the context of sustainable fashion (SF) and to provide a possible approach for the decision-making about sustainable AIs and their development. Through the discussion of relevant concepts such as sustainability, AI, and the hidden impact of AIs, which was termed physicality, a definition of sustainable AI for SF was developed. This definition consists of six principles which together with Fleddermann's line drawings form the basis for the suggested approach to sustainable AI.

The analysis showed the importance of reconnecting AI with its physicality for the discussion of sustainability. Without acknowledging the physicality of AI, a significant part of AI's sustainability implications is ignored. Ignoring these impacts could lead to problems in the future and might undermine sustainability goals. The thesis provides an ideal definition of what sustainable AI for SF could be, consisting of six principles, which take AI's physicality into account. This ensures an AI is sustainable in its entirety if it adheres to the definition. The proposed design tool supports the development of sustainable AI by visualizing the sustainability of different solutions and making it comparable.

# Acknowledgements

The last few months, of working on this thesis were a challenge, which I could only master thanks to the help of many people.

I would like to thank Dr. Pak-Hang Wong, who inspired me to take on this topic. Furthermore, I would like to thank my first supervisor Dr. Alexandria Poole who supported me with valuable feedback on my many ideas and throughout the administrative troubles. On that note, I would also like to thank Dr. Michael Nagenborg for taking on the role of a mediator and helping to resolve these troubles. Furthermore, I would like to thank my second supervisor Prof. Dr. Fokko Jan Dijksterhuis for providing important feedback during the final stretch and sharing your enthusiasm and I would like to thank Bruno Endres Forlin, for explaining computers to me.

Finally, I would like to thank my friends and family who supported me throughout the whole process. Thank you for listening to my monologoues and offering your insights. Thank you for proofreading and boosting my confidence in my work and its relevancy. And most importantly, thank you for supporting me without any questions and being there when I needed you.

# Table of Contents

# Glossary

| | |
|---|---|
| A & M | Agriculture and animal husbandry, processing and manufacturing industry |
| AI | Artificial Intelligence |
| CPU | Central Processing Unit |
| DS | Data Science |
| E & C | Energy and chemical industry |
| GPU | Graphics Processing Unit |
| ICT | Information and Communication Technology |
| IOL | International Labor Organization |
| ML | Machine Learning |
| NLP | Natural Language Processor |
| PUE | Power Usage Effectiveness |
| R&D | Research and Development |
| RE | Rare earths |
| SDGs | (UN) Sustainable Development Goals |
| SF | Sustainable Fashion |
| SR | Supply Risk |
| TPU | Tensor Processing Unit |

# Introduction: The Problem of AIs as the Solutions to Fashion's Sustainability Problems

At the beginning of 2022, the Intergovernmental Panel on Climate Change (IPCC) published a new report. This report is the result of a collaboration between researchers and decision-makers from all over the world. It emphasises that climate change is real and only a drastic reduction in carbon emissions can mitigate global warming.[1] Part of the emission problem are industries such as fashion. To mitigate the problem drastic changes are necessary. Some companies and researchers consider Artificial Intelligence (AI) as possible mitigation tool.[2]

The fashion industry is consistently growing. Between 2000 and 2014 the number of garments purchased per capita increased by 60% and in 2014 alone over 100 billion garments were produced.[3] This rapid growth is possible due to innovations in garment production, which dramatically shortened the fashion cycle and reduced costs per item, creating a fast fashion market.[4] Clothing production has always been resource intensive, but the increased scale has further intensified it. In 2015 the fashion industry was estimated to have produced 1714 million tonnes of carbon emissions which is estimated to increase to 3030 million tonnes by 2025. The water use is estimated to rise from 141 million to 170 million cubic meters and the land use will go up to 41 million hectares, which is an increase of 7%.[5] In total, the fashion industry is estimated to produce 10% of global greenhouse gases and 20% of global wastewater.[6] Next to environmental issues, the fashion industry is also critiqued due to its poor treatment of labourers.[7]

---

[1] "The IPCC Climate Change 2022 Impacts Report: Why It Matters," National Oceanic and Atmospheric Administration, accessed August 25, 2022, https://www.noaa.gov/stories/ipcc-climate-change-2022-impacts-report-why-it-matters.
[2] "Taking Sustainable Fashion to a New Level with Tech," June 2, 2021, https://hmgroup.com/our-stories/taking-sustainable-fashion-to-a-new-level-with-tech/. This article provides insights into H&M's plans to use AI and other digital technologies to improve its sustainability; Ricardo Vinuesa et al., "The Role of Artificial Intelligence in Achieving the Sustainable Development Goals," *Nature Communications* 11, no. 1 (2020), https://doi.org/10.1038/s41467-019-14108-y. In this paper, Vinuesa and colleagues assess the possible impact of AIs on the sustainable development goals. They find that many goals could be positively affected.
[3] Nathalie Remy, Eveline Speelman, and Steven Swartz, "Style That's Sustainable: A New Fast-Fashion Formula," October 20, 2016, https://www.mckinsey.com/business-functions/sustainability/our-insights/style-thats-sustainable-a-new-fast-fashion-formula.
[4] Deborah Drew and Genevieve Yehounme, "The Apparel Industry's Environmental Impact in 6 Graphics," July 5, 2017, https://www.wri.org/insights/apparel-industrys-environmental-impact-6-graphics.
[5] Remy, Speelman & Swartz, "Style That's Sustainable: A New Fast-Fashion Formula,"
[6] "UN Helps Fashion Industry Shift to Low Carbon," September 6, 2018, https://unfccc.int/news/un-helps-fashion-industry-shift-to-low-carbon.
[7] "New Website Puts the Fashion Industry's Low Wages in the Spotlight, Accelerating the Campaign for Living Wages.," June 22, 2020, https://cleanclothes.org/news/2020/fashion-checker.

While AI at first glance seems to be a great solution with little negative environmental impact this does not reflect the reality. AIs are not Perpetuum Mobile. They consistently require energy and data to work. One aspect that is easily overlooked is the carbon footprint of AIs. An AI needs to be trained and run on a server, which is usually done in large data centres. These data centres alone account for roughly 1% of the global electricity demand and will continue to be large energy consumers.[8] To date, the expected steep incline in energy demand has been prevented through the use of more efficient equipment.[9] But the rising demand for digital technologies could outpace the technological improvements in the future, resulting in a significant increase in energy needs.

Next to energy consumption, AIs have further sustainability implications in form of resource use for data centres and the need for cheap labour. Nathan Ensmenger sketches out the life cycle of digital technologies. He discusses the required resources and their impact on the environment and people during sourcing, production, and the end of their life.[10] While the connection between a computer and the sourcing of lithium is relatively clear, the link between buying a, by an algorithm-recommended, dress online and the working conditions of people labelling datasets is more obscure. There is a disconnect between the physical and social impact of AIs and how they are perceived. Both energy use and the often precarious working conditions under which resources, such as rare earths and datasets, are mined or created are hidden from the user and rarely discussed.[11]

Sustainability and ethical practices of a company have become important factors in the decision process of customers.[12] In recent years companies have initiated sustainability campaigns and published sustainability reports. As a big industry player, H&M is at the forefront of this development, providing a sustainability report every year, pledging to move to a circular economy and achieving the net-zero standard in 2030.[13] To do this, the company heavily relies on innovation such as AI applications.[14] An AI called Movebox, for example, is

---

[8] George Kamiya, "Data Centres and Data Transmission Networks – Analysis," IEA, November 1, 2021, https://www.iea.org/reports/data-centres-and-data-transmission-networks.; Gary Cook et al., "'Clicking Clean: Who Is Winning the Race to Build a Green Internet?". Washington, 2017." (Washington, D.C.: Greenpeace Inc., 2017).
[9] George Kamiya, "Data Centres and Data Transmission Networks – Analysis,"
[10] Nathan Ensmenger, "The Environmental History of Computing," *Technology and Culture* 59, no. 4S (2018): pp. 7-33, https://doi.org/10.1353/tech.2018.0148.
[11] Kate Crawford, *Atlas of AI Power, Politics, and the Planetary Costs of Artificial Intelligence* (New Haven, Conn: Yale University Press, 2021), chap. TWO. Labor.
[12] Anna Granskog et al., "Survey: Consumer Sentiment on Sustainability In Fashion," McKinsey & Company (McKinsey & Company, July 17, 202AD), https://www.mckinsey.com/industries/retail/our-insights/survey-consumer-sentiment-on-sustainability-in-fashion.
[13] H&M Group, "H&M Group Sustainability Disclosure," 2022, pp. 1-74.
[14] "Taking Sustainable Fashion to a New Level with Tech," June 2, 2021, https://hmgroup.com/our-stories/taking-sustainable-fashion-to-a-new-level-with-tech/.

supposed to reduce overproduction by redirecting returns to locations with high demand for the item. Reducing overproduction is an integral factor in increasing the sustainability of H&M, as deadstock is an economic problem for the company and the waste and carbon emissions produced during production are a problem for the environment. Racheal Dottle and Jackie Gu estimate that H&M has unsold inventory worth $ 4.3 billion, based on their quarterly reports.[15] However, the progress toward more sustainable practices within H&M might be undermined, if the used AI is inherently unsustainable. Using carbon-emission-heavy AIs to reduce their own carbon emissions will only move the problem out of sight of the customers. I propose that, since there is currently a disconnect between AIs and their physical form people in the field might overlook topics which are important for the development of sustainable AIs.

This leads to my research questions, (i) what should sustainable AI be in the context of sustainable fashion (SF) and (ii) how could a development approach for sustainable AI for SF look like? To answer these research questions, it is important to understand the involved concepts. Both AI and sustainability tend to be fuzzy concepts which are defined in a variety of ways. Thus, chapter one provides a brief overview of both sustainability and AI definitions as well as a discussion of SF and AI applications in the fashion industry. To illustrate the conception of SF and the approach to AI by some fashion companies, I will explore the leading fashion corporation, H&M, and their approach to fashion topics as an example for analysis. H&M was chosen as an example for analysis because they provide extensive documentation about their sustainability approach. Chapter two then elaborates on how the discussion of AI as almost magical is disconnected from the physicality of AI and provides an overview what the physicality of AI entails. Chapter three provides a definition of sustainable AI for sustainable fashion in the form of six principles. The definition is based on findings from chapter one and a discussion of current literature on the topic of sustainable AI. The fourth chapter provides insights into how sustainable AI for SF could be developed and provides a design tool inspired by Charles Fleddermann's line drawings. Additionally, the chapter contributes an overview of how to calculate the carbon footprint and some practical tips on how to decrease it. Finally, the chapter offers an example of how the definition of sustainable AI for sustainable fashion and the suggested approach could be used.

[15] Rachael Dottle and Jackie Gu, "The Global Glut of Clothing Is an Environmental Crisis," February 23, 2022, https://www.bloomberg.com/graphics/2022-fashion-industry-environmental-impact/.

# Chapter One: Defining Important Basics

## 1. Clarifying the Fuzzy Term of Sustainability and Relating it to Fashion

### 1.1. Finding the Meaning of Sustainability

Sustainability and sustainable development have become buzzwords over the last decades. Groups such as 'Fridays for Future' or the 'Extinction Rebellion' have emphasised the importance of sustainability as a guiding principle to address the increasing threat climate change poses to human life. Governmental institutions and political unions, such as the UN, recognize the importance of concepts such as sustainability and sustainable development (SD) for building a desirable future as well. This is reflected in policies, declarations, and resolutions such as the SDGs or the Paris Agreement.[16] Sustainable development appears to be an integral part of solutions to mitigate current problems.[17] Although the terms are used widely there is little agreement about their definitions.[18] The discourse of sustainability takes place in a variety of fields with different goals. This impacts the conception of sustainability and sustainable development. In this section, I will provide a brief overview of definitions and relevant terms that will guide the process of finding a suitable definition of sustainable AI for sustainable Fashion (SF).

*1.1.1 Sustainability or Sustainable Development*

The terms sustainability and SD are often used interchangeably, even in academic literature. But, strictly speaking, they are two distinct terms. While sustainability refers to the state that should be achieved, sustainable development describes the process to get there.[19] According to Dale Jamieson, the use of the term sustainability instead of sustainable development was an attempt to leave the tensions surrounding SD behind. Sustainable Development allows emphasising different aspects of the concept to fit specific goals.[20] For example, when emphasising development for poverty relief, environmental concerns can be traded off more easily. The possibility of this trade-off resulted in tension between environmentalists and

[16] United Nations, "The 17 Goals | Sustainable Development," (United Nations), accessed March 1, 2022, https://sdgs.un.org/goals.
[17] Justice Mensah, "Sustainable Development: Meaning, History, Principles, Pillars, and Implications for Human Action: Literature Review," *Cogent Social Sciences* 5, no. 1 (2019): pp. 1-21, https://doi.org/10.1080/23311886.2019.1653531.
[18] Robert O. Vos, "Defining Sustainability: A Conceptual Orientation," *Journal of Chemical Technology & Biotechnology* 82, no. 4 (2007): pp. 334-339, https://doi.org/10.1002/jctb.1675.
[19] Mensah, "Sustainable Development."
[20] Dale, Jamieson "Sustainability and Beyond," *Ecological Economics* 24 (1998): pp. 183-192.

economists using the term. In the following discussion, I will only distinguish between sustainability and sustainable development as used by the authors. I will summarise shared characteristics and discuss complementary aspects next to each other. Throughout the rest of the report, I will mainly use the term sustainability to refer to the concepts discussed here.

*1.1.2. Defining Sustainable Development and Sustainability*

Many of the currently used sustainability concepts date back to the 1980s and 1990s. Although widely used there is little consensus on their exact meaning.[21] Sustainable development literally describes a development that can be sustained either indefinitely or over a specified time.[22] Similarly, sustainability means sustaining something over time.[23] Sustain as the basis of sustainability can be interpreted in two ways, either as sustenance which is concerned with meeting the needs of the present, or as maintaining something in existence which is related to preservation and the interests of the future.[24]

Generally, definitions of sustainability or sustainable development are rather imprecise and sometimes misused.[25] This impreciseness is simultaneously disadvantageous and advantageous.[26] While a clear understanding of the meaning is essential to a successful implementation, the fuzziness of the concepts allows communication across fields.[27] Depending on the angle someone takes the exact definition can differ. But in general, most definitions of SD aim at systematically integrating environmental, social, and economic concerns into decision-making processes.[28] Sustainability is understood slightly differently, as most people understand it to be concerned with human survivability and avoiding ecological disasters.[29]

Probably the most influential definition of sustainable development can be found in the 'Our Common Future' report by the World Commission on Environment and Development, often referred to as the Brundtland report. In it, the commission stated: 'Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.'[30] Especially the latter

---

[21] Vos, "Defining Sustainability."
[22] Mensah, "Sustainable Development."
[23] Wilfred Beckerman, "'Sustainable Development': Is It a Useful Concept?," *Environmental Values* 3, no. 3 (1994): pp. 191-209, https://doi.org/10.3197/096327194776679700.
[24] Jamieson "Sustainability and Beyond."
[25] Jeffry L. Ramsey, "Defining Sustainability," *Journal of Agricultural and Environmental Ethics* 27, no. 6 (2014): pp. 1049-1054, https://doi.org/10.1007/s10806-014-9514-y.
[26] Vos, "Defining Sustainability"; Jamieson "Sustainability and Beyond."
[27] Mensah, "Sustainable Development."
[28] "ibid"
[29] Jamieson "Sustainability and Beyond."
[30] World Commission on Environment and Development, "'Our Common Future,'" 1987, p. 24.

half of this statement is used as the definition of sustainability and is referenced regularly.[31] The UN furthered its sustainable development plans in subsequent agendas such as the 'Agenda 2030' which has the UN Sustainable Development Goals (SDGs) at its core. These 17 goals further specify the vision of sustainability held by the UN, breaking it down into smaller specific topics and goals.[32]

Many authors argue that sustainable development rests on three pillars, which are also reflected in the definition of the Brundtland report. To achieve sustainability, it is necessary to approach economic, social, and environmental sustainability holistically.[33] Special emphasis is often placed on present and intergenerational equity.[34] More recently, researchers and organisations have begun to argue for the inclusion of a fourth pillar, to better reflect the complexity of society.[35] The United City and Local Governments committee (UCLG), for example, suggests using culture as the fourth pillar.[36] Next to culture, or cultural-aesthetic, as the fourth pillar, researchers have suggested a political-institutional or religious-spiritual perspective.[37] Gemma Burford and her colleagues suggest, instead of choosing one of the three to use ethical values as fourth pillar, as it provides some common ground between the three fields and is more flexible.[38]

Beyond these core elements, authors seem to disagree about what should be included. The economist Justice Mensah has identified several additional principles in the literature on sustainable development: conservation of the ecosystem, population control, proper human resource management, and a participatory process. Of these key principles, the idea of a necessary participatory process is shared by Andrew Dobson, Michael Jacobs and Rajni Kothari. Dobson and Jacobs also consider futurity and quality of life as additional core ideas.

---

[31] Vos, "Defining Sustainability:,"; Mensah, "Sustainable Development."; Patricia Ikouta Mazza, "Concepts of Sustainable Development; a Literature Review and a Systematic Framework for Connecting the Role of Education with the Sustainable Development Goals (SDGs).," *International Journal of Humanities, Social Sciences and Education* 8, no. 8 (2021): pp. 106-112, https://doi.org/10.20431/2349-0381.0808009.

[32] United Nations, "The 17 Goals | Sustainable Development."

[33] Vos, "Defining Sustainability."; Mensah, "Sustainable Development."; Rajni Kothari, "Environment, Technology, and Ethics," in *Reflecting on Nature. Readings in Environmental* Philosophy, ed. Luri Gruen and Dale Jamieson, 1st ed. (Oxford University Press, 1994), pp. 228-237.; Mazza, "Concepts of Sustainable Development."; Leslie Paul Thiele, Sustainabiltiy (Polity Press, 2013).

[34] Vos, "Defining Sustainability."; Mensah, "Sustainable Development."; Rajni Kothari, "Environment, Technology."; Andrew Dobson and Michael Jacobs, "Sustainable Development as a Contested Concept," in *Fairness and Futurity: Essays on Environmental Sustainability and Social Justice* (Oxford: Oxford University Press, 1994), pp. 21-45.

[35] UCLG (United Cities and Global Governance), 'Culture: fourth pillar of sustain- able development,' policy document, (2010) Available at: http://www.agenda21culture. net/sites/default/files/files/documents/en/zz_culture4pillarsd_eng.pdf (accessed 10. September 2022).; Gemma Burford et al., "Bringing the 'Missing Pillar' into Sustainable Development Goals: Towards Intersubjective Values-Based Indicators," *Sustainability* 5, no. 7 (December 2013): pp. 3035-3059, https://doi.org/10.3390/su5073035, p. 3036.

[36] UCLG, 'Culture.'

[37] Burford et al., "Bringing the 'Missing Pillar'," pp. 3036.

[38] "ibid," p. 3038.

Robert Vos further requires sustainability to go beyond mere compliance with existing regulations. Although the core elements overlap, it is not possible to maximize all of them at the same time. For example, it is impossible to maximize the economy without negatively affecting the environment therefore, it is necessary to find compromises which is difficult on a global scale and long term.

Intergenerational equity has become a focal point of some definitions. But again, there are distinctions in how it should be quantified. Some definitions consider the ability to fulfil needs as a measure, while others discuss sustainability in terms of welfare, and still others consider the mixture of opportunities and constraints encountered by future generations as a benchmark.[39]

Instead of identifying core elements, one could also assess the different dimensions of sustainability. The environmental ethics researchers John A. Vucetich and Michael Paul Nelson, for example, identified the following four dimensions: developing technologies and markets to meet human needs, understanding the ecosystem, understanding how exploitation affects human cultures and understanding the meaning of used normative concepts.[40] In their opinion, the last, the ethical dimension, has been neglected which is a problem in defining sustainability as sustainability should combine science and ethics. They consider it essential to develop the ethical dimension to avoid vastly different interpretations.[41] Implementing the fourth pillar into sustainability definitions could achieve this.

### *1.1.3. Weak vs. Strong Sustainability and similar Distinctions*

It is possible to distinguish two interpretations of sustainability, usually termed strong sustainability (ss) and weak sustainability (ws). Weak sustainability focuses on well-being and is more likely to be embraced by economists.[42] Furthermore, a weak interpretation often considers manmade and natural capital as substitutes, only requiring the total capital to be maintained.[43] Strong sustainability on the other hand is focused on the maintenance of natural

---

[39] Herman E Daly, "On Wilfred Beckerman's Critique of Sustainable Development," *Environmental Values* 4, no. 1 (1995): pp. 49-55, https://doi.org/doi.org/10.3197/096327195776679583.; Michael Boylan and Brian G Norton, "Sustainability and Adaptation: Environmental Values and the Future," in *Environmental Ethics*, 2nd ed. (John Wiley & Sons, 2022), pp. 358-370.; Michael Boylan and Randall Curren, "Sustainability: What It Is and How It Works Defining Sustainability Ethics," in *Environmental Ethics*, 2nd ed. (John Wiley & Sons, 2014), pp. 331-345.
[40] John A. Vucetich and Michael P. Nelson, "Sustainability: Virtuous or Vulgar?," *BioScience* 60, no. 7 (2010): pp. 539-544, https://doi.org/10.1525/bio.2010.60.7.9, p. 539.
[41] "ibid," p. 541.
[42] Jamieson "Sustainability and Beyond," p. 184.
[43] Daly, "On Wilfred Beckerman's," p.49.

capital.[44] Wilfred Beckerman argues that in a strong conception manmade and natural capital are complements and both need to be maintained separately. While Hermann Daly disagrees with Beckerman's interpretation, Jamieson argues that this claim is to be understood as normative instead of descriptive.[45]

Jamieson (1995) criticises both weak and strong sustainability as insufficient. Weak sustainability lacks a clear reference to environmental goods. Furthermore, there is little to object against declines in well-being as long as the optimal path is pursued. Additionally, it could be rejected that ws is characterised in terms of welfare instead of resources.[46] Similarly, Beckerman considers ws as redundant, as it can be replaced with welfare. Strong sustainability requires a distinction between manmade and natural capital, which is difficult as natural capital is required to produce manmade capital.[47] Beckerman sees the strong conception as morally repugnant, since not diminishing natural capital is especially detrimental to already vulnerable groups.[48] Solutions which do not rely on natural resources, such as oil, for example, are likely to be expensive, making them unattainable for the poor.

Depending on the viewpoint and focus other distinctions are possible too. Vucetich & Nelson focus on the ethical dimension of sustainability. Thus, they distinguish between vulgar and virtuous sustainability. In this case vulgar could be compared to weak sustainability and virtuous to strong sustainability. The chosen terms imply a stronger value judgement and focus on ethical concerns than weak and strong.

Vos on the other hand defines sustainability as either thick or thin against the dominant paradigm (DP). For example, the understanding of economic growth does not know a limit in the DP, while thin sustainability emphasises a win-win relationship and a thick version would require growth to slow and reverse.[49] The understanding of sustainability as thin or thick allows sustainability to be seen on a spectrum it is not either of the extremes but can be thinner or thicker. This flexibility could be beneficial in defining sustainability in a company context as, a company might be better at adhering to thick sustainability in one aspect and to a thinner understanding in another.

---

[44] Jamieson "Sustainability and Beyond," p. 185.
[45] Jamieson "Sustainability and Beyond."
[46] "ibid."
[47] "ibid."
[48] Beckerman, "'Sustainable Development'."
[49] Vos, "Defining Sustainability."

*1.1.4. Shortcomings of Sustainability Definitions*

Although sustainability and sustainable development are generally seen as positive and important concepts they are not without critique. A general criticism of sustainable development is the incorrect privileging of growth in many conceptualisations.[50] Furthermore, sustainable development is often underdefined which can cause, among others, miscommunication.[51] Another problem is the use of contested concepts such as interconnectedness without reflection and clarification.[52] Some definitions also lack consideration for the ethical dimension.[53] On the other hand, Beckerman considers sustainable development flawed for mixing the technical characteristics of a particular development path with a moral injunction that should be pursued.

More specific critiques target for example the concept of sustainability as the welfare of future generations. This definition is logically redundant as sustainability can then be replaced by welfare.[54] Furthermore, it is not possible to pass on welfare. It is only possible to pass on the physical requirements to guarantee the capacity to produce welfare.[55] Kothari specifically criticised the Brundtland report for falsely promising "underdeveloped" countries that they can achieve the same living standard as the West without further destroying the environment, although the wasteful lifestyle practised by the West is the root of all problems addressed by sustainability.[56]

*1.1.5. Tips and Tricks for Better Sustainability Definitions*

The discussion and critique of current sustainability and sustainable development definitions provide suggestions for more suitable definitions. While many academics try to define sustainability and SD in a general, overarching way these definitions appear to be unfit for easy, practical applications. Authors such as Jamieson, Vos, Thiele, and Norton point out that the use of sustainability concepts is more effective when applied to very specific contexts and phrased negatively than when applied to its intended, global context. Defining what is unsustainable in a specific situation is easier to define and understand, than trying to describe a sustainable action for the same situation.[57] Taking this into account, creating specific, action-oriented definitions

---

[50] Ramsey, "Defining Sustainability."
[51] Beckerman, "'Sustainable Development."
[52] Ramsey, "Defining Sustainability."
[53] Vucetich and Nelson, "Sustainability: Virtuous or Vulgar?."
[54] Beckerman, "'Sustainable Development'."
[55] Daly, "On Wilfred Beckerman's."
[56] Rajni Kothari, "Environment, Technology."
[57] Jamieson "Sustainability and Beyond."

of sustainability for global companies might be a way to bridge the gap between academics and practitioners.

Taking a pluralistic view in regard to the specific values supporting a conception of sustainability avoids categorical discussions and leads to more environmental protection, as the why is of lesser importance.[58] Furthermore, taking an environmental pragmatist stance can also avoid theoretical issues as it is problem-focused and forward-looking.[59]

Kothari suggests understanding the adoption of sustainable development as an ethical shift rather than a technological fix.[60] This includes valuing nature for itself and not its functional properties. Taking such a position allows for the critical assessment of technologies and their role in achieving sustainability.

## 1.2. Making Sustainability Fashionable

The definition of sustainable fashion (SF) is similarly fuzzy as the definition of sustainability itself. In papers on SF, the focus is often more on how it should be translated into action than on providing a definition.[61] It appears that often a pragmatic approach is taken, which can avoid some difficulties encountered when defining sustainability. The focus on what needs to change instead of discussing overarching values allows companies to identify opportunities for improvement more easily. The goals are, more or less, spelt out and the companies can choose which to tackle first. But the variety of explicit and implicit definitions of sustainability used by experts and companies also causes difficulties in the debate. Participants tend to assume a common understanding of the materials which is not given due to the fuzzy nature of sustainability.[62]

Some authors define SF by providing a definition of sustainability which is then applied to the fashion context. Kate Fletcher, for example, defines sustainability as integrating human well-being and natural integrity.[63] This covers both social and environmental sustainability as well as ethical values. Carolina Obregón extends this simple definition by focusing on the ethical and responsible harnessing of resources without threatening social and ecological

---

58 Boylan and Norton, "Sustainability and Adaptation."
59 "ibid"
60 Rajni Kothari, "Environment, Technology, and Ethics."
61 Claudia E. Henninger, Panayiota J. Alevizou, and Caroline J. Oates, "What Is Sustainable Fashion?," *Journal of Fashion Marketing and Management: An International Journal* 20, no. 4 (2016): pp. 400-416, https://doi.org/10.1108/jfmm-07-2015-0052, p.410. provides requirements such as the need to use raw materialsor local sourcing; Obregón, Carolina. "Sustainable Fashion: from Trend to Paradigm," (Master Thesis, Aalto University, 2012)), p.23. According to her SF strongly relates to green machine processes, repair and social business practices and a new way of viwing and living fashion
62 Sara Greco and Barbara De Cock, "Argumentative Misalignments in the Controversy Surrounding Fashion Sustainability," *Journal of Pragmatics* 174 (2020): pp. 55-67, https://doi.org/10.1016/j.pragma.2020.12.019, p. 58, 65.
63 Kate Fletcher, "Sustainable Fashion and Textiles: Design Journeys," in *Sustainable Fashion and Textiles: Design Journeys*, 2nd ed. (London: Routledge Taylor & Francis Group, 2014), pp. 1-4, p. 1.

balance.[64] She then suggests that sustainable fashion translates these basic values into the choice of materials, fairer employment models, efficient processing techniques, empowering community projects, and green design concepts. These translations could also be understood as approaches to SF.

Very generally speaking SF is used to describe clothing or fashion-related behaviours which are less damaging to people and the planet.[65] Claudia Henninger and her team found, in a survey of four British sustainable fashion producers, that SF is mainly associated with environmental sustainability, such as the use of renewable and eco-friendly materials and the reduction of carbon footprints.[66] Fair wages, safety measures, and labour rights are the top concerns regarding social aspects and are considered in many definitions and approaches.[67] In their interviews, Henninger et al. found a number of underlying principles within the individual definitions of the participants. They found that most definitions include local sourcing and production, which is linked to good labour conditions, fair wages and a reduced carbon footprint. Furthermore, transparency across the supply chain, traceability of work processes, eco-friendly (raw) materials, and consideration of social aspects, such as working conditions and fair wages, come up in most personal definitions.[68]

While there is no simple truth about how to make things better or right, there are different approaches to improving the current situation.[69] One recurring theme is to consider the whole cycle (sourcing, manufacturing, logistics, retail, product use, disposal, and behaviour patterns created by the product) instead of only one aspect.[70] Throughout all these stages a variety of approaches could mitigate sustainability issues.

In a meta-narrative systematic literature review of SF literature in the management field, Amira Mukendi, Iain Davies, Sarah Glozer, and Pierre McDonagh found the following means to improve the sustainability of a garment or behaviour.[71] According to Mukendi and her team

---

[64] Obregón, "Sustainable Fashion," p. 23.
[65] Amira Mukendi et al., "Sustainable Fashion: Current and Future Research Directions," *European Journal of Marketing* 54, no. 11 (2020): pp. 2873-2909, https://doi.org/10.1108/ejm-02-2019-0132, 2873.
[66] Claudia E. Henninger, Panayiota J. Alevizou, and Caroline J. Oates, "What Is Sustainable Fashion?," *Journal of Fashion Marketing and Management: An International Journal* 20, no. 4 (2016): pp. 400-416, https://doi.org/10.1108/jfmm-07-2015-0052.
[67] "ibid"
[68] "ibid", p. 410.
[69] Kirsi Niinimäki, "Ethical Foundations in Sustainable Fashion," *Textiles and Clothing Sustainability* 1, no. 1 (2015), https://doi.org/10.1186/s40689-015-0002-1.
[70] Carolina Obregón "Sustainable Fashion."; Niinimäki Kirsi, "Tenents of Sustainable Fashion," in *Sustainable Fashion: New Approaches* (Helsinki, Finland: Aalto University, 2013), pp. 12-29.
[71] Behaviour is a broad term which was not further defined by either Mukendi et al., Obregón or Niinimäki. It probably relates to consumption behaviours and how the garments are treated. For example, some garments can be easily fixed or are naturally sturdier while others break more easily or are harder to fix so people throw them away earlier. Similarly, very trendy pieces go out of style quickly and end up in the bin even though they are still functional.

environmental, social, cruelty-free, and anti-consumptionist (production) practices could improve the sustainability of fashion as well as slow fashion, reuse, and recycling practices. Other specific actions to achieve sustainability are the attempt to develop green industrial machine processes and changing business practices by reconceptualising how living, especially garment consumption, is practised.[72] When choosing the right approach, it should be considered what is right for the ecosystem, societies and communities on a system level, how human health issues will be affected, and how resources can be used sustainably.[73]

The various approaches mentioned above can be categorized into two groups. Mukendi and her colleagues found that approaches can be pragmatic which includes incremental changes relying on already established systems. Kate Fletcher calls this "more of the same, but more efficient", suggesting mainly technological improvements.[74] Implementing such approaches seems easier, but also bears the risk of the rebound effect. The rebound effect describes, how improvements in efficiency can lead to higher consumption, as the behaviour is perceived to have a lower impact, which incentivises it. This results in little overall change. At the other end of the spectrum, Mukendi and her team found radical change which aims to change the system. Fletcher includes in this category fundamental personal, social and institutional change.

*1.2.1. H&M: A Fashion Company's View on Sustainability*

The H&M group[75] is a fashion company which embraces sustainability. In 2020 Helena Helmersson took over as CEO and declared sustainability to be a core value.[76] This sentiment is reflected in the goal to make sustainable fashion accessible, affordable and easy to understand for all customers.[77] Considering Helmersson's public statements, in which she strongly focuses on the technological innovations and their possible sustainability benefits, one could get the impression that she thinks it is possible to achieve sustainable fashion through the implementation of clever solutions, which will allow the scaling of sustainable production.[78]

To achieve their goal of sustainability H&M have defined a sustainability vision, which should guide their decision processes. According to this vision H&M wants to 'lead the change

[72] Obregón "Sustainable Fashion."
[73] Niinimäki, "Ethical Foundations."
[74] Kate Fletcher, "Sustainable Fashion," p. 10.
[75] The H&M group includes the brands: H&M, COS, WEEKDAY, MONKI, H&M Home, & other Stories, ARKET and A FOUND. These brands target different market segements.
[76]Emily Chan, "H&M's New CEO Wants to Fix Fast Fashion. Is That Possible?," October 14, 2020, https://www.vogue.co.uk/news/article/article/helena-helmersson-interview.
[77]Joseph DeAcetis, "H&M Drives Innovation in Sustainability with 2021 Style," May 7, 2021, https://www.forbes.com/sites/josephdeacetis/2021/05/06/hm-drives-innovation-in-sustainability-with-2021-style/.; Charlotte Owen-Burge, "H&M Group CEO: Our Mission Is to Make Sustainable Fashion Accessible to All," February 25, 2022, https://climatechampions.unfccc.int/hm-ceo-sustainable-fashion-accessible-to-all/.
[78] Owen-Bruge, „H&M Group CEO."

towards circular and climate-positive fashion while being a fair and equal company.'[79] H&M provides very detailed information about their sustainability ambitions and current progress in their sustainability reports, this years' sustainability disclosure, and in articles on their website.[80] Due to the scale of the thesis, it is not possible to provide a complete overview of H&M's interpretation of sustainability. But the discussion below provides some further clarification on concepts used in H&M's sustainability vision.

Leading the change, for H&M, means scaling innovation, promoting transparency, and engaging with partners for industry-wide progress.[81] Furthermore, they tend to equate climate-positive fashion with a circular business model which operates within the planetary boundaries and has a net positive effect on biodiversity.[82] These ideas are further substantiated by referring to external standards. The circular economy approach of H&M, for example, is developed in line with ideas presented by the Ellen MacArthur Foundation.[83] According to this foundation a circular economy, enables the gradual decoupling of growth from the consumption of finite resources by designing out waste and pollution, keeping products and materials in use as long as possible, and regenerating natural systems.[84] Another standard H&M adapted is the SBTI Corporate Net-Zero Standard, which is the basis for their net-zero emissions goal. The general goal of this standard is to halve the company's emissions before 2030 and achieving net-zero emissions by 2050.[85] Net-zero means reducing emissions to a residual level which are then neutralized.[86] H&M aims to achieve this by 2040.[87]

H&M also specify what they consider to be a fair and equal company. To them this means fair jobs for everyone which includes diverse and inclusive workplaces and communities.[88] To further define what a fair job is H&M refer to the idea of decent labour as defined by the International Labor Organization (ILO).

> *'Decent work sums up the aspirations of people in their working lives. It involves opportunities for work that is productive and delivers a fair income,*

[79] H&M Group, "H&M Group Sustainability Performance Report 2020," 2021, pp. 1-84, p.13.
[80] H&M Group, "H&M Group Sustainability Disclosure," 2022, pp. 1-74.; "Sustainability Commitment," H&M Group, accessed June 22, 2022, https://hmgroup.com/sustainability/standards-and-policies/sustainability-commitment/.; H&M Group, "Annual and Sustainability Report 2021," 2022, pp. 1-118.
[81] H&M Group, "H&M Group Sustainability Disclosure," p. 4, 7.
[82] "ibid," p. 4.
[83] "ibid," p. 29.
[84] Ellen MacArthur Foundation, "Artificial intelligence and the circular economy. AI as a tool to accelerate the transition," 2019, p. 4.
[85] Emma Watson et al., "SBTi Corporate Net-Zero Standard. Version 1.0," October 2021, p. 4.
[86] Neutralisation includes measures companies take to remove carbon from the atmosphere and store it permanently to counterbalance emissions that cannot be avoided (Watson et al., 2021 p.10).
[87] H&M Group, "H&M Group Sustainability Disclosure," p. 19.
[88] H&M Group, "H&M Group Sustainability Disclosure," p. 48.

*security in the workplace and social protection for all, better prospects for personal development and social integration, freedom for people to express their concerns, organize and participate in the decisions that affect their lives and equality of opportunity and treatment for all women and men.'*[89]

Furthermore, they rely on the UN Guiding Principles on Business and Human Rights as the basis for their human rights policy and are committed to enforcing them across their own operations and supply chain.[90]

The vision and understanding of SF shown by H&M are similar to the definitions found in the literature. The focus of H&M's SF definition is on environmental and social sustainability, which according to Henninger et al. is very common for industry stakeholders. The move towards circular and climate-positive fashion reflects the concern for environmental sustainability and the goal to be a fair and equal company reflects concerns for social sustainability. Referring to external standards such as the UN human rights also reflects concern for ethical values. Another interesting aspect is, that H&M incorporates both incremental and fundamental changes. By scaling innovation, for example, current production processes can be made more efficient and less resource intensive, which is an incremental change towards sustainability. Aiming for a circular business model on the other hand could constitute a fundamental change, as it requires significant changes in the business model and company culture. By using specific standards and frameworks H&M is more specific about its interpretation of SF and thereby reduces the fuzziness of the term which makes it more tangible. Furthermore, these specific standards can be used as a measuring tool against which one can compare the current progress.

### 1.3. Conclusion: Setting the Basic Sustainability Framework for Fashion and AI

There are already a variety of sustainability definitions. The majority of these definitions share the same basic concerns for economic, environmental, and social sustainability. These three aspects are then formalized in a variety of definitions ranging from general definitions to very specific applications only applicable to a specific case or field. Both general and specific definitions can be categorized as weak and strong or thick and thin, depending on their approach to resource maintenance. This is illustrated in Figure 1 below.

[89] "Decent Work," accessed July 7, 2022, https://www.ilo.org/global/topics/decent-work/lang--en/index.htm.
[90] H&M Group, "H&M Group Sustainability Disclosure," p. 49.

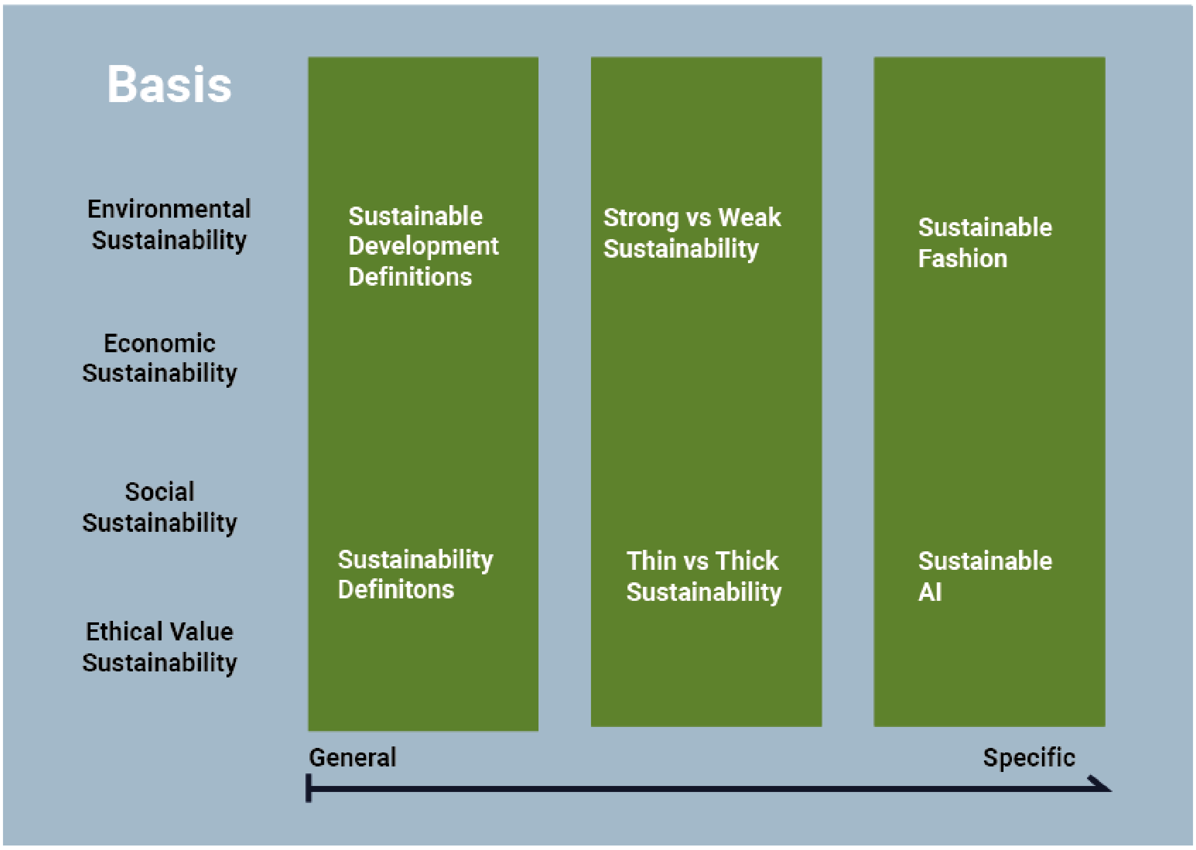



*Figure 1: Overview of a variety of sustainability definitions and how they relate to one another. Most definitions include environmental, social, and economic sustainability which are also referred to as the three pillars of sustainability. Additionally, more recently a fourth pillar has been suggested which is represented as ethical value. They can be considered the basis of sustainability definitions. Based on these four pillars a variety of general definitions for both sustainable development and sustainability have been developed. Additionally, some authors distinguish between strong and weak sustainability or make similar distinctions. These distinctions can exist on a spectrum providing an overview of more or less sustainable behaviours and solutions. Strong and weak can be defined in general terms or specific to a case. Finally, there are specific definitions which apply to distinct fields, applications or contexts and provide more detailed requirements and ideals relevant to their application case*

.

The focus of this thesis is on a specific field of application therefore, I will not attempt to find a suitable overarching definition. Instead, I will take a definition of the ideal case of sustainable fashion as a starting point.

The specific definition I propose draws on some of the overarching definitions to ensure it is in line with a general understanding of sustainability. The principles raised in the Brundtland definition, such as, consideration of future needs and the four pillars of sustainability[91] are guiding principles for the majority of sustainability definitions and should

[91] Burford et al., "Bringing the 'Missing Pillar'.";. Mensah, "Sustainable Development." pp. 9.

also be reflected in the definition used in this thesis. Based on the sustainable fashion definitions provided above I define sustainable fashion as follows.

Fashion is sustainable if it has a minimal environmental impact throughout its life cycle. Since fashion requires the processing of resources it is impossible to not impact the environment, but this impact can be minimised and counteracted. This includes a low carbon footprint, minimal water consumption, the use of renewable, recycled and eco-friendly materials, no use of environmentally harmful chemicals and designing for longevity and low impact. Furthermore, sustainable fashion promotes human rights, as defined in the Universal Declaration of Human Rights, and decent work, as defined by the ILO (see section 1.2.1). The definition of decent labour requires a fair wage. To be considered fair a wage should reflect the invested hours and skills of workers, including necessary education. Furthermore, it should enable workers to support their families and build reserve funds for possible emergencies.

Additionally, sustainable fashion should have a positive impact by changing the behaviours of users to be more environmentally friendly. This could be by, for example, promoting recycling, up-cycling, repair, and slow consumption. Since sustainable fashion is still part of an industry, economic concerns are also relevant but were not mentioned in any SF definitions above. The goal of growing sales and profits is *currently* inherently unsustainable as it promotes a throw-away mentality and requires significant amounts of resources which cannot be maintained endlessly. Therefore, I suggest that sustainable fashion seeks economic sustainability by favouring maintenance to sustain current structures and support workers in the future.[92] To summarise, sustainable fashion has a minimal environmental impact throughout its life cycle, promotes decent work and human rights, encourages environmentally friendly practices, and has a persistent business model which is not based on the idea of endless growth.

The sustainable fashion definition I outlined represents an ideal that should be achieved over time. It should therefore be considered as a type of thick sustainability. If a company does not reach it, it does not mean it is inherently unsustainable, but that it has the potential to further improve. Depending on how closely it adheres to this thick SF understanding it can be considered as more or less sustainable.

[92] A thorough discussion of the sustainability of economic growth would go beyond the scope of this thesis. As long as it is not proven that growth and resource consumption can be decoupled, as suggested by the circular economy models, it is likely that growth, especially endless growth, will result in an increased environmental impact which is unsustainable.

# 2. The current Reality of Artificial Intelligence

The field of Artificial Intelligence (AI) has gained global impact over the last few decades, affecting people's lives in both positive and negative ways.[93] To be able to discuss the various consequences of AI one needs to have a clear understanding of what AI entails. This section will give a brief overview of what AI encompasses and provide a definition of AI that will be used throughout this thesis.

## 2.1. The Changing Understanding of AI

Currently, there is no universally accepted definition of AI. The rather fast development of the field makes it difficult to define what should be considered AI. This also means definitions have changed over the years.[94] As people become accustomed to technology their perception changes and technologies lose their status as AI.[95] This also suggests that AI needs to be new and somewhat futuristic to be perceived as such. The lack of a precise definition brings both advantages and disadvantages. While it complicates the discussion of AI, it likely also allowed the field to advance so quickly by offering a rough direction, while remaining open to different approaches and interpretations.[96]

The term Artificial Intelligence was first coined by John McCarthy in the 1950s to describe the science and engineering of intelligent machines.[97] Throughout the years a variety of authors have extended and altered this definition. Nils Nilsson, for example, suggests 'Artificial Intelligence (AI) broadly (and somewhat circularly) […] is concerned with intelligent behavior in artifacts.'[98] According to him, this involves perception, reasoning, learning, communicating and acting in complex environments. David Lynton Poole, Alan Mackworth and Randy Goebel suggest that 'Artificial intelligence or AI, is the field that studies the synthesis and analysis of computational agents that act intelligently.'[99] Andreas Kaplan and Michael Haenlein are even more specific and 'define AI as a system's ability to interpret

---

[93] Christoph Bartneck et al., "An Introduction to Ethics in Robotics and Ai," *SpringerBriefs in Ethics*, 2021, https://doi.org/10.1007/978-3-030-51110-4.; P. Stone et al., "Artificial Intelligence and Life in 2030: One Hundred Year Study on Artificial Intelligence: Report of the 2015-2016 Study Panel, Stanford University, Stanford, CA, Doc: http://ai100.stanford.edu/2016-report.

[94] Bartneck et al., "An Introduction to Ethics in Robotics and Ai."; Stone et al., "Artificial Intelligence and Life in 2030."; Andreas Kaplan and Michael Haenlein, "Siri, Siri, in My Hand: Who's the Fairest in the Land? on the Interpretations, Illustrations, and Implications of Artificial Intelligence," *Business Horizons* 62, no. 1 (2019): pp. 15-25, https://doi.org/10.1016/j.bushor.2018.08.004.

[95] Bartneck et al., "An Introduction to Ethics in Robotics and Ai."; Stone et al., "Artificial Intelligence and Life in 2030."

[96] Stone et al., "Artificial Intelligence."

[97] Kaplan and Haenlein, "Siri, Siri, in My Hand."; Christopher Manning, "Artificial Intelligence Definitions," 2020, https://hai.stanford.edu/sites/default/files/2020-09/AI-Definitions-HAI.pdf.

[98] Nils J Nilsson, *Artificial Intelligence: A New Synthesis* (San Francisco, CA: Morgan Kaufmann Publishers, 1998), p. 1.

[99] David Lynton Poole, Alan K. Mackworth, and Randy G. Goebel, *Computational Intelligence: A Logical Approach* (New York, NY: Oxford Univ. Press, 1998).

external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation.'[100] The more recent definitions emphasise the ability to learn from experience instead of intelligent behaviour suggesting a shift in focus as the former is a more specific definition of intelligence.

The examples above suggest that the majority of definitions include the study or creation of intelligent agents, capable of achieving goals.[101] The used terms are open for interpretation, and therefore need to be specified to allow for clear communication. An agent is something that acts, which includes systems and artefacts.[102] Defining intelligence is less straightforward. According to Bartneck et al. and Poole and Mackworth, an agent is intelligent if it fulfils the following requirements:[103]

- it reacts appropriately to its goals and circumstance, also considering long- and short-term consequences
- it is flexible when confronted with changes in the environment and goals
- it learns from experience
- it makes appropriate[104] choices given its perceptual and computational limits

But intelligence can also be described on a multidimensional spectrum with different scales for speed, degree of autonomy, and generality.[105] This perspective allows different types of AIs to be considered more or less intelligent. An expert system, for example, could be considered less intelligent (or not intelligent at all) compared to machine learning systems because it cannot learn from experience and depends on human input, therefore lacking autonomy. In general, human intelligence is often seen as a benchmark against which AIs should be measured but it is only a sufficient measure, because AI could exceed human capabilities in many aspects, such as speed.[106]

[100] Kaplan and Haenlein, "Siri, Siri," p. 17.
[101] Bartneck et al., "An Introduction to Ethics."
[102] "ibid."; Poole, Mackworth, and Goebel, "*Computational Intelligence.*"
[103] David L. Poole and Alan K. Mackworth, *Artificial Intelligence: Foundations of Computational Agents*, 2nd ed. (New York, NY: Cambridge University Press, 2017), http://artint.info/2e/html/ArtInt2e.html.; Bartneck et al., "An Introduction to Ethics in Robotics and Ai."
[104] Appropriate is context specific and not further defined by the authors.
[105] Stone et al., "Artificial Intelligence."
[106] "ibid."

In their definition of AI Stuart Russel and Peter Norvig replace acting intelligently with doing 'the right thing'.[107] This definition appears to be even broader as the right thing can be defined in numerous ways, possibly adding an ethical dimension. According to Russel and Norvig, the right thing is determined by the objective given to the system, which can be very broad. This definition also struggles with the value alignment problem, as it is not certain that the input objective sufficiently represents the preferences of the user.[108] Considering this, it seems difficult to objectively judge if an agent does the right thing, which results in an extremely vague definition.

Another way to define AIs is through a test. Alan Turing proposed a test to determine if a machine can think. This test, while highly influential, is also controversial and recent definitions go beyond the requirements necessary to pass the test. To pass the test, a system needs to be indistinguishable in its answers from a human, so that a participant can no longer determine if they are interacting with a human or a machine.[109] According to Russel and Norvig, a machine requires the following capabilities, natural language processing, knowledge representation, automated reasoning, and machine learning to pass the test. The total Turing test, which includes physical appearance, also requires computer vision and robotics[110]. These six requirements are some of the sub-disciplines of AI.[111]

## 2.2. Distinguishing Different Types of AIs

In general, the field of AI is interested in understanding and building intelligent agents.[112] The distinction between understanding and building can also be expressed as a distinction between scientific and engineering goals. While the central scientific goal of AI is to understand the principles of intelligent behaviour, the central engineering goal is to create useful, intelligent artefacts and to develop the necessary design methods.[113] The systems used to achieve these goals are distinct, and especially the engineering of systems is not confined to biologically observable methods.[114]

---

[107] Stuart J. Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach*, 4th ed. (Harlow, England: Pearson Educación, 2022).
[108] Russell and Norvig, "Artificial Intelligence."
[109] Bartneck et al., "An Introduction to Ethics."; Nilsson, "Artificial Intelligence*".;* Russell and Norvig, "*Artificial Intelligence.";* John McCarthy "What is Artificial Intelligence?" (Stanford, 2007).
[110] Russell and Norvig, "Artificial Intelligence."
[111] Bartneck et al., "An Introduction to Ethics."; Russell and Norvig, "Artificial Intelligence." John McCarthy "What is Artificial."
[112] Russell and Norvig, "Artificial Intelligence."
[113] Nilsson, "Artificial Intelligence."; Poole, Mackworth, and Goebel, "Computational Intelligence."
[114] Poole and Mackworth, "Artificial Intelligence."; John McCarthy "What is Artificial."

It is also possible to distinguish between strong and weak AI. Weak AI describes systems that are valuable because they are beneficial tools. Strong AI describes programs that mimic the workings of a brain.[115] Another way to express weak and strong is in terms of narrow and general AI. Currently, AIs are only good at the specific task they were intended for. This type of AI is called Artificial Narrow Intelligence (ANI).[116] In the future, AIs might be able to reason, plan and solve problems autonomously beyond their original task. This is called Artificial General Intelligence (AGI), which has yet to be achieved.[117] For now, AI works best in specific environments and with clear assignments, as it lacks the ability of abstract reasoning and common sense necessary to navigate poorly defined problems.[118]

Throughout the years, different approaches and types of systems were developed. In the consulted literature, about 16 different types of systems were mentioned, including (knowledge) representation, pattern recognition, and genetic programming systems[119]. Special attention is currently paid to machine learning, deep, learning and cloud computing, as these are drivers of the current AI development.[120] Machine learning algorithms can learn from experience either in a supervised or unsupervised manner or through other reinforcement methods.[121] Many of the AI solutions discussed in the next section are based on machine learning, indicating the importance of the field to the economy.

### 2.3. Conclusions: Setting the Basis of AI for Sustainable AI

The definitions of AI are broad and encompass a variety of concepts, which can lead to confusion. In this thesis, I will focus on the engineering field of AI, and therefore consider AIs, as (useful and intelligent) artefacts. To avoid the ambiguity of intelligence or the right thing, and considering the practical interest of the thesis, I will use a definition of AI based on Kaplan and Haenlein.[122] When referring to AI, I mean a system which can achieve specific tasks by autonomously interpreting external data correctly and learning from it, adapting to the problem at hand. This definition encompasses machine learning and deep learning, which are currently the most commonly used types of AI. This definition excludes blockchain technology unless it is used in combination with another AI, such as a machine learning algorithm. Since no autonomous decisions are made based on external data, blockchains are not considered AIs

---

[115] John R. Searle, "Minds, Brains, and Programs," The Behavioral and Brain Sciences 3, no. 3 (1980): pp. 417-424, https://doi.org/10.1017/s0140525x00005756.
[116] Kaplan and Haenlein, "Siri, Siri."; Manning, "Artificial Intelligence."
[117] Kaplan and Haenlein, "Siri, Siri."; Manning, "Artificial Intelligence."
[118] Bartneck et al., "An Introduction to Ethics."
[119] "ibid."; John McCarthy "What is Artificial."
[120] Stone et al., "Artificial Intelligence."
[121] "ibid."; Kaplan and Haenlein, "Siri, Siri."; Manning, "Artificial Intelligence."; John McCarthy "What is Artificial"
[122] Kaplan and Haenlein, "Siri, Siri," p.17.

under the given definition. Nevertheless, this technology is used by companies, such as H&M, in their sustainability endeavours towards, for example, increasing the transparency of the sustainable fibre supply chain. Due to the high energy consumption, a discussion of blockchain for sustainability purposes would be worthwhile but is beyond the scope of this thesis.

# 3. The Relevance and Use of AI in Sustainable Fashion

Introducing AI systems into business strategies affects a company both internally and externally. Tasks can be conducted more efficiently and the relationship with customers and other businesses changes.[123] The retail and fashion industries cautiously embrace AI systems to enhance their services and production processes.[124] In general, the implementation of AIs is supposed to attract new customers, cut operational costs, boost revenue, increase production speed, create a competitive edge, and support more sustainable business practices.[125] Companies such as 'intelistyle' and 'Vue.ai', for example, provide systems, which use AI to provide customers with personalised styling suggestions to improve their shopping experience.[126] The company 'RubyGarage' provides all kinds of AI solutions for retailers which can improve performance. An example of such a solution is their program for inventory management. [127]

The fashion industry and other retailers have adopted a variety of AI applications, which can be broadly categorized as customer-facing AI, which is aimed at customer interaction and back-end AI, which mainly optimises processes in production and planning. In this section, I will provide a brief overview of AI applications used by fashion retailers and highlight the ones aiming at improving the sustainability of a company.

The application of AI is complex and touches upon a variety of ethical concerns like privacy. I recognise the importance of discussing such issues regarding AI, but it is outside the scope of this thesis, which focuses on sustainability concerns.

## 3.1. Customer-facing AI

Application possibilities of AI range from personalisation to Virtual Reality (VR) applications. When asked, marketing and sales experts considered VR (40%) and AI (34%) as the biggest game-changers in retail and the majority either planned to or had already implemented VR or AI solutions.[128] Implementing customer-facing AIs like Veu.ai's personalisation suite can

---

[123] Kaplan and Haenlein, "Siri, Siri, ," p. 17.
[124] "AI in Fashion: An Extensive Guide to All Applications for Retail," January 25, 2022, https://www.intelistyle.com/ai-fashion-retail-applications/.
[125] "AI in Fashion"; Fabrice Beaux, "How Fashion Retailers Can Benefit from AI in 2022," February 14, 2022, https://www.bbntimes.com/technology/how-fashion-retailers-can-benefit-from-ai-in-2022.
[126] "Company," Intelistyle, n.d., https://www.intelistyle.com/company/.,; "AI for Fashion Retail," Vue.ai, accessed September 16, 2022, https://vue.ai/industries/ai-in-fashion-retail/.
[127] "E-Commerce & Retail Software Development Services," RubyGarage, accessed September 16, 2022, https://rubygarage.org/expertise/retail-software-development.
[128] Oracle, "Can Virtual Experiences Replace Reality?"

significantly increase revenue per customer. Customer-facing AI entails four main applications: personalisation, search, chatbots and fitting.

### *Personalisation*

By implementing AI solutions retailers can build, track and manage comprehensive customer profiles, which allow for individualisation instead of segmentation when targeting customers.[129] AI enables hyper-personalised recommendations.[130] Furthermore, AI can be used to provide tailored pricing and loyalty programs.[131] The possibility of recommending similar products, in case a garment is not available in the right size, and providing full looks incorporating the chosen item, reduces sales lost to the competition and increases the basket size of customers.[132]

### *Search*

The use of natural language and image search make the searching process more intuitive and simplifies the overall process for the customers.[133] Furthermore, the implementation of voice-activated smart devices offers new possibilities for reaching customers and further simplifies the process for them.[134]

### *Chatbots*

Chatbots are a widely used AI-powered application.[135] Their main function is to provide 24/7 customer service by, for example, answering questions and providing recommendations.[136] Additionally, chatbots can collect detailed information about customers which can then be used to feed other AI systems, such as gender or location.

---

[129] "AI in Fashion."; Vue.ai. Rep. *A.I. in Retail 2022*, n.d..
[130] "ibid."; P. Daryna, "11 Superb Ways AI Can Revamp the Retail Industry," September 26, 2018, https://rubygarage.org/blog/11-use-cases-of-ai-in-retail.; Katrine Spirina, "Top 12 AI Trends in Retail and E-Commerce in 2021," July 7, 2021, https://indatalabs.com/blog/ai-ecommerce-trends.
[131] "AI in Fashion."
[132] "ibid."; Spirina, "Top 12 AI Trends."
[133] "AI in Fashion."; Ron Schmelzer, "The Fashion Industry Is Getting More Intelligent with Ai," July 17, 2019, https://www.forbes.com/sites/cognitiveworld/2019/07/16/the-fashion-industry-is-getting-more-intelligent-with-ai/; Daryna, "11 Superb Ways."; Spirina, "Top 12 AI Trends."
[134] Daryna, "11 Superb Ways."
[135]"ibid."; Oracle, "Can Virtual Experiences Replace Reality?: The Future Role for Humans in Delivering Customer Experience" (Redwood Shores, CA: Oracle, 2016).
[136] "AI in Fashion.";. Schmelzer, "The Fashion Industry."; Daryna, "11 Superb Ways."

### *Fitting*

AI systems in combination with virtual reality or smart mirrors offer new ways of trying on clothes. The virtual fitting room allows online shoppers to see items on different body types or themselves and offers recommendations suited to the specific customer. This increases sales and reduces returns.[137] Currently, about 22% of returns are due to a product looking different in person.[138] H&M is currently working on such a system, which will allow customers to create a virtual avatar to try on garments and experience size and fit better, to avoid returns due to not meeting the customer's expectations.[139]

## 3.2. Backend-AI

Behind-the-scenes AI can be applied to optimize the supply chain and sales process, addressing every step from location selection for shops and factories to sales forecasting.[140] Especially the optimization of production processes offers possibilities for increasing the sustainability of a company by improving efficiency and avoiding negative environmental impacts.

### *Automated Tagging*

Using machine learning and image recognition for automated tagging increases the quality of data, boosts productivity, bypasses the scalability issue, reduces costs, and speeds up the sales process.[141] The more accurate tagging also helps to recommend customers relevant products. Furthermore, it enables a better understanding of customers' relationships with specific attributes and benefits inventory management.[142]

### *Predictive Analytics*

Predictive analytics can be used to forecast trends and demand by using AI approaches, such as fuzzy linguistics or machine learning, to analyse social media, sales history and more.[143] H&M for example analyses store returns, receipts and loyalty cards to predict future demand.[144]

---

137 Beaux, "How Fashion Retailers."; Vue.ai. "*A.I. in Retail 2022*."; Spirina, "Top 12 AI Trends."
138 Vue.ai. "A.I. in Retail 2022."
139 "Taking Sustainable Fashion to a New Level with Tech," June 2, 2021, https://hmgroup.com/our-stories/taking-sustainable-fashion-to-a-new-level-with-tech/.
140 W. K. Wong, Zhaoxia Guo, and Yung-sun Leung, Optimizing Decision Making in the Apparel Supply Chain Using Artificial Intelligence (AI): From Production to Retail (Cambridge: Woodhead Publishing Ltd, 2013).
141 "AI in Fashion."; Vue.ai. "*A.I. in Retail 2022*."; Vue.ai and Diesel, "Image Attribute Extraction Using VueTag - Vue.ai's Automated Tagging Solution: An Impact Study," n.d.; Daryna, "11 Superb Ways."; Spirina, "Top 12 AI Trends."
142 "AI in Fashion."; Vue.ai. "*A.I. in Retail 2022*."
143 Daryna, "11 Superb Ways."
144 "ibid."."; Lisheng Jiang, Huchang Liao, and Zhi Li, "Probabilistic Linguistic Linear Least Absolute Regression for Fashion Trend Forecasting.," in *Artificial Intelligence on Fashion and Textile: Proceedings of the Artificial Intelligence on Fashion and Textiles (AIFT) Conference 2018, Hong Kong, July 3-6, 2018*, ed. W. K. Wong (Cham, Switzerland: Springer,

Furthermore, H&M developed a tool called Movebox, which allows the redistribution of products to locations where it is in demand. Additionally, it will make it easier to react to changes in customer preferences, and thereby reduce overproduction.[145] Using predictive AIs has a variety of advantages, for example, it can reduce forecasting errors by as much as 50%.[146] The reduced error margin results in better stock management, less overproduction, better supply management, robust risk management strategies, and increased stock turnover.[147] This can increase the sustainability of a company, especially from an environmental perspective, as resources are saved. Additionally, it can increase profits. Furthermore, AIs can be used to determine the best pricing strategy by collecting data on competitors and other non-store data.[148]

### *Digital content creation*

The use of AI for content creation allows to reduce costs and environmental impact, as physical photo shootings are no longer necessary. Digital models and designs can also be used to test the demand for products by posting them on social media. This can avoid overproduction.[149] Similarly, AI-powered copywriters free human workers to work on higher concept creative projects instead of daily content creation.[150] AI can also be used to create NFTs which can be sold at high prices.[151] Digital content can be both beneficial and detrimental to sustainability as it generally has the potential to reduce resource usage but technologies such as NFTs can increase energy consumption significantly.

### *Design and Product Development*

AI offers many possibilities for analysing both current trends and the performance of past products, which can be utilized in the design process. They can also create designs based on this data, including the necessary cutting patterns. This speeds up the design process.[152]

---

2019), pp. 337-346.; Ming Tang and Huchang Liao, "Multiple Criteria Group Decision-Making Based on Hesitant Fuzzy Linguistic Consensus Model for Fashion Sales Forecasting.," in *Artificial Intelligence on Fashion and Textile: Proceedings of the Artificial Intelligence on Fashion and Textiles (AIFT) Conference 2018, Hong Kong, July 3-6, 2018*, ed. W. K. Wong (Cham, Switzerland: Springer, 2019), pp. 329-336.

145 "Taking Sustainable Fashion."

146 Schmelzer, "The Fashion Industry."

147 "AI in Fashion."; Beaux, "How Fashion Retailers." ; Schmelzer, "The Fashion Industry."; Daryna, "11 Superb Ways."

148 "AI in Fashion."; Spirina, "Top 12 AI Trends."

149 Beaux, "How Fashion Retailers."; Vue.ai. "*A.I. in Retail 2022*."

150 "AI in Fashion."

151 Oracle, "Can Virtual Experiences."

152 "AI in Fashion."

### *Performance Optimization*

Performance optimization through AI applications can be implemented at any moment of the supply, production and sales process. In the production process, AI is mainly used for improved quality control and automation of processes, such as fabric spreading and cutting, which increase productivity and reduces waste and costs[153]. The logistics of the supply chain and inventory management offer many opportunities to improve performance. AIs can analyse the performance of products and predict the amount of required stock, thereby avoiding overproduction and last-minute procurements.[154] Furthermore, AI systems can be used to find the most efficient and sustainable supply partners and modes of transport thereby, increasing sustainability and profitability at the same time.[155] A third application field is in stores and human resource management. Performance analysis allows for the optimal organization of employees, which can improve their performance. Styling and inventory management apps support sales personnel in offering the best customer service possible.[156]

## 3.3. The Role of AI for Sustainability: A Company's Perspective

H&M emphasizes innovation to achieve their goal of becoming sustainable.[157] A significant part of this is technological innovation, which includes digital technologies such as AIs as well as machines which change the lifecycle of garments by impacting their development and recycling. The Green Machine is one example of this. It enables the recycling of polyester-cotton blends at scale.[158] Another example is the Circulator tool. It allows designers to visualize how choices affect the circularity of a product, which creates opportunities to avoid waste and reduce pressure on virgin resources.[159]

More interestingly in the context of this thesis, H&M also embraces artificial intelligence and is currently working on developing and implementing a variety of applications to improve processes and further sustainability.[160] For example, H&M is currently developing a forecasting AI called Movebox and 3D models, which allow customers virtual try-ons.[161]

---

[153] "AI in Fashion."; Schmelzer, "The Fashion Industry."; Wong, Guo, and Leung, "*Optimizing Decision Making.*"
[154] Schmelzer, "The Fashion Industry."
[155] Zhaoxia Guo et al., "Coordinated Optimization of Production and Delivery Operations in Apparel Supply Chains Using a Hybrid Intelligent Algorithm," in *Artificial Intelligence on Fashion and Textile: Proceedings of the Artificial Intelligence on Fashion and Textiles (AIFT) Conference 2018, Hong Kong, July 3-6, 2018*, ed. W. K. Wong (Cham, Switzerland: Springer, 2019), pp. 9-15.
[156] "AI in Fashion."; Daryna, "11 Superb Ways."
[157] H&M Group, "H&M Group Sustainability Performance Report 2020," 2021, pp. 1-84, p. 21.
[158] Jasmin Malik Chua, "H&M's Green Machine: A Recycling Solution?," November 19, 2020, https://www.voguebusiness.com/sustainability/handms-green-machine-a-recycling-solution.
[159] "Circulator™," 2021, https://circulator.hmgroup.com/.
[160] H&M Group, "H&M Group Sustainability," 2021.
[161] "Taking Sustainable Fashion to a New Level with Tech," June 2, 2021, https://hmgroup.com/our-stories/taking-sustainable-fashion-to-a-new-level-with-tech/.

Another example is the collaboration with TextileGenesis, who developed a platform that allows companies to track and verify sustainable fibres through all five to six levels of the supply chain. To do so they use blockchain and a rule-based AI engine.[162] This technology could be an example of developing to achieve sustainability while neglecting the sustainability of the product itself. Since the technology relies on a blockchain it likely requires a significant amount of energy, which is not discussed by either party.

AI applications have the potential to positively impact businesses and society while helping to solve humanity's biggest challenges. At the same time, they are still immature and require attention to ensure negative effects are avoided. This is recognized by H&M in the form of Lina Leopold, who is head of the Responsible AI and Data team.[163] To ensure the developed AI will have a positive effect H&M, created a project focusing on responsible AI. Since 2018 this group is tasked to ensure two goals. The first goal is that AI is used for good, to create sustainable growth and help the company reach its sustainability goals. The group's second goal is to actively prevent any unintentional harm caused by AI-driven business operations.

Part of the approach to responsible AI is a checklist which supports identifying and discussing potential risks and ensuring the alignment with company values. [164] This checklist is part of a framework, which follows nine main principles to guide the development process. According to Leopold, the principles are: focused, beneficial, fair, transparent, governed, collaborative, reliable, respecting human agency, and secure.[165]

Currently, the list is focused on issues raised in AI ethics, such as concerns about unintentionally programmed bias (addressed by transparency and fairness) or the fear of removing human agency. It does not directly address concerns related to the physicality of AI, such as the environmental impacts of servers or the working conditions under which the resources, such as for example datasets, for AIs are created. The term beneficial could encompass avoiding carbon emissions or good labour conditions if it was considered broadly. But this is a stretch as, for example, being beneficial to the environment and explicitly not harming it are two distinct features. In medical ethics, this distinction is expressed as beneficence and non-maleficence.

H&M's approach to innovation and especially AI, as a solution for the business' problems, reflects an interesting attitude. They lack consideration for the physicality of AI,

---

[162] TextileGenesis, "Creating traceable supply Chains," accessed June 22, 2022, https://textilegenesis.com/.

[163] "Responsible AI, Is Better AI," June 15, 2021, https://hmgroup.com/our-stories/responsible-ai-is-better-ai/.
[164] H&M Group, "H&M Group Sustainability Disclosure," p. 9.; H&M Group, "H&M Group Sustainability," p. 21.; "Responsible AI, Is Better AI,"
[165] "Responsible AI, Is Better AI,"

which affects the sustainability of the used AI. The case of H&M shows why it is so important to connect the discussion of AI applications with the discussion of the physicality of AI, especially if they are intended for sustainability purposes such as sustainable fashion (SF).

H&M has decided to use TextileGenesis to ensure their sustainable fabrics indeed adhere to sustainability standards throughout their whole supply chain. But this technology relies on blockchain, next to AI algorithms. During the development, probably a significant amount of energy was necessary to train the AI and during the use of the program, the blockchain probably requires a significant amount of energy too. The program is furthering the sustainability agenda and apparently in line with the responsible AI checklist, as it is used by H&M. It is therefore, a responsible AI used for sustainability purposes. But due to the high energy demand, the software probably has a negative effect on the environment. From the publications about the software, it is unclear if sustainability concerns such as energy use were weighed against the positive environmental impact of the implementation. Should there have been no such deliberations, it is possible that the use of this application counteracts its positive impact. This then would be a zero-sum game in which H&M gains no sustainability advantage. This illustrates the necessity to take the physicality of AI into consideration during the development of sustainable AI. Chapters two and three elaborate on physicality of AI and how it should be considered in the definitions of sustainable AI for SF.

### 3.4. The Potential of AI for Fashion Retailers

The fashion industry can apply AI in a variety of ways that increase its revenue, either by increasing sales or by reducing costs through process optimisation. Customer-facing AIs are intended to improve the customer experience and in turn, increase sales. While further increasing sold items increases revenue, it also reinforces the environmental problems the fashion industry causes. Global consumption of garments reached 62 million metric tons in 2019 and is predicted to further increase.[166] Combined with the reduced wear time of roughly 7-10 wears per item, this results in a further increase of garments in the waste cycle.[167] AI for process optimisation on the other hand has the potential to reduce the environmental impact by reducing resource consumption and $CO_2$ production during production, transportation, and marketing. Especially predictive analytics seem promising in fighting overproduction which is a significant factor in increasing sustainability. Depending on the consideration during the

[166] "How Much Do Our Wardrobes Cost to the Environment?," October 8, 2019, https://www.worldbank.org/en/news/feature/2019/09/23/costo-moda-medio-ambiente#:~:text=Every%20year%20the%20fashion%20industry,needs%20of%20five%20million%20people.&text=The%20fashion%20industry%20is%20responsible,flights%20and%20maritime%20shipping%20combined.
[167] Dottle and Gu, "The Global Glut."

development and the implementation, AI hold the potential to increase or decrease the sustainability of a company. As the example of H&M illustrates the current standards for responsible AI might not be enough to ensure sustainable AI, as they lack consideration for the physicality of AI and thereby part of the environmental sustainability of an AI.

# Chapter Two: Connecting AI and Its Physicality for Sustainability

When reading articles about AI or listening to experts in the field, one can get the impression that AI has the potential to provide a solution to any problem. But such an overly positive picture overlooks some of the negative aspects of AI. This chapter will provide a discussion on the perception of AI as a magical solution, which neglects the physicality of AI. Furthermore, it provides a discussion of this physicality.

### 1.1. AI as a Magical Solution

AI is portrayed as a solution to the public by a variety of groups. Companies, such as Intelistyle, RubyGarage, InDataLabs or Vue.ai, offer big data analytics and other AI solutions like recommender or automatic tagging systems to the industry. To ensure sales, a positive image of the products is important. On their websites they provide information about their products highlighting their benefits. Possible downsides are discussed less. The information about products is sometimes provided in the form of case studies or articles which creates a sense of objectiveness and authority.[168] These sources provide a good overview of current developments and goals. Nevertheless, they should be assessed critically as there is a tendency to focus on what technology can accomplish in the future and less consideration of possible drawbacks.[169]

The Media and literature also portray AI as a solution beyond corporate interests. Information and communications technology (ICT) is generally viewed positively in the sustainability community. This suggests that AI is considered as a possible solution to sustainability issues.[170] This view is supported by a study on the impact of AIs on the SDGs in which the positives significantly outweigh the negatives.[171] AI for social good (AI4SG) has even become its own field of research.[172]

---

[168] Vue.ai and Diesel, "Image Attribute Extraction Using VueTag - Vue.ai's Automated Tagging Solution: An Impact Study," n.d.; "AI in Fashion."; Daryna, "11 Superb Ways AI Can Revamp the Retail Industry," September 26, 2018, https://rubygarage.org/blog/11-use-cases-of-ai-in-retail.
[169] M. C. Elish and danah boyd, "Situating Methods in the Magic of Big Data and AI," *Communication Monographs* 85, no. 1 (2017): pp. 57-80, https://doi.org/10.1080/03637751.2017.1375130.
[170] Lotfi Belkhir and Ahmed Elmeligi, "Assessing ICT Global Emissions Footprint: Trends to 2040 & Recommendations," *Journal of Cleaner Production* 177 (2018): pp. 448-463, https://doi.org/10.1016/j.jclepro.2017.12.239, 448.
[171] Ricardo Vinuesa et al., "The Role of Artificial Intelligence in Achieving the Sustainable Development Goals," *Nature Communications* 11, no. 1 (2020), https://doi.org/10.1038/s41467-019-14108-y. The findings of this study should be considered cautiously. As the authors themselves note, there is a lack of studies about the possible negative impacts of AI on sustainability goals.
[172] Anibal Monasterio Astobiza et al., "AI Ethics for Sustainable Development Goals," *IEEE Technology and Society Magazine* 40, no. 2 (2021): pp. 66-71, https://doi.org/10.1109/mts.2021.3056294, 66.

The positive image of AI is supported by several beliefs about it. Both Kate Crawford, who is an expert on the social implications of AI, and historian Nathan Ensmenger argue that the information economy, which includes AI, is usually portrayed and understood as a clean and green economy, especially compared to the industries of the 19th and 20th centuries. This belief is reinforced by the language used to describe information technologies.[173] An example used by both Ensmenger and Crawford would be the term 'cloud' which is used to describe an outsourced storing and computing system. The term itself invokes the idea of a light, airy, intangible technology that has little environmental impact. In reality "clouds" are extensive server farms that require resources such as water and energy to run 24/7. This means they have a material form and environmental impact. The idea of information technologies as free from material constraints is not new. Already in the 1970s bits were discussed as immaterial information carriers.[174] Compared to analogue media carriers, bits can be sent with almost no cost, no noise, and no degradation.[175] This idea of bits as more or less intangible supports the idea of the information economy as clean and green.

But it is not just the terms used to describe AI and other information technology that support the grand vision of AI as a solution while obscuring its negative aspects. Some terms commonly used to describe the discourse and perception of AI are magical and mythical. Noel and Amanda Sharkey, for example, describe AI as a science of illusions which they see as a continuation of the long tradition of automatons and natural magic.[176] They discuss how, similar to today's AIs, automatons were often portrayed as smarter, more capable and more automated than they actually were. A famous example is the Turk, a chess-playing automaton, that beat several high-ranking chess players and travelled to various courts, before it became public that the automaton was just an elaborate "costume", operated by a human. Such spectacular presentations of the capabilities of machines continue today and influence the perception of AI: Deep Blue[177] beat the chess master Garry Kasparov in the 1990s, Watson[178] won Jeopardy in

[173] Kate Crawford, *Atlas of AI Power, Politics, and the Planetary Costs of Artificial Intelligence* (New Haven, Conn: Yale University Press, 2021).; Nathan Ensmenger, "The Environmental History of Computing," *Technology and Culture* 59, no. 4S (2018): pp. 7-33, https://doi.org/10.1353/tech.2018.0148.
[174] Nathan Ensmenger and Rebecca Slayton, "Computing and the Environment: Introducing a Special Issue of Information & Culture," *Information & Culture* 52, no. 3 (2017): pp. 295-303, https://doi.org/10.7560/ic52301.
[175] Jean-François Blanchette, "A Material History of Bits," *Journal of the American Society for Information Science and Technology* 62, no. 6 (2011): pp. 1042-1057, https://doi.org/10.1002/asi.21542, 1042.
[176] Noel Sharkey and Amanda Sharkey, "Artificial Intelligence and Natural Magic," *Artificial Intelligence Review* 25, no. 1-2 (2007): pp. 9-19, https://doi.org/10.1007/s10462-007-9048-z, p. 9,10.
[177] Deep Blue is a (brute force) chess engine developed by IBM. The system uses search trees with millions of possible moves and chooses the one with the best possible outcome.
[178] Watson is a machine learning system developed by IBM. Originally it was programmed to answer complex quiz questions as used in Jeopardy. Since 2011 it has been further developed and is the basis for a variety of AI solutions offered by IBM.

2011, and AlphaGo[179] beat the best Go player in 2016.[180] All these events generated publicity for AIs, created hype and strengthened the sense of AI as more capable than humans. These displays also foster the myth of AIs as modular solutions that can be easily adapted to any scenario or as transformative technologies that change everything.[181] Products such as chatbots or assistance software are advertised as solving daily tasks like magic. Marketing AIs as magic emphasises its results while obscuring the necessary means.[182]

Alexander Campolo and Kate Crawford describe the discourse around specifically deep learning as 'enchanted determinism.'[183] The term is an attempt to encompass a discourse that declares deep learning to have magic-like capabilities, which are outside the scope of current scientific knowledge, because the exact reasoning of the systems is not understood yet. At the same time, these systems are deterministic due to advanced pattern recognition which allows unprecedented access to people including their emotions and identities. Especially the unilateral application of such systems in critical social contexts is deterministic. The concept of enchanted determinism as proposed by Campolo and Crawford focuses on the possible negative impact deep learning has on minority groups. According to them, the lack of understanding combined with the hype and sense of magic surrounding deep learning results in the development of applications that potentially endanger people. Although Campolo and Crawford do not explicitly discuss the material aspects of AI, their concept can be easily applied to it. AI is also enchanted, because its material form is often invisible to the public and it can be considered deterministic since the continued use of AI has environmental consequences that cannot be changed. Hiding this aspect prevents the necessary implementation of changes in the system.

The discussed literature suggests that the current public portrayal of AI is overly positive, evoking a sense of the magical which is displaced and glosses over a variety of serious shortcomings. I suggest that this sense of magic surrounding AI results in a disconnect from the physicality of AI, which encompasses its material form such as servers and its impact on the

---

[179] AlphaGo was developed by DeepMind now a subsection of Google to play the game Go. The program uses advanced search trees and deep neural networks and was mainly trained through reinforcement learning. Due to this strategy, it can choose the best next move and can even create new ones showing attributes of creativity.

[180] Stephan Schnieber, "IBM Watson: Von Jeopardy! Zum Business Champion," March 3, 2022, https://www.ibm.com/blogs/think/de-de/2022/03/ibm-watson/.; DeepMind, "AlphaGo," accessed May 3, 2022, https://www.deepmind.com/research/highlighted-research/alphago.

[181] Emanuel Moss and Friederike Schüür, "How Modes of Myth-Making Affect the Particulars of DS/ML Adoption in Industry," *Ethnographic Praxis in Industry Conference Proceedings* 2018, no. 1 (2018): pp. 264-280, https://doi.org/10.1111/1559-8918.2018.01207.

[182] Elish and boyd, "Situating Methods."

[183] Alexander Campolo and Kate Crawford, "Enchanted Determinism: Power without Responsibility in Artificial Intelligence," *Engaging Science, Technology, and Society* 6 (2020): pp. 1-19, https://doi.org/10.17351/ests2020.277, p. 3.

world. A discussion of the choice for the term physicality can be found in Appendix A. This disconnect is especially problematic for the consideration of sustainable AI.

## 1.2. Critique of AI in Philosophy and Ethics

So far, the literature on the philosophy and ethics of AI has focused on ethical concerns which are human-centred[184] Prominent issues are privacy, data protection, fairness, and the blackbox problem which addresses transparency and explainability concerns.[185] Articles addressing these issues mainly discuss them or suggest mitigation strategies by taking different approaches.

Another aspect addressed by ethicists is the responsibility of researchers. Currently, there is a lack of ethical considerations during the development process of AIs. This is exemplified by the lack of a common framework and the lack of testing the consequences of big-scale implementation.[186] Illah Reza Nourbakhsh suggests that these issues could be addressed by implementing Human Rights as constraints in the development process. On the other hand, Anibal Monasterio Astobiza and their colleagues suggest broad educational interventions to engage researchers in ethical considerations. These could also prevent furthering the gap between what is currently possible, and the hyperbole narratives presented by companies and media when extended to the public. But the discussion of AI ethics is not limited to academic research. Among others, it touches upon politics and its regulating institutions which can and should ensure that negative impacts of AIs are avoided.[187]

The issues currently addressed by AI ethics are very important and need to be considered in the sustainability assessment of AI. However, they only address one aspect. The focus on issues directly affecting humans addresses the social side of sustainability and partially the economic as well as some ethical values, but it misses the environmental impact of AIs.

## 1.3. The Physicality of AI

Recently more attention has been paid to the environmental impact of AI. Mark Coeckelbergh criticised the human-centredness of AI ethics, which seems to ignore AI's link to global inequalities.[188] To rectify this, he argues it is important to also consider its use and production.

---

[184] Mark Coeckelbergh, *AI Ethics* (Cambridge, Massachusetts: MIT Press, 2020).
[185] Anibal Monasterio Astobiza et al., "AI Ethics for Sustainable Development Goals," *IEEE Technology and Society Magazine* 40, no. 2 (2021): pp. 66-71, https://doi.org/10.1109/mts.2021.3056294. found that there is a lack of testing the consequences of AI which they link to issues of lacking ethics, education, fairness, transparency and explainability.
Pak-Hang Wong, "Democratizing Algorithmic Fairness," *Philosophy &Amp; Technology* 33, no. 2 (2019): pp. 225-244, https://doi.org/10.1007/s13347-019-00355-w. discusses algorithmic fairness
[186] Astobiza et al., "AI Ethics."; Ensmenger and Slayton, "Computing and the Environment."; Illah Reza Nourbakhsh, "AI Ethics: A Call to Faculty," *Communications of the ACM* 64, no. 9 (2021): pp. 43-45, https://doi.org/10.1145/3478516.
[187] Wong, "Democratizing Algorithmic Fairness."
[188] Mark Coeckelbergh, *AI Ethics,* chap.2.

According to Coeckelbergh, how we currently use and produce AI could also aggravate current problems such as exploitation and possibly widen the gap between rich and poor due to insufficient consideration of environmental and ethical issues. He finds the understanding of AI as solution to every problem especially dangerous[189] While Coecklebergh remains vague in this publication, others have outlined the areas of impact and the impact itself. Researchers in fields such as economics and AI (begin to) provide the data necessary for a comprehensive analysis of the impact of AI. One way of assessing the impact of AIs is to calculate their carbon footprint sometimes also called the digital carbon footprint. The carbon footprint describes all carbon emissions and effects related to one product throughout its life cycle. This includes the acquisition of rare materials, production and assembly, transportation, operation, and end-of-life-treatment.[190] This concept can also be applied to whole industries such as the ICT sector as described by Jens Malmodin and Dag Lundén, which provides relevant insights for the analysis of AI carbon footprints too.[191]

A variety of hardware pieces and well-developed software are necessary to operate an AI. The hardware most familiar to users is likely their personal device such as a smartphone, laptop, tablet or computer. This device might trigger the use of an AI, such as a language processor, when using a chatbot or accesses information previously created by an AI, such as tags in online stores. Another important hardware piece, or rather pieces, are data centres and their servers. Depending on the use context, the AI software is run either on a local server or on external resources such as Amazon Web Services or Google Cloud (Computing). Before an AI can be run it needs to be developed and trained. All these stages and parts have an environmental impact which I will outline in this section. For a better overview, I will distinguish between impacts related to hardware production and software development and running.

### *1.3.1. The Sustainability Impact of Hardware Production and Recycling*

The production and recycling of the necessary hardware are problematic both from an environmental and social perspective. One issue is the extreme water consumption for the production of semiconductors and other parts.[192]. Furthermore, the production conditions are not much different from traditional industrial methods and workers are still exposed to health

[189] Mark Coeckelbergh, *AI Ethics,* chap.2.
[190] Ericsson, "Background Report to 'A Guide to Your Digital Climate Impact'," 2020, pp. 1-51.
[191] Jens Malmodin and Dag Lundén, "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015," *Sustainability* 10, no. 9 (2018): pp. 3027-3058, https://doi.org/10.3390/su10093027.
[192] Ensmenger, "The Environmental History."

threats, such as hazardous chemicals.[193] Although most of the toxic production has been moved outside of western countries, its remains can still be found. Silicon Valley, for example, has the largest concentration of Superfund sites[194], which are linked to the semiconductor production of the 1980s.[195] Moving the production abroad removes it from the sight of its beneficiaries, further supporting the idea of clean and green digital technologies and perpetuating the disconnect between digital technologies such as AIs and their physical form. Not only the production, but also the recycling of the electronics, is problematic and again removed from the sight of the beneficiaries. In 2019, 53.6 Mt of electronic waste was produced globally, of which 11.4 Mt are screens, monitors, small IT, and telecommunication equipment.[196] Only 17.4% of this waste is currently properly recycled. For the rest, it is unclear under which conditions and where in the world it is handled. This means that digital pollution is not limited to the western world.[197] But its benefits are mainly enjoyed in the west, resulting in a social imbalance.

The energy consumption, problematic production, and waste conditions are not the only issues regarding the hardware. To produce digital technologies, a number of rare or at least finite materials are required. Modern batteries used for mobile devices and backup power units in data centres, for example, require lithium which needs to be mined. Other important materials, such as tin or rare earths, are also mined or collected in similarly hazardous ways. Crawford points out that mining is only profitable for a few through the exploitation of natural resources and humans. The true costs are paid by the environment, the miners, and the communities which are displaced. Additionally, mining tends to create a concentration of corporate and geopolitical power which is highly problematic for the supply of some rare earths. Lithium, for example, is sourced in Bolivia, Central Congo, Mongolia, Indonesia, and Western Australia which all struggle with ongoing political tensions. In some rare instances the mining industry even finances (civil) wars.[198] A lot of the other rare materials required for the production are found in similar areas with similar political tensions and issues. The use of these, often called, "conflict" minerals causes social and environmental suffering, which should make it unfavourable from a sustainability perspective. Tech Companies in the US have implemented

193 "ibid."
194 Superfund sites are highly polluted areas in need of immediate remediation. In the case of Sillicon Valley the harmful pollutants are chemicals in the soil.
195 "ibid"; Ensmenger and Slayton, "Computing and the Environment."
196 V Forti et al., "The Global E-Waste Monitor 2020: Quantities, Flows and the Circular Economy Potential" (Bonn/Geneva/Rotterdam: United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), 2020).
197 Ensmenger, "The Environmental History," p. 25.
198 Crawford, *Atlas of AI, chap. ONE*

certificates and analysed their supply chains to ensure they only buy humanely produced materials. However, the supply chain is so complex it is almost impossible to keep track of, this means the occurrence of human suffering cannot be completely ruled out.[199] This means it is currently not possible to accurately determine if a server used for AI training was created under humane conditions.

Another problem is, that embodied rare earth flows are a vulnerable system.[200] The embodied rare earth flow encompasses the total amount of directly and indirectly consumed rare earths during the whole process, this includes machining, manufacturing and transportation. Disturbances in one sector will quickly impact the other sectors.[201] Due to a variety of risk factors, such as political tensions, disturbances are possible. Nedal T. Nassar and their team analysed the risk factor for a number of minerals.[202] They found that the supply risks are increasing and decreasing with the changing global market and that the conditions are specific to each commodity and the industry it is used in. One threat that determines the risk factor are monopolies. China, for example, currently has a monopoly on certain rare earths as they are mainly mined there. The monopoly on these resources allows China to use resource nationalism as a tool to increase its geopolitical influence, as other countries are dependent on the supply.[203]

To summarise, the hardware necessary to operate AI systems is problematic for the following reasons. The production requires vast amounts of water and energy and relies on mineral resources which are finite and conflict laden. By requiring rare earths, the production of hardware relies on a sensitive supply chain that is built on exploitation and is vulnerable to political power struggles.

### *1.3.2. The Sustainability Impact of Developing and Running AI*

Before an AI can be used it needs to be developed and in the case of machine learning algorithms it needs to be trained. The process of developing and training an AI has environmental and social impacts. How severe these are depends on the type of AI and the used hardware. In 2019 Emma Strubell, Ananya Ganesh and Andrew McCallum published one of

199 "ibid."
200 Xibo Wang et al., "Embodied Rare Earths Flow between Industrial Sectors in China: A Complex Network Approach," *Resources, Conservation and Recycling* 125 (2017): pp. 363-374, https://doi.org/10.1016/j.resconrec.2017.07.006.
201 "ibid."
202 Nedal T. Nassar et al., "Evaluating the Mineral Commodity Supply Risk of the U.S. Manufacturing Sector," *Science Advances* 6, no. 8 (2020), https://doi.org/10.1126/sciadv.aay8647.
203 M. Aczel, "Political economy, economies and development," review of *China and the geopolitics of rare earths,* by S. Kalantzakos, International Affairs, 94, 4, 2018

the first studies assessing the energy consumption of developing a Natural Language Processor (NLP), a form of AI necessary for language-operated programs, such as chatbots or sophisticated search functions.[204] They assessed two different program types and found that the training of a model consumes a significant amount of energy which is increased a thousandfold by R&D processes such as retraining and experimenting with architectures. During their testing a Transformer model, for example, produced 192 Ibs of $CO_2e$[205] emissions in one training, when they applied neural architecture search this increased to 626 155 Ibs of $CO_2e$. This is more than a car produces on average throughout its entire life cycle (126 000 Ibs).[206] The approach taken by Strubell and her team has been criticised in a recent publication by David Patterson and colleagues (2022) who find that these numbers are 100-100 000 times higher than the actual carbon footprint.[207] They also provide a more differentiated view on different development and research methods, arguing that the search for better algorithms reduces the impact of machine learning downstream, outweighing the costs of searching.[208] Specifically, Neural Architecture Search is considered to provide environmental gain if the model is trained more than once.[209] Although the energy consumption of AIs might not be as drastic as calculated by Strubell et al., the lack of consideration for energy efficiency is a topic of concern. Da Li, Xinbo Chen, Michela Becchi & Ziliang Zong (2016) criticised the lack of consideration for energy efficiency even earlier, pointing out that it is never an element of consideration in comparing different models.[210] The exact energy use of an AI depends on both soft- and hardware aspects. In regard to software, some algorithms are better suited for specific applications than others which can impact energy consumption. A better-suited machine learning approach should reduce training time and energy use. Nevertheless, some methods such as deep learning seem to inherently require more computing power and energy than others.

[204] Emma Strubell, Ananya Ganesh, and Andrew McCallum, "Energy and Policy Considerations for Deep Learning in NLP," *Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics*, 2019, pp. 3645-3650, https://doi.org/10.18653/v1/p19-1355.
[205] $CO_2e$ encompasses carbon emissions and carbon equivalent emissions of greenhouse gases, such as for example methane.
[206] Strubell et al., "Energy and Policy," p.1
[207] David Patterson et al., "The Carbon Footprint of Machine Learning Training Will Plateau, Then Shrink," *Computer*, July 2022, pp. 18-28. It should be mentioned that three of the cited authors currently work for Google and others have previously had relationships with it. There could be an interest to portray AI more positively. The version published in Computer makes the relationship clear and references Google as a positive example. A previous version accessible online did not mention the connection of the researchers to Google.
[208] "ibid", p. 8.
[209] "ibid", p. 28.
[210] Da Li et al., "Evaluating the Energy Efficiency of Deep Convolutional Neural Networks on CPUs and GPUs," 2016 IEEE International Conferences on Big Data and Cloud Computing (BDCloud), Social Computing and Networking (SocialCom), Sustainable Computing and Communications (SustainCom) (BDCloud-SocialCom-SustainCom), 2016, https://doi.org/10.1109/bdcloud-socialcom-sustaincom.2016.76.

Thompson and their colleagues argue that this is related to the amount of input data points.[211] The more data points are used, the more deep learning parameters are necessary, which increases the need for computing power and energy.

Lie et al. also found that energy consumption is influenced by the used processors such as CPUs or GPUs. Recently, hardware specifically built for machine learning purposes, such as TPUs, provide further energy savings due to increased efficiency.[212]

Operating an AI requires data centres or at least one server. These data centres are made up of thousands of servers relying on the previously discussed processors and cooling equipment. Data centres are running 24/7 and are a central part of the infrastructure necessary to run Information and Communication Technologies. Belkhir and Elmeligi found that data centres contribute 33% to the overall ICT carbon footprint, which they estimated would further increase to 45% in 2020. This equates to 155 Mt $CO_2$ in 2010 and 455 Mt $CO_2$ in 2020.[213] Currently, the progress in the energy efficiency of the required systems mitigates the increased energy demand and the feared jump in energy consumption has not yet happened.[214] According to Miyuru Dayarathna and their colleagues the used energy is split between cooling (50%), lighting (3%), power conversion (11%), network hardware (10%), and server storage (26%).[215] The exact percentages might change with improvements in the hardware of the systems. How much energy is used by a data centre depends on its construction. Google's most advanced facilities, for example, work at higher temperatures and rely on a water-based cooling system, which saves significant amounts of energy, compared to traditional air-cooled centres.[216] In the summer of 2022 several blackouts took place in London facilities because the high temperatures put too much stress on the system. Such instances might occur more often in the future if the (cooling) systems are not updated to better handle high temperature levels, as the recent weather trends suggest a further increase in temperatures in future summers.[217] The increased need for cooling might raise the energy consumption for data centres and increase risk of blackouts. Currently, most centres reach a utilization of 95% but with the increasing digitalisation, this

---

[211] N.C. Thompson, K. Greenewald, K. Lee, and G.F. Manso, "The computational limits of deep learning." (2020), arXiv preprint arXiv:2007.05558.

[212] Alexandre Lacoste et al., "Quantifying the Carbon Emissions of Machine Learning," *Preprint*, 2019, 2.

[213] Belkhir and Ahmed Elmeligi, "Assessing ICT," p. 458.

[214] Ericsson, "Background Report."; George Kamiya, "Data Centres and Data Transmission Networks – Analysis," IEA, November 1, 2021, https://www.iea.org/reports/data-centres-and-data-transmission-networks.;

[215] Miyuru Dayarathna, Yonggang Wen, and Rui Fan, "Data Center Energy Consumption Modeling: A Survey," *IEEE Communications Surveys & Tutorials* 18, no. 1 (2016): pp. 732-794, https://doi.org/10.1109/comst.2015.2481183, 455

[216] Steven Levy, "Google Throws Open Doors to Its Top-Secret Data Center," October 17, 2012, https://www.wired.com/2012/10/ff-inside-google-data-center/.

[217] Chris Stokel-Walker, "Data Centers Are Facing a Climate Crisis," August 1, 2022, https://www.wired.com/story/data-centers-climate-change/.

might change.[218] Considering the current climate crisis and weather trends it is essential to find new cooling methods which will not use more energy.

For the calculation of the carbon footprint or energy use of AIs usually, only the operational costs of running the AI in a data centre are calculated. Most parts in the data centre system have a useful life of roughly ten years. But servers only have a useful life of three to five years. While only little is known about the costs of data centres throughout their life, their costs are estimated to be small compared to the consistent use by people spread across different regions.[219] Although the impact of producing data centres seems small it still affects many people and regions. Mining materials for servers and other electronics can affect people negatively as discussed. Furthermore, it appears that data centres are sometimes built without concern for how they will affect the local flora, fauna, and society. So, while it is hard to acknowledge their costs in the carbon footprint calculations of AIs, they should be considered in the choice of data centre.

Next to energy, data centres require land and a significant amount of water, mainly for their cooling systems. While the intense consumption of water is already concerning, Mél Hogan finds the political implications of current solutions even more concerning.[220] To ensure enough water is provided at a low price many corporations make deals with local governments to build wells and water pumps and to share water treatment plans, which are supposed to benefit both. This entanglement of public service and corporations creates a co-dependency which could prove detrimental to the public, especially with such a precious good as water.

The development and running of AIs is therefore, not only detrimental to the environment, but the hidden labour also exploits humans. Crawford compares AIs to Potemkin's villages. According to her, many automated systems rely on both the underpaid work of digital pieceworkers and consumers taking on functions of the systems without any pay. The true labour costs are consistently downplayed and the use of AIs is part of a long tradition of exploitation and deskilling.[221] In the end, AI systems may be even less effective or reliable than the systems they replace, but their scalability allows for a reduction in costs and an increase in profit, which makes them attractive to companies.[222] Especially the deskilling of labour and use of crowdsourcing platforms such as Amazon's Mechanical Turk, which

[218] "ibid"
[219] Belkhir and Ahmed Elmeligi, "Assessing ICT," p. 455.
[220] Mél Hogan, "Data Flows and Water Woes: The Utah Data Center," *Big Data & Society* 2, no. 2 (2015): p. 1-12, https://doi.org/10.1177/2053951715592429.
[221] Crawford, *Atlas of AI*, p. 65.
[222] "ibid", p. 66.

outsources simple tasks such as tagging data for low costs, can advance existing global inequalities.

Both the high resource demand (for both water and energy) and the possible increase of global inequalities due to the effect of AIs on labour markets are detrimental sustainability goals and can hardly be considered sustainable behaviour.

### 1.4. Conclusion: The Hidden Costs of AI

AIs are not the clean, green, magic solutions that media and companies portray and want people to believe in. They are not immaterial entities that simply exist without severe consequences. They are the opposite, and we should talk about them as such. It is necessary to acknowledge the importance of material aspects of AIs for their sustainability assessment, especially if they are employed to increase the sustainability of a company such as a fashion retailer. This discussion should include the environmental impact of AIs, such as their carbon footprint and their social impact on labour conditions.

The discussion of AI needs to connect the intended consequences, which can be furthering sustainability goals, with its accidental consequences, such as the perpetuation of societal biases, and its physical consequences, which can be detrimental to sustainability goals. Only the discussion and consideration of all these aspects in the development and implementation of AIs will result in AI systems that can achieve their purpose of addressing societal issues without furthering or creating other problems. To achieve this, costs and benefits need to be carefully weighed against each other. Such an analysis should include social and environmental concerns, such as energy and resource consumption, labour conditions as well as ethical considerations, such as fairness or privacy. This only seems possible if AI is seen realistically by acknowledging its physicality, which includes the dependency on a massive infrastructure of end devices, fibre optic cables, data centres, R&D and hidden labour.

# Chapter Three: Sustainable AI for Sustainable Fashion

Sustainable AI is currently discussed in publications of fields such as computer engineering or AI ethics. In general, these publications can be grouped into two categories which need to be combined to have a truly sustainable AI. Aimee van Wynsberghe identified publications about AIs *for* sustainability and papers about the sustainability *of* AI.[223] Within these two categories, van Wynsberghe found more publications on AI for sustainability which led her to believe more attention and funding is paid to this category. Although creating AIs to achieve sustainability goals is important, doing so without considering the sustainability of AI might be detrimental, as it neglects the physicality of AI discussed in chapter two section one. In the following, I will outline the current understanding of AI for sustainability and sustainability of AI. Based on this and the established definition of sustainable fashion I will provide a definition for sustainable AI in the sustainable fashion context.

## 1.1. AI for Sustainability

The literature on AI for sustainability usually considers the implementation of AI as a solution to current problems such as the SDGs. In a study, based on a literature review, evaluating the impact of AIs on the SDGs, Ricardo Vinuesa and their colleagues found that AI could enable 134 (71%) of the SDG targets while only impacting 59 (23%) negatively.[224] Although this paints a bright future for AI applications, Henrik Skaug Sætra has criticised the study based on its methodology and scope.[225] The authors also acknowledge that the literature might have been biased towards positive results, since long-term studies, that are more likely to also show negative effects, were not yet available.

But Vinuesa and their team are not the only ones considering AI applications as possible solutions for the SDGs. Astobiza and their colleagues also view AIs as tools to achieve the SDGs, under the condition they are developed from an ethical standpoint which includes environmental concerns.[226] To make the development of such an AI easier, Lucian Floridi and

---

223 Aimee van Wynsberghe, "Sustainable AI: AI for Sustainability and the Sustainability of Ai," *AI and Ethics* 1, no. 3 (2021): pp. 213-218, https://doi.org/10.1007/s43681-021-00043-6.
224 Ricardo Vinuesa et al., "The Role of Artificial Intelligence in Achieving the Sustainable Development Goals," *Nature Communications* 11, no. 1 (2020), https://doi.org/10.1038/s41467-019-14108-y.
225 Henrik Skaug Sætra, "AI in Context and the Sustainable Development Goals: Factoring in the Unsustainability of the Sociotechnical System," *Sustainability* 13, no. 4 (2021): p. 1738, https://doi.org/10.3390/su13041738.
226 Anibal Monasterio Astobiza et al., "AI Ethics for Sustainable Development Goals," *IEEE Technology and Society Magazine* 40, no. 2 (2021): pp. 66-71, https://doi.org/10.1109/mts.2021.3056294.

his colleagues have developed the AI4People framework.[227] This framework outlines what AI for sustainability should entail and how different stakeholders such as governments and companies can contribute. Floridi et al. think that AI will benefit humans, but also has the potential for harm if overused or misused.

Another way of implementing AI for sustainability is to help implement new processes and methods which then contribute toward sustainability. An example of this would be using AI to implement a circular economy as outlined by the Ellen McArthur foundation.[228] Such reports provide a starting point for companies, such as H&M, who want to achieve sustainability by, for example, implementing a circular economy business model.

Although AI for sustainability has a lot of potential, some authors criticise it. Both Astobiza et al. and Coeckelbergh raise concerns that AIs have the potential to create new political and social problems, while solving current ones.[229] Furthermore, Coeckelbergh finds the idea of AI as a solution for everything problematic.[230] According to him, this attitude of techno-solutionism reflects the problematic, overbearing human control of the planet, which is the root problem of climate change.

AI for sustainability aims to solve problems which contribute mainly to climate change but also other social and economic issues. In doing so, the focus is on problem solutions, which can lead to neglecting possible adverse effects of AIs and reflects the previously discussed attitude of AI as a magic solution. Supplementing AI for sustainability with concerns about the sustainability of AI might resolve some of these issues.

### 1.2. Sustainability of AI

The discussion of the sustainability of AI touches mainly on three points. It discusses sustainability as an overarching framework, which adds future and ecological concerns to the AI discussion.[231] Furthermore, it stresses the importance of acknowledging and measuring the

[227] V. Forti et al., "The Global E-Waste Monitor 2020: Quantities, Flows and the Circular Economy Potential" (Bonn/Geneva/Rotterdam: United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), 2020).
[228] M. C. Elish and danah boyd, "Situating Methods in the Magic of Big Data and AI," *Communication Monographs* 85, no. 1 (2017): pp. 57-80, https://doi.org/10.1080/03637751.2017.1375130.
[229] Mark Coeckelbergh, "AI for Climate: Freedom, Justice, and Other Ethical and Political Challenges," *AI and Ethics* 1, no. 1 (2021): pp. 67-72, https://doi.org/10.1007/s43681-020-00007-2.
[230] "ibid," Mark Coeckelbergh, *AI Ethics* (Cambridge, Massachusetts: MIT Press, 2020).
[231] Larissa Bolte, Tijs Vandemeulebroucke, and Aimee van Wynsberghe, "From an Ethics of Carefulness to an Ethics of Desirability: Going beyond Current Ethics Approaches to Sustainable AI," *Sustainability* 14, no. 8 (2022): pp. 4472-4485, https://doi.org/10.3390/su14084472.

energy use of AIs.[232] Finally, it emphasises the need to view AI in context as infrastructures and socio-economic systems[233] The latter point links back to the topic of AI for sustainability.

In chapter two section 1.3.1 and 1.3.2, I outlined the physical impact of AIs on the environment. One big aspect of this impact is the increasing energy consumption of running and training AIs. Therefore, Coeckelbergh argues for the need to acknowledge energy use as a relevant ethical value, which ideally also becomes a measure of success.[234] This sentiment is iterated in the 'AI now' report which suggests that 'Governments should mandate public disclosure of the AI industry's climate impact.'[235] Van Wynsberghe also argues that such calculations should be explicit and open to debate. Additionally, she sees the need to incentivise researchers and industry to measure and report carbon emissions by, for example, using existing carbon trackers.

Some authors in the field of computer science have similar ideas, although they might use different terms. Roy Schwartz and his team provide definitions for green AI, which pursues novel results while considering computational costs, and red AI, which focuses on improving accuracy by using immense computational power, neglecting its costs. The former is comparable to sustainable AI while the latter is the industry standard that most publications focus on, as it pushes boundaries.[236] Similarly to Coeckelbergh, they suggest using efficiency instead of accuracy as a measure for the success of green AI. But determining efficiency as a global measure is difficult. Factors such as the server set-up also impact the efficiency of an AI next to how the code utilises resources. Therefore, a variety of measures have been suggested. Schwartz and his team favour FPOs. But to assess the sustainability of an AI, many authors focus on carbon emissions, which has its own difficulties. Strubell and her team provided an initial approach for calculating the carbon emissions of an AI.[237] Other authors created pieces of code which can be implemented in an AI to calculate or monitor the carbon emissions of training the AI more easily.[238]

---

[232] van Wynsberghe, "Sustainable AI."; Coeckelbergh, "AI for Climate."
[233] Bolte, Vandemeulebroucke, and Wynsberghe, "From an Ethics of Carefulness."; Scott Robbins and Aimee van Wynsberghe, "Our New Artificial Intelligence Infrastructure: Becoming Locked into an Unsustainable Future," Sustainability 14, no. 8 (2022): pp. 4829-4840, https://doi.org/10.3390/su14084829.
[234] Coeckelbergh, "AI for Climate," p. 61.
[235] Kate Crawford et al., "AI Now", 2019 Report. New York: AI Now Institute, 2019, https://ainowinstitute.org/AI_Now_2019_Report.html .
[236] Roy Schwartz et al., "Green AI," *Communications of the ACM* 63, no. 12 (2020): pp. 54-63, https://doi.org/10.1145/3381831.
[237] Emma Strubell, Ananya Ganesh, and Andrew McCallum, "Energy and Policy Considerations for Deep Learning in NLP," *Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics*, 2019, pp. 3645-3650, https://doi.org/10.18653/v1/p19-1355.
[238] Peter Henderson et al., "Towards the Systematic Reporting of the Energy and Carbon Footprints of Machine Learning," *Journal of Machine Learning Research* 21 (2020): pp. 1-42.; L.F. Wolff Anthony, B. Kanding, and R. Selvan,

An increase in efficiency also means a decrease in required computing power, which is the driving factor in energy consumption. Reducing the necessary computing power is also beneficial for cost reduction, as computers less powerful than super-computers can run the programs and the energy costs are lower. This is important to ensure access for students and researchers, who lack the financial means to access a supercomputer.[239]

While the carbon footprint is a good measure for the environmental sustainability of AI, it does not capture social and economic impacts. To do so, it is necessary to see AIs as infrastructures.[240] This allows recognizing the potential risks of a lock-in beyond the emissions. Relying on AIs without an understanding of their connection to environmental consequences could lock in society in a way that prevents any change in infrastructures should it be deemed necessary. AIs can be evaluated by analysing them on several levels, for example on a societal, implementation and application level or on a micro, meso and macro level.[241]

Considering AI as infrastructure, or rather socio-economic systems, facilitates the recognition of problems slightly removed from the application of AIs. As a socio-economic system AIs, are dependent on supply chains, the energy grid, workers and more. As discussed in chapter two section 1.4.1 the procurement of important resources is likely connected to bad labour conditions. Furthermore, the trade of certain materials is prone to (political) disruptions, as few countries, which are partly politically unstable, have monopolies over important materials. Considering AIs within the bigger context opens the discussion of different problems and could be a first step to resolving them.

### 1.3. Defining Sustainable AI for Sustainable Fashion

In chapter one section 1.1.5, it becomes clear that context-specific definitions are advantageous, as they are often more tangible and easier to translate into actions. Defining sustainable AI is a more specific definition of sustainability, but the context of this thesis requires an even narrower definition. Therefore, I will provide a definition of sustainable AI for sustainable fashion.

Sustainable fashion is defined as fashion that has minimal environmental impact throughout its life cycle, promotes decent labour and human rights, encourages environmentally friendly behaviour, and has a persistent business model (not relying on consistent growth but maintenance). AIs can be tools to support companies in achieving these ideals.

" Carbontracker: Tracking and Predicting the Carbon Footprint of Training Deep Learning Models," ICML Workshop on "Challenges in Deploying and Monitoring Machine Learning Systems", 2020.

239 Strubell, et al., "Energy and Policy," p. 1.; Schwartz et al., "Green AI," p. 54.

240 Robbins and van Wynsberghe, "Our New Artificial."

241 Frederike Rohde et al., "Nachhaltigkeitskriterien Für Künstliche Intelligenz. Entwicklung Eine Kriterien- Und Indikatorensets Für Die Nachhaltigkeitsbewertung Von KI-Systemen Entlang Des Lebenszyklus" (Berlin: Institut für ökologische Wirtschaftsforschung GmbH, 2021).: Sætra, "AI in Context."

According to the discussion above, an AI should encompass both AI for sustainability and sustainability of AI. This includes supporting sustainability goals and facilitating the necessary change as well as taking into account ethical considerations such as privacy or concerns of possible biases. Additionally, developing a sustainable AI means taking future and environmental considerations into account. Furthermore, it requires the analysis of the AI within the context of infrastructures and paying special attention to energy use or rather carbon emissions as an environmental sustainability measure. Another important consideration is to avoid techno-solutionism. Although AIs are very promising, they will not resolve current problems without necessary societal change.

To be considered a sustainable AI for sustainable fashion, the AI needs to promote the ideals of sustainable fashion both in how it is developed and how it is applied. Since the ideals of sustainable fashion and sustainable AI overlap, combining the two definitions or requirement lists results in a rather long list of principles a sustainable AI for sustainable fashion should follow.

A sustainable AI for sustainable fashion:

- Supports achieving sustainable fashion goals such as reducing the environmental impact of production or moving to a circular economy business model.
- Has a minimal environmental impact throughout development and use. This includes a low carbon footprint and efficient use of resources such as computing power or materials necessary to build servers and data centres.
- Adheres to AI ethics standards, such as protecting privacy and preventing biases.
- Adheres to decent labour and human rights standards both when applied and during the development process. This includes the software developers and workers in the supply chain, such as workers in data centres or creators of training datasets.
- Is understood as an important infrastructure which will impact the future beyond direct application consequences.
- Is only used if an analogue or less technical solution is not feasible or the benefits outweigh possible downsides significantly.

The last principle is intended to avoid tendencies of technosolutionism which can lead to problems in the future. This is an extensive list which ideally is completely fulfilled.

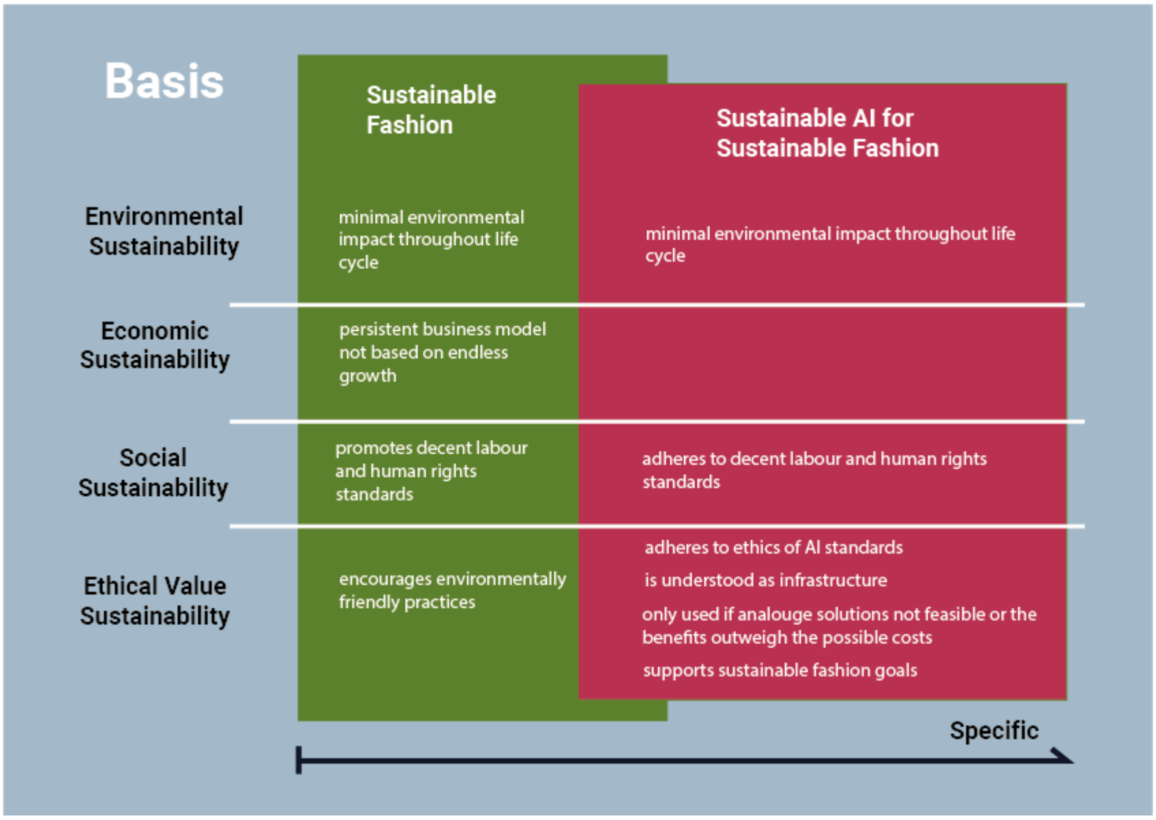



*Figure 2: Visualisation of the sustainable AI for sustainable fashion definition in relation to the sustainable fashion definition and thee four pillars of sustainability. The definition of sustainable AI for sustainable fashion draws on the definition of. Sustainable fashion and applies them to AI. Additionally, some concerns from the discussion of sustainable AI are represented as well*

But even if some aspects are not achieved, an AI can still be sustainable it will only be closer to thin sustainability than to the ideal thick definition outlined here. Some of the principles can be attained more easily than others. H&M, for example, already has set requirements for ethical AI and one can draw from the already existing field of AI ethics. Ensuring good working conditions throughout the supply chain could be more difficult. Due to the complexity of the supply chain, the insight and impact of companies can be limited. Nevertheless, wherever possible the most sustainable option should be chosen. The definition of sustainable AI for sustainable fashion and its realtion to the sustainable fashion definition and four pillars of sustainability are illustrated in figure 2.

# Chapter Four: Developing Sustainable AI for Sustainable Fashion

## 1. Approaching Sustainable AI with Responsibility

Ensuring the sustainability of a sustainable fashion AI is not easy. The list of things that need to be considered is very long and not everything can be always fulfilled, which means trade-offs are necessary. A checklist appears to be one of the easiest ways to ensure everything is accounted for. Although it is an easy tool, it is not ideal for such a complex problem. The shortcomings of this method can be observed in the field of architecture. They use checklists to ensure, for example, the accessibility of buildings. Nevertheless, adhering to the list does not always prevent the exclusion of minorities. A good example of this is the Hunters Point Library in the US. Although the construction adheres to all requirements, including the American Disabilities Act, upon opening, people with walking impairments could not access all sections of the library. They could only access five floors with an elevator but not the raised levels, which housed a large part of the fiction section and working spaces.[242] This example illustrates the problem with checklists: they need to be narrow to be useful as requirements and at the same time general enough to apply to most situations. For example, requiring an elevator to access all floors does not take into account possible outliers such as half levels.

Instead of providing a typical ethical or rather sustainable design approach, I suggest taking note of Philippe d' Anjou's Sartrean design approach.[243] This approach emphasises the designer's or developer's awareness of their design freedom and responsibility, as well as external and contextual demands and practical limitations.[244] The core value of this approach is freedom. Confronted with the task to develop or implement a sustainable AI for sustainable fashion (SF), this freedom is challenged. The person responsible for the sustainable AI can either leave the project or accept the sustainability principles presented in chapter three and make them their own. This applies to the AI developers as well as the decision makers of a company who initiate the use of an AI or ensure sustainability standards are adhered to. How

---

[242] Elizabeth Kim, "The New $41 Million Hunters Point Library Has One Major Flaw," October 3, 2019, https://gothamist.com/news/new-41-million-hunters-point-library-has-one-major-flaw.; Lisa Peet, "Hunters Point Library Confronts Accessibility Issues," November 4, 2019, https://www.libraryjournal.com/?detailStory=hunters-point-library-confronts-accessibility-issues.; Stone, Leilah. "Hunters Point Library Called out over Accessibility Issues," October 8, 2019. https://www.archpaper.com/2019/10/hunters-point-library-called-out-over-accessibility-issues/.
[243] Philippe d'Anjou, "An Alternative Model for Ethical Decision-Making in Design: A Sartrean Approach," *Design Studies* 32, no. 1 (2011): pp. 45-59, https://doi.org/10.1016/j.destud.2010.06.003.
[244] "ibid," p. 51.

these standards are fulfilled is up to them. Essentially the designer or decision maker is responsible for the outcome of their choices and recognises this burden.

But to be able to fully acknowledge their responsibility AI developers and the company's decision makers need to understand the scope of their decisions. If AI is understood as a magic solution, the decision makers and developers might not think further than how well the AI will solve a specific problem. With such an approach many sustainability concerns could be overlooked. Acknowledging the physicality of AI, as discussed in chapter two section one and taking the principles from chapter three as ideals, or at least as thinking points, should reduce the number of overlooked sustainability issues significantly. Taking these aspects into consideration will lead to better solutions long-term, as not only current problems are mitigated but future problems are ideally avoided.

I suggest that the designer takes the principles provided in chapter three and develops ideas on how to fulfil them. The different solutions will be more or less sustainable. In chapter one section 1.1.3, I suggested that sustainability exists on a spectrum. It can be thick, providing an ideal case, or thin, only fulfilling a minimum of requirements. The proposed solutions can be compared to each other and placed within this spectrum to determine the best solution, which should be as close as possible to thick sustainability. To compare the sustainability of a solution, it is possible to use some objective factors such as the energy used, or waste produced by a solution. In this case the lesser of both the better.

To support the decision process, it can be helpful to use a visualization tools. Charles B. Fledderman has outlined a methodology for analysing the applicability of moral principles to a problem, in which it is clear which two moral principles are relevant, but unclear which one applies to the situation at hand.[245] In these visualisations different variations of the situation are played through. Fledderman begins by drawing a straight, horizontal line. On one end of the line, an example of something applicable to the situation and unambiguously morally negative is placed. This is the negative paradigm. At the other end of the line the positive paradigm, something unambiguously morally positive, is placed. Between these two examples, the initial problem is placed along with other similar examples. The examples are placed on the line in such a way, that they are closer to the paradigm they conform to more closely. The initial problem should be placed between the other examples, after careful consideration of the

[245] Adapting Fledderman too was derived from educational toolkit as proposed by Poole, See, Poole. Alexandria Two Skills for Integrating Ethical Requirements into Design, Lecture for CreaTe, Spring 2022. University of Twente. Charles B Fleddermann, *Engineering Ethics*, 4th ed. (Upper Saddle River, NJ: Person Education , 2012), p.59.

continuum. If it is placed correctly, it is possible to determine if the initial problem is more like the positive or negative example and thereby if it is morally acceptable or not.[246]

Inspired by Fledderman's line drawings, I have adapted this methodology to apply to the decision-making process during the development of sustainable AI. The methodology provides a tool to visualise and analyse the different degrees of sustainability different solutions can achieve. Instead of calling these diagrams line drawings as Fledderman does, I will refer to my iteration as sustainability spectrum drawings. By placing the different solutions on the sustainability spectrum drawing they can be compared to one another and their relations to thick and thin sustainability become visible. This visualisation supports the choice for the most sustainable solution possible. To be successful the tool requires a reflective and honest attitude from its users.

To use a spectrum drawing, first, the two extremes of the spectrum need to be defined. I propose to use thin and thick sustainability for the two extremes. These can then be exemplified by examples. An example of thick sustainability would adhere to all applicable principles as defined in the ideal definition. In the context of this thesis, this would be the definition of sustainable AI for sustainable fashion, as provided in chapter three. Depending on the context it might not yet be possible to fulfil all requirements of the ideal definition. Nevertheless, it is the ideal decision makers should aspire to. To illustrate thin sustainability an example of a solution, which adheres to one more principle of the ideal definition than the current status quo would suffice. By using the concept of thin sustainability as the lower end of the spectrum at least a minor improvement compared to the status quo is ensured. The closer a solution is to thick sustainability, the more favourable it is. An example of a sustainability spectrum for different examples of fair wages can be found in Figure 3.

[246] "ibid.".

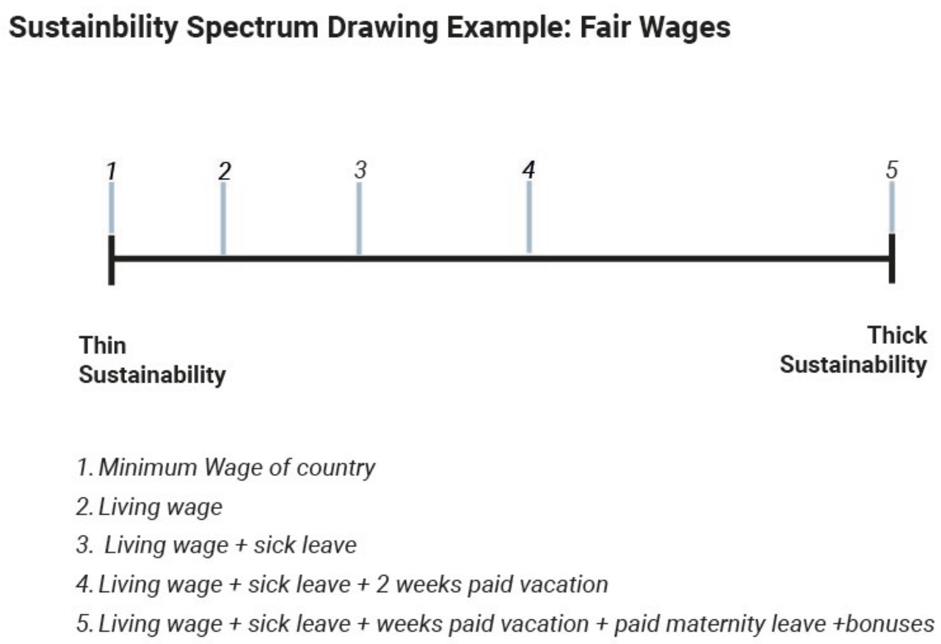



*Figure 3: Example of a sustainability spectrum drawing*

During the development of a sustainable AI, many factors and solutions need to be considered. To ensure the best combination of solutions is chosen, the use of sustainability spectrum drawings could be helpful to illustrate all possible solutions. Often, it is necessary to make trade-offs. By comparing the different solutions and taking the socio-economic context into consideration, the best choice can be made, including necessary trade-offs. Before I provide an example of this approach, I will outline methods to reduce carbon emissions during the development of AIs. Carbon emissions are an essential measure for the environmental sustainability of an AI and one aspect of the AI development which can be influenced more easily.

## 2. Reducing the carbon footprint of AIs

It should be clear by now that AIs have a significant impact on the environment and people. It is difficult to assess the various impacts, as most cannot be easily translated into quantifiable measures. The social, environmental and economic impacts of AIs are relevant for their sustainability assessment. The economic impact could be quantified by comparing costs before and after implementation, as well as profits. But it is important to remember that this will only show correlations as there are a variety of other factors such as inflation or general consumption behaviour that also affect the costs and wins of a fashion company. The social impact is more difficult to measure. Much of the labour necessary to keep an AI running such as mining rare earths or data preparation is hidden and behaviour and societal changes become only visible with time. Furthermore, they are not easily quantified. The environmental impact is a little bit easier to measure. Nevertheless, the impacts caused by, for example, the behavioural changes of individuals are hard to quantify for similar reasons as the social impact. Still, aspects such as the water and energy use and carbon footprint of the AI can be quantified, or at least estimated. Additionally, its effects on the company's environmental sustainability, such as energy and resource use be quantified and compared.

The relative ease of quantifying the carbon footprint of AI makes it an important measure of sustainability. For climate change mitigation, a reduction of carbon emissions is vital. Reducing carbon emissions has beneficial short-term and long-term effects, such as improving air quality and keeping global warming to a minimum, which avoids premature deaths and loss of harvests.[247]

To calculate the carbon footprint of an AI, most approaches only look at the operational costs of training and running the AI for a certain amount of time on a server or in a data centre. The production costs of servers, cooling systems buildings and other necessary pieces are neglected, especially when calculating the costs of an AI in a data centre. Neglecting these costs can be considered permissible, as they are small compared to the operational costs and divided across thousands of applications.[248]

Most calculations provide the $CO_2$-equivalent emissions, which include other greenhouse gasses such as methane, nitrous oxide and more. To calculate the emissions first, the energy use of the servers needs to be calculated. The energy consumption is proportional to

[247] Drew Shindell et al., "Temporal and Spatial Distribution of Health, Labor, and Crop Benefits of Climate Change Mitigation in the United States," *Proceedings of the National Academy of Sciences* 118, no. 46 (2021), https://doi.org/10.1073/pnas.2104061118.
[248] Lotfi Belkhir and Ahmed Elmeligi, "Assessing ICT Global Emissions Footprint: Trends to 2040 & Recommendations," *Journal of Cleaner Production* 177 (2018): pp. 448-463, https://doi.org/10.1016/j.jclepro.2017.12.239.

the number of processors and the duration of the training. The term processor includes all necessary parts of a server such as local memory, network links etc. Additionally, the energy consumption of the data centre needs to be considered which requires energy for cooling, lighting and more. This is captured by the Power usage Effectiveness (PUE)[249] of a data centre or cloud computing service.

$$Energy\ use = (training\ hours \times number\ of\ processors \times average\ power\ per\ processor) \times PUE$$

Once the required energy is calculated, it can be transformed into carbon emissions by multiplying it with the carbon intensity of the energy supply.[250]

The carbon intensity depends on a variety of factors, such as the location of the data centre and time of running which can affect the energy mix and thereby the carbon emissions. Since calculating the carbon emissions for an AI is quite laborious, people have developed ‘carbontrackers’, which can be easily plugged into the code, providing information about the carbon emissions of the AI. The tracker developed by Wolff Anthony et al., for example, is available as open source code and can be implemented in any Python script.[251] A group around Peter Henderson has developed a similar tool, they call the experiment-impact-tracker that can also be implemented in python.[252] These tools are a great way to easily measure the carbon footprint of an AI, as long as it is written in the same programming language as the AI. An even simpler tool is the Machine Learning Emissions calculator.[253] On this website it is possible to calculate the estimated emissions by providing the hardware type, use hours, provider, and computing region. But before implementing any of the carbon trackers, it is necessary to check if the parameters used by the program are up to date and align with the personal expectations. Henderson’s program, for example, only uses operational data and ignores life-cycle aspects, such as the production of servers and their recycling.

---

[249] The PUE is the industry standard measure of data centre efficiency. It is defined as the ratio of total energy divided by the energy directly consumed by the computing equipment. (Patterson et al., 2022 p. 20)

[250] David Patterson et al., “The Carbon Footprint of Machine Learning Training Will Plateau, Then Shrink,” *Computer*, July 2022, pp. 18-28, p. 21.

[251] L.F. Wolff Anthony, B. Kanding, and R. Selvan, “Carbontracker: Tracking and Predicting the Carbon Footprint of Training Deep Learning Models,” ICML Workshop on “Challenges in Deploying and Monitoring Machine Learning Systems”, 2020.

[252] Peter Henderson et al., “Towards the Systematic Reporting of the Energy and Carbon Footprints of Machine Learning,” *Journal of Machine Learning Research* 21 (2020): pp. 1-43.

[253] “Machine Learning CO2 Impact Calculator,” Machine Learning CO2 Impact Calculator, accessed September 12, 2022 https://mlco2.github.io/impact/#compute.

## 2.1. Carbon Footprint Reduction Methods

The carbon emissions of an AI can be reduced in a variety of ways. I will discuss four of these below. One way to improve the carbon footprint of AIs is to choose efficient hardware settings and optimized processors.[254] Relying on optimised TPUs and GPUs can improve the performance of a server by a factor of two to five.[255]

Next to the right hardware, it is important to choose an efficient model. By choosing a model suited for the application and favouring efficiency over accuracy, the energy consumption can be reduced three to ten times.[256]

Another way to reduce the carbon footprint is to use a data centre in a region with a high amount of green energy[257] Doing so can reduce the carbon footprint by a factor of five to ten, and relying on a carbon-neutral data centre service such as Google, which matches 100% of their energy use with renewable energy, thereby offsetting their emissions, would reduce the emissions even further.[258] By moving to 100% renewable energy for cloud computing, 45% of the total ICT sector's emissions could be cut.[259] While the training of an AI can be moved to a different location, applications which have difficulties with latencies cannot.[260] Time-sensitive programs, such as applications for the stock market, could be less accurate due to latencies. Similar to choosing the right location, shifting the training to a low carbon-intense time period can reduce the emissions further.[261] Finally, choosing cloud computing over local servers can reduce energy costs by a factor between 1.4 and 2 as it is more efficient and higher utilised.[262]

The carbon footprint of AIs as a sustainability measure can be relatively easily calculated with tools such as carbon trackers. Furthermore, AI developers and decision-makers in companies can reduce emissions significantly with a few simple changes. Adhering to all four of the mentioned steps can reduce the energy consumption of an AI by a factor of 83 and the

---

254 Wolff et al, " Carbontracker."; Alexandre Lacoste et al., "Quantifying the Carbon Emissions of Machine Learning," Preprint, 2019, 2.; Da Li et al., "Evaluating the Energy Efficiency of Deep Convolutional Neural Networks on CPUs and GPUs," 2016 IEEE International Conferences on Big Data and Cloud Computing (BDCloud), Social Computing and Networking (SocialCom), Sustainable Computing and Communications (SustainCom) (BDCloud-SocialCom-SustainCom), 2016, https://doi.org/10.1109/bdcloud-socialcom-sustaincom.2016.76.
255 Patterson et al., "The Carbon Footprint," p. 19.
256 "ibid," p.19.
257 Wolff Anthony, et al., " Carbontracker."; Lacoste et al., "Quantifying the Carbon Emissions," p. 2; Henderson et al., "Towards the Systematic Reporting," p. 22.
258 Patterson et al., "The Carbon Footprint," p. 19.
259 Belkhir and Elmeligi, "Assesing ICT," p. 460.
260 Henderson et al., "Towards the Systematic Reporting," p. 22.
261 Wolff et al., " Carbontracker."
262 Patterson et al., "The Carbon Footprint," 19, p. 24.

$CO_2e$ emissions by a factor of 747, over the course of four years.[263] This illustrates how with small changes significant changes can be achieved for the sustainability of AIs.

[263] “ibid,” p. 24.

# 3. Embodying Physicality as a Sustainable Tool: Applying the Concept of Physicality and Sustainability Spectrum Drawings to the Hypothetical Development of a Sustainable, Fashion Trend Forecasting AI

In order to illustrate the importance of considering the physicality of AI during the development of a sustainable AI, as well as how the sustainability spectrum drawing could be used, I will outline a basic development process for a forecasting AI. Forecasting AIs are used to anticipate trends and the demand for different pieces. Some applications and benefits of this type of AI were already addressed in chapter one, in the section on predictive analytics. For the current section, I wanted to use an example of how an AI, positively influences the progression of a fashion company towards reaching its sustainability goals. With this example, I want to illustrate that, AIs are not inherently unsustainable if their physicality is considered during the development process and deliberately weighed against their benefits before implementation.

Physicality is an important concept to be considered during the development of an AI. But the physicality of AI is not one tangible thing. Rather it is an umbrella term which encompasses all the hidden components, which are often overlooked but integral to the creation and running of AIs. As I have detailed in chapter two section 1.3, the physicality of AI includes all kinds of environmental and social impacts, such as carbon emissions, the use of rare resources, and poor labour conditions, which are mainly linked to servers, data centres and (hidden) labourers who, for example, create datasets for the training of AIs. The following section provides a step-by-step discussion of the development process of a forecasting AI and how to ensure it is sustainable by considering its sustainability and following the six principles for sustainable AI for sustainable fashion (SF) proposed in chapter three. In this discussion, physicality will be addressed in the form of energy use of algorithms, the conditions under which datasets are created, and the environmental impact of data centres, which includes the set-up of servers.

Developing an AI is difficult, and ensuring it is sustainable makes it even more complex, as it restricts possibilities, such as relying on continuously increasing computing power. Nevertheless, it is necessary to move to sustainable AI that not only helps to achieve sustainability goals but is sustainable in itself.

AIs can be built in a variety of ways and understanding the distinctions between different algorithm approaches goes beyond the scope of this thesis. While the exact algorithm development is specific to a company or developer, the overall approach and general requirements of AI are similar enough to allow for a general example to be illustrative of the development process. For this example, I will discuss what should be considered during the development of a fashion trend forecasting AI. I choose this application as it has the potential to significantly reduce the overproduction of fashion companies which would significantly improve the sustainability performance of the company.

### 3.1. Sustainability Principles and the Potential of Forecasting AIs for Sustainable Fashion

The choice of which AI to consider building should be guided by the intent to support sustainable fashion goals such as reducing waste and carbon emissions. A forecasting AI can help to achieve these goals by more exactly estimating the future demand for garments, which reduces the overproduction and thereby waste and resource use, including energy and water. The implementation of a forecasting AI can reduce the forecasting error by as much as 50% compared to human forecasts.[264] Furthermore, it allows for better supply management and improves the risk management.[265] Some fashion companies, such as H&M, are already working on developing forecasting AIs specific to their needs.[266] In this initial phase, the ethics of AI, for example regarding the data input and possible privacy issues, should also play a role.

First, the goal of the application needs to be considered in the context of aiming for sustainability improvements. Furthermore, it should be discussed if there are no better or at least similar analogue methods to achieve the same goal. This step is intended to avoid the use of technology for the sake of innovation, which could create new problems while solving current problems.

For different types of products different forecasting AIs can be developed. Some fashion companies sell basic and trendy products. Basic products are simple standard pieces such as white or black t-shirts or white and black socks. The demand for these kinds of products remains relatively stable over the years and can therefore be calculated with the historic, quantitative data of the company.[267] Trend products change per season and year and include garments made from printed fabric, bold colours and cuts, new fabrics, and much more. Before the triumph of

[264] Ron Schmelzer, "The Fashion Industry Is Getting More Intelligent with Ai," July 17, 2019, https://www.forbes.com/sites/cognitiveworld/2019/07/16/the-fashion-industry-is-getting-more-intelligent-with-ai/.
[265] Katrine Spirina, "Top 12 AI Trends in Retail and E-Commerce in 2021," July 7, 2021, https://indatalabs.com/blog/ai-ecommerce-trends.
[266] "Taking Sustainable Fashion to a New Level with Tech," June 2, 2021, https://hmgroup.com/our-stories/taking-sustainable-fashion-to-a-new-level-with-tech/.
[267] Shuyun Ren, Hau-Ling Chan, and Tana Siqin, "Demand Forecasting in Retail Operations for Fashionable Products: Methods, Practices, and Real Case Study," *Annals of Operations Research* 291 (2019): pp. 761-777, https://doi.org/10.1007/s10479-019-03148-8, p. 767

fast fashion, there were two seasons a year, spring-summer and autumn-winter. Today, some companies have between 50 to 100 micro seasons.[268] As the trends change more quickly it becomes increasingly more difficult to forecast what will be trendy in a few months and how high the demand for specific items will be. Trend forecasting AIs proof to be more accurate in forecasting these trendy items.[269] This is likely due to them being better at handling complex datasets and finding connections humans overlook. While the forecasting of basic items relies on quantitative, historic data, forecasting trends additionally requires qualitative and recent data.[270] This data can be drawn from social media, such as Instagram and Pinterest and the data produced by the company, such as online reviews, page visits and more.[271] The task of a forecasting AI for basic products could probably be accomplished similarly well by a skilled human, because it is based on existing quantitative data which can be interpreted clearly. Relying on a human worker could therefore avoid the resource-intensive training of an AI. Furthermore, there are comparatively few changes in demand over time. Trend forecasting on the other hand requires the interpretation of highly complex data at which an AI is significantly better than humans. Therefore, the application of a trend forecasting AI seems more relevant to achieving the sustainability goals of reducing waste and resource use.

Although different approaches can be taken, most forecasting AIs require the following steps. First, the raw fashion-related data needs to be filtered from noise, as too much of it can negatively affect the training time. Second, a feature extraction needs to be applied to determine relevant and irrelevant features of the dataset. Third, machine learning is applied as the model is trained and fitted to the dataset. Finally, most programs are built in a way that will allow them to be improved by iterating the training process.[272] Throughout these steps the sustainable AI principles should be considered and followed.

---

268 Deborah Drew and Genevieve Yehounme, "The Apparel Industry's Environmental Impact in 6 Graphics," World Resources Institute, July 5, 2017, https://www.wri.org/insights/apparel-industrys-environmental-impact-6-graphics.

269 Schmelzer, "The fashion industry."

270 Shuyun Ren, Hau-Ling Chan, and Tana Siqin, "Demand Forecasting in Retail Operations for Fashionable Products: Methods, Practices, and Real Case Study," *Annals of Operations Research* 291 (2019): pp. 761-777, https://doi.org/10.1007/s10479-019-03148-8.

271 Ren, Chan, and Siqin, "Demand Forecasting."; Satya Shankar Banerjee, Sanjay Mohapatra, and Goutam Saha, "Developing a Framework of Artificial Intelligence for Fashion Forecasting and Validating with a Case Study," *International Journal of Enterprise Network Management* 12, no. 2 (2021): pp. 165-180, https://doi.org/10.1504/ijenm.2021.116438.

272 Ren, Chan, and Siqin, "Demand Forecasting." P. 15.

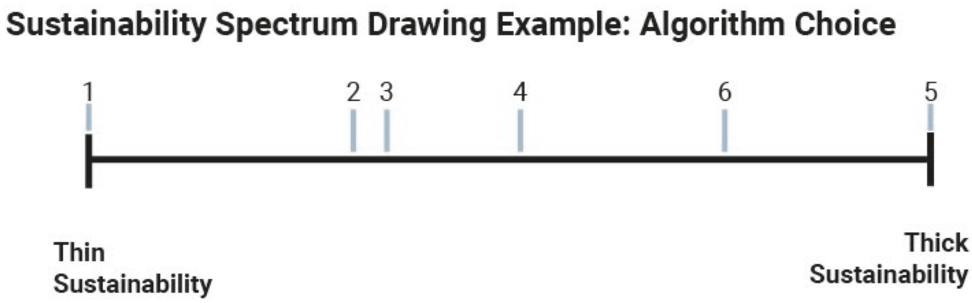
### 3.2. Illustrating the Impact of Algorithm Choice on the Sustainability of a Fashion Trend Forecasting AI through Sustainability Spectrum Drawings

The choice of the right algorithm should be guided by the goal to ensure minimal environmental impact throughout the development and use phase. This can be achieved by choosing the most efficient set-up, which saves energy and carbon emissions.

For fashion trend forecasting the input data is multidimensional, including small samples and short life-cycle data, which can negatively affect the accuracy and efficiency of the AI system. Artificial neural networks (ANN), evolutionary neural networks (ENN) and extreme learning machine methods (ELM) are all suitable for forecasting but require time to create the desired output, which can be a hurdle. Of these approaches, ELM seems to be most suitable for fashion trend forecasting.[273] The choice of the right approach should be guided by the goal of using as little energy as possible while achieving the best possible result by choosing the most efficient solution. This might require weighing energy use against accuracy or level of detail and deciding if re-training further down the road is necessary or if it can be avoided. So-called carbon trackers provide a rather easy way to estimate the produced carbon emissions. The basics of carbon tracking and the energy use of AIs are explained in section two of this chapter.

The decision process can be supported by sustainability spectrum drawings as discussed in section one of this chapter. Figure 4 provides an illustration of possible options of algorithms and how they compare to one another.

[273] "ibid."




1. High accuracy, high energy use and need for retraining
2. Low accuracy, low energy use and no retraining
3. medium accuracy, low energy use and need for retraining
4. medium accuracy, medium energy use and no retraining
5. high accuracy, low energy use and no retraining
6. high accuracy, low energy use and need for retraining

*Figure 4: Sustainability spectrum drawing example for algorithm choice.*

### 3.3. Supporting the Choice for the Most Sustainable Datasets with Sustainability Spectrum Drawings

The choice of the training dataset should be guided by concerns for the labour conditions under which the dataset was developed and how the quality of the dataset could affect the efficiency and environmental impact of the application.

Creating a new dataset for the project is time-consuming and costly if workers are compensated appropriately. Furthermore, it might waste resources as there are often pre-existing databases. Currently, a number of single- and multiple-task sets for fashion research are available and suitable for training AIs.[274] Choosing an existing database reduces labour but usually does not completely avoid it, as the dataset often needs to be adapted to the specific task. For their research, Shi et al. adapted an existing dataset but did not correct possible mislabelled items due to the high labour costs. That the labour costs for correcting such a dataset are too high suggests, that in the creation of the first data set, workers were paid very little to ensure the product's viability. The creation and maintenance of necessary datasets is one of the (social) sustainability aspects of AI often overlooked. It is what Crawford means with the hidden (human) labour that keeps AIs running. Important considerations for the choice of a

[274] Mengyun Shi et al., "The Exploration of Artificial Intelligence Application in Fashion Trend Forecasting," *Textile Research Journal* 91, no. 19-20 (2021): pp. 2357-2386, https://doi.org/10.1177/00405175211006212.

dataset, next to it fitting the context, is under which labour conditions it was created. Furthermore, it is important to weigh how accurate the labelling is, since a high percentage of mislabelled data will negatively affect the accuracy of the AI system, which results in less value for similar resources compared to a more accurately labelled dataset. Such considerations should be part of the development process and can be illustrated in a sustainability spectrum drawing as depicted in figure 5

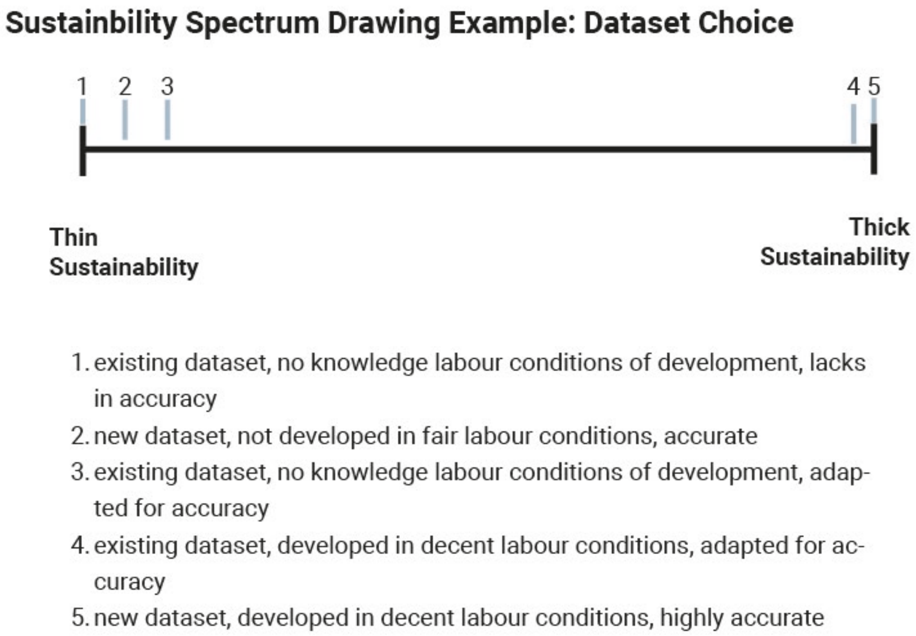



*Figure 5: Sustainability spectrum drawing example for dataset choice*

### 3.4. The Impact of Data entre Choice on the Carbon Footprint of a Fashion Trend Forecasting AI

The choice for the right data centre or server should be guided by concerns for the environmental impact, such as energy and water use and, ideally considerations of labour conditions, if information is available.

In section 2 of this chapter, I provided an overview of ways to keep the carbon emissions of an AI low. The first choice is whether the AI will be trained on a local server, a big data centre or a cloud computing facility. Of the three, the latter two tend to be more sustainable as they are working closer to capacity. In the choice of the data centre, the efficiency of the used hardware should be considered in light of the intended algorithm. TPUs and GPUs tend to provide better results than traditional CPUs. Furthermore, the more renewable energy is used for the data centre the better, this can be influenced by the choice of location and time of running the training. Additionally, one should pay attention to water management. This includes how the wastewater is managed, what water is used (potable water or nonpotable water), and how much is used. A simplified sustainability spectrum drawing for these decisions is depicted in figure 6.

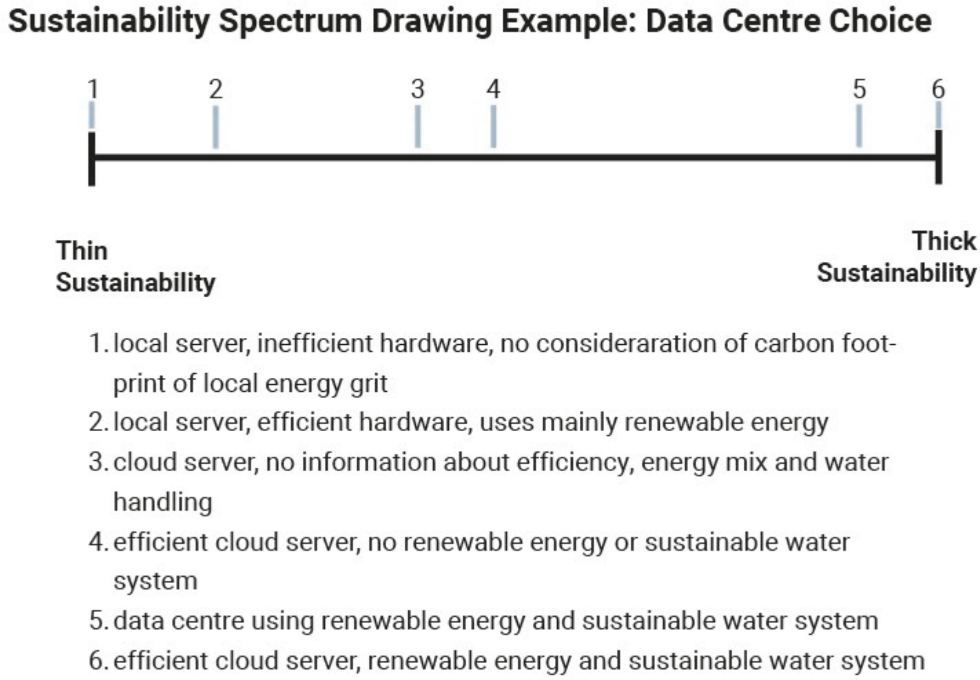



*Figure 6: Sustainability spectrum drawing example for data centre choice*

### 3.5. Weighing the Sustainability of a Trend Forecasting AI

Finally, the AI application should be viewed as an infrastructure to better assess its possible impact. This means asking questions such as: how are the consumers affected, what happens if the AI fails, what if part of the infrastructure fails, etc. If such questions can be answered in a satisfactory way, the next step can be deliberated. Do the benefits of this application outweigh its downsides and is it sustainable enough? To this, both benefits and downsides need to be listed based on the previous considerations and decisions. Furthermore, a cumulative judgement of the sustainability of the AI based on all sustainability spectrum drawings and the position of the chosen solutions on them should be made. If the developer finds the positives outweigh the negatives, and the AI is sustainable to a satisfactory level, it can be produced.

In the case of a trend-forecasting AI, the application is probably more advantageous than detrimental, given that sustainable choices are made during the development. The potential to reduce overproduction, by better estimating demand for trendy items means a possible reduction of used resources, waste, dead stock and unnecessarily shipped items. This translates to fewer carbon emissions, water pollution, littering and space requirements for storage. It has also economic benefits such as increasing full-price sales, which means a better return on investments, and will lead to an initial growth in profits without the need to increase production. Compared to all these positive effects, the negative effects such as energy consumption for training and running the AI seem relatively small. A definite statement about the sustainability of a trend forecasting AI can only be made regarding a specific example, as many aspects, such as energy use and saved, depend on the context of the developed AI. Since this is only a hypothetical example based on general practices it is not possible to make such a statement, as detailed numbers are unknwon.

# Conclusion: The Importance of Reconnecting AI and its Physicality for Sustainability

The current climate change requires an urgent shift towards more sustainable practices. Companies in the fashion industry are not exempt from this. To quickly achieve their sustainability goals companies, such as H&M, rely on technological innovation including artificial intelligence. But as I discussed, blindly relying on technology might not yield the impact hoped for. This thesis was intended to support the sustainability endeavours of fashion companies by providing them with necessary tools for the creation of sustainable AI for sustainable fashion.

At the beginning of this thesis, I stated two research questions, which I will address again one after the other. The first question was about what sustainable AI should be in the context of SF and the second was concerned with how a development approach for such a sustainable AI could look like. The first question is addressed throughout the chapters one to three, culminating in six principles defining sustainable AI for SF. In the discussion of the necessary concepts, the following ideas became clear.

Sustainability is a complex concept, which can be interpreted in many ways. But a few ideas are common to most definitions and form the basis of sustainability discussions. These basic themes are called the three or four pillars of sustainability. While economic, social, and environmental sustainability are set pillars, the decision about what the fourth one should be is still open. But it is clear, that it should reflect the complexity of today's societies. In this thesis, the fourth pillar is concerned with ethical values as it combines some of the integral concerns of other considered pillars, such as culture or politics. Including this pillar, enables a discussion which acknowledges the complexity of today's societies.

General definitions of sustainability are relatively vague which makes it difficult to work with them in practice. Therefore, a variety of specific definitions for distinct fields have been developed such as sustainable fashion. For this thesis, I provided such a definition based on the four pillars and ideas from the field of sustainable AI, in chapter one section 1.3. Sustainable AI could be another of these specific definitions. In this thesis, I defined sustainable AI in the specific context of sustainable fashion to avoid some of the troubles of more general sustainability definitions. Furthermore, defining sustainable AI for an intended use context, such as sustainable fashion, allows to be very specific which in the end should make it easier for the practitioners, such as AI developers and the people responsible for the implementation of sustainable AI, to make decisions enabling sustainable AI.

Since the definition of sustainable fashion provides the context for the definition of sustainable AI, the four pillars are also relevant in the definition of sustainability which requires the consideration of the impact of AIs. But the presentation and perception of AIs as magical, green solutions to all kinds of problems obscure important impacts of AI by disconnecting it from its physicality. The term physicality is a new concept I developed to represent all the hidden impacts AIs cause throughout their life cycle. The hidden impacts caused by AIs are economic, social, ethical, and environmental and therefore an important part of the discussion of sustainable AI. Understanding the physicality of AI provides a necessary basis for the discussion of sustainable AI.

The discussion of AI as green and almost magical, makes it seem as if AIs do not require a physical form to exist. Terms, such as cloud computing, try to suggest that AIs are a few lines of code which float through the air and require no resources to work. This is ironic and false advertisement, considering the substantial infrastructure it requires. Behind the term cloud computing hide tremendous server farms. These server farms, or in some cases individual servers, make up a significant part of the physicality of AI. They are the physical embodiment of AIs, which has significant impacts on the environment and people, such as carbon emissions, high water use, and the need for finite (and rare) resources, such as lithium. The impact of servers is discussed in more detail in chapter two section 1.3.1. But servers are not the only aspect which is encompassed by physicality. To work AIs, require data and to be able to properly process this data they require training. This training data needs to be processed to ensure the AI will learn the intended concepts from it. AIs can be used to automate laborious processes and are sometimes perceived as independent from human input. But again, this image is a twisted reflection of reality. The creation of AIs requires a significant amount of human labour. It needs AI developers who write the code and workers who sort and label data inputs according to the requirements of the AI. Especially, the labour necessary for pre-processing datasets is hidden, often done in dreadful working conditions and paid poorly. The discussion of the physicality of AI also encompasses these hidden labour costs and their impact on people and communities.

The physicality of AI is an important concept for the discussion of sustainable AI. Currently, the disconnect between AIs and the consideration of their physicality is limiting the development of sustainable AIs. As the analysis of current sustainable AI discussions in the literature on sustainable AI, in chapter three, showed, the focus is often more on how AI could further the sustainability goals of companies and organisations. Some publications, especially in the field of computer sciences, are more strongly focused on improving the sustainability of AIs by emphasising the need to focus on efficiency instead of accuracy as a measure of success. Nevertheless, for now, the main focus when discussing sustainable AI is often on AI for sustainability. This focus neglects the sustainability of AI in which the physicality of AI, as the representation of hidden environmental, economic, social, and ethical impacts, plays an important role.

The definition of sustainable AI for sustainable fashion, proposed in chapter three, relies on the four pillars of sustainability, the definition of sustainable fashion provided in chapter two, and the physicality of AI. A good understanding of the physicality of AI is necessary to, for example, ensure concerns for minimizing the environmental impact of AIs are comprehensive, by ensuring aspects of AI's physicality such as its carbon footprint are considered during the development of sustainable AI for sustainable fashion. Briefly summarised the six principles for sustainable AI for sustainable fashion, offered in chapter three, suggest that a sustainable AI for SF supports sustainability goals of SF and adheres to similar standards as sustainable fashion regarding environmental and social impact. Furthermore, sustainable AI for sustainable fashion should be understood as infrastructure which will possibly affect the future in unintended ways, and it should only be applied if there is no better low-tech solution or the benefits outweigh the negatives significantly. Since the basic concepts the definition relies on, such as environmental, social, economic, and ethical values sustainability, are similar across most sustainability definitions it should be possible to adapt the provided sustainable AI definition for other fields. The most significant change will be, which sustainability goals it should support instead of sustainable fashion. The other five principles could remain the same.

My second research for this thesis is concerned with, how a development approach for such a sustainable AI could look like. To answer this question, I suggested an approach and developed a visualisation tool, which helps to compare the different options and their sustainability. Furthermore, I provided an exemplary discussion of how to develop a sustainable AI for fashion trend forecasting.

The approach I suggest relies on the decision makers embracing the provided sustainable AI for sustainable fashion definition and taking on the responsibility for their decisions and the consequences. The definition should not be understood as a blueprint for building a sustainable AI. It only provides the ideal framework, which the decision makers and

AI developers need to interpret and fill in themselves. Additionally, the definition is not a checklist but a list of principles, which should guide the decision process during the development and implementation of a sustainable AI. To support this process, I suggest using a tool inspired by Fleddermann's line drawings, which I call sustainability spectrum drawings. For the tool, it is necessary to consider sustainability as existing on a spectrum. In the discussion of sustainability, some people make a distinction between strong and weak AI. I suggest to instead use the terms thick and thin sustainability, to suggest sustainability exists on a spectrum. Thick definitions present an ideal version of sustainability, which might not be achievable under given circumstances. Thin sustainability, at the other end of the spectrum, provides a minimal definition, which requires significantly less than the ideal definition, but is still an improvement compared to the status quo. Between these definitions of thin and thick sustainability is room for more or less sustainable solutions, which are important steps towards realising the thick sustainability definition. Considering sustainability as existing on a spectrum, supports the idea, that even small steps towards more sustainable practices are important and should be implemented. In the end, all the small changes combined can lead to significant improvements.

The sustainability spectrum drawing tool is explained in chapter four. But essentially, it is a line of which one end represents a thin sustainability definition while the other provides a thick. The possible solutions to the development step at hand are placed between the extremes depending on how close they are to the extremes. By laying out all decisions and determining their degree of sustainability, it can become easier to make the most sustainable decisions within the given context. Comparing the spectrums for different decisions can also support the process of deciding on necessary trade-offs. Essential to these decision processes is at least a basic understanding of the physicality of AI. It is necessary to determine possible solutions and to judge their degree of sustainability. During the development process, it is also advantageous to keep in mind, that achieving the thick definition of sustainability should be the goal, but that small steps towards more sustainability are also important.

Throughout, the thesis it becomes clear that the physicality of AI, as presented, should be integral to the development and discussion of sustainable AI. Ignoring the hidden impacts represented by the physicality of AI results in AIs which work towards sustainability goals but do not adhere to the necessary standards themselves. The program developed by TextileGenesis described in chapter one adheres to the rules of responsible AI, as set by H&M, but the use of blockchain suggests that sustainability concerns, such as energy use, were of lesser importance or not considered at all. Incorporating the concept of physicality and the principles of sustainable AI for sustainable fashion suggested in this thesis adds another level of responsibility to the creation of AI, which so far has been missing from many approaches to responsible AI. It is very important for companies in the fashion industry, such as H&M, to become sustainable. The discussion of the physicality of AI, the definition of sustainable AI for sustainable fashion and the design tool provided in this thesis can support these companies in their endeavour by ensuring the used AI is not unintentionally undermining their sustainability goals.

Due to the stronger focus on the environmental impacts of AI, and especially carbon emissions as a quantitative measure, the discussion of social impacts and how to impact them, as well as considerations of economic and ethical value concerns, remained superficial. Future research could dive deeper into the labour processes involved in AI development and how they should be considered in sustainable AI for sustainable fashion. Another way forward is to use a similar approach to define sustainable AI for different contexts, such as the motor industry or governmental structures.

# Bibliography


"The 17 Goals | Sustainable Development." United Nations. United Nations. Accessed March 1, 2022. https://sdgs.un.org/goals.

Aczel, M. (2018). Political economy, economies and development [Review of the book China and the geopolitics of rare earths, by S. Kalantzakos]. International Affairs, 94, 4.

"AI for Fashion Retail." Vue.ai. Accessed September 16, 2022. https://vue.ai/industries/ai-in-fashion-retail/.

"AI in Fashion: An Extensive Guide to All Applications for Retail," January 25, 2022. https://www.intelistyle.com/ai-fashion-retail-applications/.

Astobiza, Anibal Monasterio, Mario Toboso, Manuel Aparicio, and Daniel Lopez. "AI Ethics for Sustainable Development Goals." *IEEE Technology and Society Magazine* 40, no. 2 (2021): 66–71. https://doi.org/10.1109/mts.2021.3056294.

Banerjee, Satya Shankar, Sanjay Mohapatra, and Goutam Saha. "Developing a Framework of Artificial Intelligence for Fashion Forecasting and Validating with a Case Study." *International Journal of Enterprise Network Management* 12, no. 2 (2021): 165–80. https://doi.org/10.1504/ijenm.2021.116438.

Bartneck, Christoph, Christoph Lütge, Alan Wagner, and Sean Welsh. "An Introduction to Ethics in Robotics and Ai." *SpringerBriefs in Ethics*, 2021. https://doi.org/10.1007/978-3-030-51110-4.

Beaux, Fabrice. "How Fashion Retailers Can Benefit from AI in 2022," February 14, 2022. https://www.bbntimes.com/technology/how-fashion-retailers-can-benefit-from-ai-in-2022.

Beckerman, Wilfred. "'Sustainable Development': Is It a Useful Concept?" *Environmental Values* 3, no. 3 (1994): 191–209. https://doi.org/10.3197/096327194776679700.

Belkhir, Lotfi, and Ahmed Elmeligi. "Assessing ICT Global Emissions Footprint: Trends to 2040 & Recommendations." *Journal of Cleaner Production* 177 (2018): 448–63. https://doi.org/10.1016/j.jclepro.2017.12.239.

Blanchette, Jean-François. "A Material History of Bits." *Journal of the American Society for Information Science and Technology* 62, no. 6 (2011): 1042–57. https://doi.org/10.1002/asi.21542.

Bolte, Larissa, Tijs Vandemeulebroucke, and Aimee van Wynsberghe. "From an Ethics of Carefulness to an Ethics of Desirability: Going beyond Current Ethics Approaches to Sustainable AI." *Sustainability* 14, no. 8 (2022): 4472–85. https://doi.org/10.3390/su14084472.

Boylan, Michael, and Brian G Norton. "Sustainability and Adaptation: Environmental Values and the Future." Essay. In *Environmental Ethics*, 2nd ed., 358–70. John Wiley & Sons, 2022.

Boylan, Michael, and Randall Curren. "Sustainability: What It Is and How It Works Defining Sustainability Ethics." Essay. In *Environmental Ethics*, 2nd ed., 331–45. John Wiley & Sons, 2014.

Burford, Gemma, Elona Hoover, Ismael Velasco, Svatava Janoušková, Alicia Jimenez, Georgia Piggot, Dimity Podger, and Marie Harder. "Bringing the 'Missing Pillar' into Sustainable Development Goals: Towards Intersubjective Values-Based Indicators." *Sustainability* 5, no. 7 (2013): 3035–59. https://doi.org/10.3390/su5073035.

Campolo, Alexander, and Kate Crawford. "Enchanted Determinism: Power without Responsibility in Artificial Intelligence." *Engaging Science, Technology, and Society* 6 (2020): 1–19. https://doi.org/10.17351/ests2020.277.

Chan, Emily. "H&M's New CEO Wants to Fix Fast Fashion. Is That Possible?," October 14, 2020. https://www.vogue.co.uk/news/article/article/helena-helmersson-interview.

"Circulator™," 2021. https://circulator.hmgroup.com/.

Coeckelbergh, Mark. *AI Ethics*. Cambridge, Massachusetts: MIT Press, 2020.

Coeckelbergh, Mark. “AI for Climate: Freedom, Justice, and Other Ethical and Political Challenges.” *AI and Ethics* 1, no. 1 (2021): 67–72. https://doi.org/10.1007/s43681-020-00007-2.

“Company.” Intelistyle, accessed  September 16, 2022, https://www.intelistyle.com/company/,

Crawford, Kate, Roel Dobbe, Theodora Dryer, Genevieve Fried, Ben Green, Elizabeth Kaziunas, Amba Kak, Varoon Mathur, Erin McElroy, Andrea Nill Sánchez, Deborah Raji, Joy Lisi Rankin, Rashida Richardson, Jason Schultz, Sarah Myers West, and Meredith Whittaker. AI Now 2019 Report. New York: AI Now Institute, 2019, https://ainowinstitute.org/AI_Now_2019_Report.html.

Crawford, Kate. *Atlas of AI Power, Politics, and the Planetary Costs of Artificial Intelligence*. New Haven, Conn: Yale University Press, 2021.

Daly, Herman E. “On Wilfred Beckerman's Critique of Sustainable Development.” *Environmental Values* 4, no. 1 (1995): 49–55. https://doi.org/doi.org/10.3197/096327195776679583.

Daryna, P. “11 Superb Ways AI Can Revamp the Retail Industry,” September 26, 2018. https://rubygarage.org/blog/11-use-cases-of-ai-in-retail.

Dayarathna, Miyuru, Yonggang Wen, and Rui Fan. “Data Center Energy Consumption Modeling: A Survey.” *IEEE Communications Surveys & Tutorials* 18, no. 1 (2016): 732–94. https://doi.org/10.1109/comst.2015.2481183.

DeAcetis, Joseph. “H&M Drives Innovation in Sustainability with 2021 Style,” May 7, 2021. https://www.forbes.com/sites/josephdeacetis/2021/05/06/hm-drives-innovation-in-sustainability-with-2021-style/.

“Decent Work.” Accessed July 7, 2022. https://www.ilo.org/global/topics/decent-work/lang--en/index.htm.

DeepMind. “AlphaGo.” Accessed May 3, 2022. https://www.deepmind.com/research/highlighted-research/alphago.

Dobson, Andrew, and Michael Jacobs. “Sustainable Development as a Contested Concept.” In *Fairness and Futurity: Essays on Environmental Sustainability and Social Justice*, 21–45. Oxford: Oxford University Press, 1994.

Dottle, Rachael, and Jackie Gu. “The Global Glut of Clothing Is an Environmental Crisis,” February 23, 2022. https://www.bloomberg.com/graphics/2022-fashion-industry-environmental-impact/.

Drew, Deborah, and Genevieve Yehounme. “The Apparel Industry's Environmental Impact in 6 Graphics.” World Resources Institute, July 5, 2017. https://www.wri.org/insights/apparel-industrys-environmental-impact-6-graphics.

d’Anjou, Philippe. “An Alternative Model for Ethical Decision-Making in Design: A Sartrean Approach.” *Design Studies* 32, no. 1 (2011): 45–59. https://doi.org/10.1016/j.destud.2010.06.003.

“E-Commerce & Retail Software Development Services.” RubyGarage. Accessed September 16, 2022. https://rubygarage.org/expertise/retail-software-development.

Elish, M. C., and danah boyd. “Situating Methods in the Magic of Big Data and AI.” *Communication Monographs* 85, no. 1 (2017): 57–80. https://doi.org/10.1080/03637751.2017.1375130.

Ellen MacArthur Foundation, (2019). Artificial intelligence and the circular economy. AI as a tool to accelerate the transition.

Ensmenger, Nathan, and Rebecca Slayton. “Computing and the Environment: Introducing a Special Issue of Information & Culture.” *Information & Culture* 52, no. 3 (2017): 295–303. https://doi.org/10.7560/ic52301.

Ensmenger, Nathan. “The Environmental History of Computing.” *Technology and Culture* 59, no. 4S (2018): 7–33. https://doi.org/10.1353/tech.2018.0148.

Ericsson. Rep. *Background Report to 'A Guide to Your Digital Climate Impact'*, 2020.

"Fashion Transparency Index 2021 Dataset draft_10.Xlsx," 2022. https://docs.google.com/spreadsheets/d/1aIkl4-gcC24Fc9K41p8BFLszgf-c2x-8/edit#gid=1939875095.

Fleddermann, Charles B. *Engineering Ethics*. 4th ed. Upper Saddle River, NJ: Person Education , 2012.

Fletcher, Kate. "Introduction." Introduction. In *Sustainable Fashion and Textiles: Design Journeys*, 2nd ed., 1–4. London: Routledge Taylor & Francis Group, 2014.

Floridi, Luciano, Josh Cowls, Monica Beltrametti, Raja Chatila, Patrice Chazerand, Virginia Dignum, Christoph Luetge, et al. "AI4People—An Ethical Framework for a Good AI Society: Opportunities, Risks, Principles, and Recommendations." *Minds and Machines* 28, no. 4 (2018): 689–707. https://doi.org/10.1007/s11023-018-9482-5.

Forti, V, C P Baldé, R Kuehr, and G Bel. Rep. *The Global E-Waste Monitor 2020: Quantities, Flows and the Circular Economy Potential*. Bonn/Geneva/Rotterdam: United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), 2020.

Granskog, Anna, Libbi Lee, Karl-Hendrik Magnus, and Corinne Sawers. "Survey: Consumer Sentiment on Sustainability In Fashion." McKinsey & Company. McKinsey & Company, July 17, 202AD. https://www.mckinsey.com/industries/retail/our-insights/survey-consumer-sentiment-on-sustainability-in-fashion.

Greco, Sara, and Barbara De Cock. "Argumentative Misalignments in the Controversy Surrounding Fashion Sustainability." *Journal of Pragmatics* 174 (2020): 55–67. https://doi.org/10.1016/j.pragma.2020.12.019.

Guo, Zhaoxia, Jingjie Chen, Guangxin Ou, and Haitao Liu. "Coordinated Optimization of Production and Delivery Operations in Apparel Supply Chains Using a Hybrid Intelligent Algorithm." In *Artificial Intelligence on Fashion and Textile: Proceedings of the Artificial Intelligence on Fashion and Textiles (AIFT) Conference 2018, Hong Kong, July 3-6, 2018*, edited by W. K. Wong, 9–15. Cham, Switzerland: Springer, 2019.

H&M Group. Rep. *Annual and Sustainability Report 2021*, 2022.

H&M Group. Rep. *H&M Group Sustainability Disclosure*, 2022.

H&M Group. Rep. *H&M Group Sustainability Performance Report 2020*, 2021.

"H&M," February 2022. https://directory.goodonyou.eco/brand/h-and-m.

Hagendorff, Thilo. "The Ethics of AI Ethics: An Evaluation of Guidelines." *Minds and Machines* 30, no. 1 (2020): 99–120. https://doi.org/10.1007/s11023-020-09517-8.

Henderson, Peter, Jieru Hu, Joshua Romoff, Emma Brunskill, Dan Jurafsky, and Joelle Pineau. "Towards the Systematic Reporting of the Energy and Carbon Footprints of Machine Learning." *Journal of Machine Learning Research* 21 (2020): 1–43.

Henninger, Claudia E., Panayiota J. Alevizou, and Caroline J. Oates. "What Is Sustainable Fashion?" *Journal of Fashion Marketing and Management: An International Journal* 20, no. 4 (2016): 400–416. https://doi.org/10.1108/jfmm-07-2015-0052.

Hogan, Mél. "Data Flows and Water Woes: The Utah Data Center." *Big Data & Society* 2, no. 2 (2015): 1–12. https://doi.org/10.1177/2053951715592429.

"How Much Do Our Wardrobes Cost to the Environment?," October 8, 2019. https://www.worldbank.org/en/news/feature/2019/09/23/costo-moda-medio-ambiente#:~:text=Every%20year%20the%20fashion%20industry,needs%20of%20five%20million%20people.&text=The%20fashion%20industry%20is%20responsible,flights%20and%20maritime%20shipping%20combined.

Ikouta Mazza, Patricia. "Concepts of Sustainable Development; a Literature Review and a Systematic Framework for Connecting the Role of Education with the Sustainable Development Goals (Sdgs)." *International Journal of Humanities, Social Sciences and Education* 8, no. 8 (2021): 106–12. https://doi.org/10.20431/2349-0381.0808009.

"The IPCC Climate Change 2022 Impacts Report: Why It Matters." National Oceanic and Atmospheric Administration. Accessed August 25, 2022. https://www.noaa.gov/stories/ipcc-climate-change-2022-impacts-report-why-it-matters.

Jamieson, Dale. “Sustainability and Beyond.” *Ecological Economics* 24 (1998): 183–92.

Jiang, Lisheng, Huchang Liao, and Zhi Li. “Probabilistic Linguistic Linear Least Absolute Regression for Fashion Trend Forecasting.” Essay. In *Artificial Intelligence on Fashion and Textile: Proceedings of the Artificial Intelligence on Fashion and Textiles (AIFT) Conference 2018, Hong Kong, July 3-6, 2018*, edited by W. K. Wong, 337–46. Cham, Switzerland: Springer, 2019.

Kamiya, George. “Data Centres and Data Transmission Networks – Analysis.” IEA, November 1, 2021. https://www.iea.org/reports/data-centres-and-data-transmission-networks.

Kaplan, Andreas, and Michael Haenlein. “Siri, Siri, in My Hand: Who’s the Fairest in the Land? on the Interpretations, Illustrations, and Implications of Artificial Intelligence.” *Business Horizons* 62, no. 1 (2019): 15–25. https://doi.org/10.1016/j.bushor.2018.08.004.

Kent, Sarah. “Norway Warns H&M, Norrøna over Misleading Sustainability Claims,” June 17, 2022. https://www.businessoffashion.com/articles/sustainability/hm-norrona-norway-sustainability-environmental-marketing-higg/.

Kim, Elizabeth. “The New $41 Million Hunters Point Library Has One Major Flaw,” October 3, 2019. https://gothamist.com/news/new-41-million-hunters-point-library-has-one-major-flaw.

Kothari, Rajni. “Environment, Technology, and Ethics.” Essay. In *Reflecting on Nature. Readings in Environmental Philosophy*, edited by Luri Gruen and Dale Jamieson, 1st ed., 228–37. Oxford University Press, 1994.

Lacoste, Alexandre, Alexandra Luccioni, Victor Schmidt, and Thomas Dandres. “Quantifying the Carbon Emissions of Machine Learning.” *Preprint*, 2019.

Levy, Steven. “Google Throws Open Doors to Its Top-Secret Data Center,” October 17, 2012. https://www.wired.com/2012/10/ff-inside-google-data-center/.

Li, Da, Xinbo Chen, Michela Becchi, and Ziliang Zong. “Evaluating the Energy Efficiency of Deep Convolutional Neural Networks on CPUs and GPUs.” *2016 IEEE International*

*Conferences on Big Data and Cloud Computing (BDCloud), Social Computing and Networking (SocialCom), Sustainable Computing and Communications (SustainCom) (BDCloud-SocialCom-SustainCom)*, 2016. https://doi.org/10.1109/bdcloud-socialcom-sustaincom.2016.76.

"Machine Learning CO2 Impact Calculator." Machine Learning CO2 Impact Calculator, accessed September 12, 2022. https://mlco2.github.io/impact/#compute.

Malik Chua, Jasmin. "H&M's Green Machine: A Recycling Solution?," November 19, 2020. https://www.voguebusiness.com/sustainability/handms-green-machine-a-recycling-solution.

Malmodin, Jens, and Dag Lundén. "The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015." *Sustainability* 10, no. 9 (2018): 3027–58. https://doi.org/10.3390/su10093027.

Manning, Christopher. "Artificial Intelligence Definitions." Stanford University , 2020. https://hai.stanford.edu/sites/default/files/2020-09/AI-Definitions-HAI.pdf

McCarthy, John. "What Is Artificial Intelligence?" Stanford : Stanford University, November 12, 2007.

Mensah, Justice. "Sustainable Development: Meaning, History, Principles, Pillars, and Implications for Human Action: Literature Review." *Cogent Social Sciences* 5, no. 1 (2019): 1–21. https://doi.org/10.1080/23311886.2019.1653531.

Moles, by: Barry. "How Virtual Changing Rooms Will Revolutionise Fashion Retail," June 2, 2015. https://theregister.co.nz/2015/06/02/virtual-changing-rooms-will-revolutionise-fashion-retail/.

Moss, Emanuel, and Friederike Schüür. "How Modes of Myth-Making Affect the Particulars of DS/ML Adoption in Industry." *Ethnographic Praxis in Industry Conference Proceedings* 2018, no. 1 (2018): 264–80. https://doi.org/10.1111/1559-8918.2018.01207.

Mukendi, Amira, Iain Davies, Sarah Glozer, and Pierre McDonagh. "Sustainable Fashion: Current and Future Research Directions." *European Journal of Marketing* 54, no. 11 (2020): 2873–2909. https://doi.org/10.1108/ejm-02-2019-0132.

Nassar, Nedal T., Jamie Brainard, Andrew Gulley, Ross Manley, Grecia Matos, Graham Lederer, Laurence R. Bird, et al. "Evaluating the Mineral Commodity Supply Risk of the U.S. Manufacturing Sector." *Science Advances* 6, no. 8 (2020). https://doi.org/10.1126/sciadv.aay8647.

"New Website Puts the Fashion Industry's Low Wages in the Spotlight, Accelerating the Campaign for Living Wages.," June 22, 2020. https://cleanclothes.org/news/2020/fashion-checker.

Niinimäki Kirsi, and Niinimäki Kirsi. "Tenents of Sustainable Fashion." In *Sustainable Fashion: New Approaches*, 12–29. Helsinki, Finland: Aalto University, 2013.

Niinimäki, Kirsi. "Ethical Foundations in Sustainable Fashion." *Textiles and Clothing Sustainability* 1, no. 1 (2015). https://doi.org/10.1186/s40689-015-0002-1.

Nilsson, Nils J. *Artificial Intelligence a New: A New Synthesis*. San Francisco, CA: Morgan Kaufmann Publishers, 1998.

Nourbakhsh, Illah Reza. "AI Ethics: A Call to Faculty." *Communications of the ACM* 64, no. 9 (2021): 43–45. https://doi.org/10.1145/3478516.

Obregón, Carolina. "Sustainable Fashion: from Trend to Paradigm," 2012. (Master Thesis, Aalto University, 2012)

Oracle. Rep. *Can Virtual Experiences Replace Reality?: The Future Role for Humans in Delivering Customer Experience*. Redwood Shores, CA: Oracle, 2016.

Owen-Burge, Charlotte. "H&M Group CEO: Our Mission Is to Make Sustainable Fashion Accessible to All," February 25, 2022. https://climatechampions.unfccc.int/hm-ceo-sustainable-fashion-accessible-to-all/.

Patterson, David, Joseph Gonzalez, Urs Hölzle, Quoc Le, Chen Liang, Lluis-Miquel Munguia, Daniel Rothchild, David R So, Maud Texier, and Jeff Dean. "The Carbon

Footprint of Machine Learning Training Will Plateau, Then Shrink.” *Computer* 55, no. 7, July 2022.

Peet, Lisa. “Hunters Point Library Confronts Accessibility Issues,” November 4, 2019. https://www.libraryjournal.com/?detailStory=hunters-point-library-confronts-accessibility-issues.

Poole. Alexandria , Two Skills for Integrating Ethical Requirements into Design, Lecture for CreaTe, Spring 2022. University of Twente

Poole, David L., and Alan K. Mackworth. *Artificial Intelligence: Foundations of Computational Agents*. 2nd ed. New York, NY: Cambridge University Press, 2017. http://artint.info/2e/html/ArtInt2e.html.

Poole, David Lynton, Alan K. Mackworth, and Randy G. Goebel. *Computational Intelligence: A Logical Approach*. New York, NY: Oxford Univ. Press, 1998.

Ramsey, Jeffry L. “Defining Sustainability.” *Journal of Agricultural and Environmental Ethics* 27, no. 6 (2014): 1049–54. https://doi.org/10.1007/s10806-014-9514-y.

Remy, Nathalie, Eveline Speelman, and Steven Swartz. “Style That's Sustainable: A New Fast-Fashion Formula,” October 20, 2016. https://www.mckinsey.com/business-functions/sustainability/our-insights/style-thats-sustainable-a-new-fast-fashion-formula.

Ren, Shuyun, Chi-leung Patrick Hui, and Tsun-ming Jason Choi. “AI-Based Fashion Sales Forecasting Methods in Big Data Era.” In *Artificial Intelligence for Fashion Industry in the Big Data Era*, edited by Sébastien Thomassey and Xianyi Zeng, 9–26. Singapore: Springer Singapore, 2018.

Ren, Shuyun, Hau-Ling Chan, and Tana Siqin. “Demand Forecasting in Retail Operations for Fashionable Products: Methods, Practices, and Real Case Study.” *Annals of Operations Research* 291 (2019): 761–77. https://doi.org/10.1007/s10479-019-03148-8.

“Responsible AI, Is Better AI,” June 15, 2021. https://hmgroup.com/our-stories/responsible-ai-is-better-ai/.

Robbins, Scott, and Aimee van Wynsberghe. “Our New Artificial Intelligence Infrastructure: Becoming Locked into an Unsustainable Future.” *Sustainability* 14, no. 8 (2022): 4829–40. https://doi.org/10.3390/su14084829.

Rohde, Frederike, Josephin Wagner, Philipp Reinhard, Ulrich Petschow, Andreas Meyer, Marcus Voß, and Anne Mollen. Rep. *Nachhaltigkeitskriterien Für Künstliche Intelligenz. Entwicklung Eine Kriterien- Und Indikatorensets Für Die Nachhaltigkeitsbewertung Von KI-Systemen Entlang Des Lebenszyklus*. Berlin: Institut für ökologische Wirtschaftsforschung GmbH, 2021.

Russell, Stuart J., and Peter Norvig. *Artificial Intelligence: A Modern Approach*. 4th ed. Harlow, England: Pearson Educación, 2022.

Schmelzer, Ron. “The Fashion Industry Is Getting More Intelligent with Ai,” July 17, 2019. https://www.forbes.com/sites/cognitiveworld/2019/07/16/the-fashion-industry-is-getting-more-intelligent-with-ai/.

Schnieber, Stephan. “IBM Watson: Von Jeopardy! Zum Business Champion,” March 3, 2022. https://www.ibm.com/blogs/think/de-de/2022/03/ibm-watson/.

Schwartz, Roy, Jesse Dodge, Noah A. Smith, and Oren Etzioni. “Green AI.” *Communications of the ACM* 63, no. 12 (2020): 54–63. https://doi.org/10.1145/3381831.

Searle, John R. “Minds, Brains, and Programs.” *The Behavioral and Brain Sciences* 3, no. 3 (1980): 417–24. https://doi.org/10.1017/s0140525x00005756.

Sharkey, Noel, and Amanda Sharkey. “Artificial Intelligence and Natural Magic.” *Artificial Intelligence Review* 25, no. 1-2 (2007): 9–19. https://doi.org/10.1007/s10462-007-9048-z.

Shi, Mengyun, Cali Chussid, Pinyi Yang, Menglin Jia, Van Dyk Lewis, and Wei Cao. “The Exploration of Artificial Intelligence Application in Fashion Trend Forecasting.” *Textile Research Journal* 91, no. 19-20 (2021): 2357–86. https://doi.org/10.1177/00405175211006212.

Shindell, Drew, Muye Ru, Yuqiang Zhang, Karl Seltzer, Greg Faluvegi, Larissa Nazarenko, Gavin A. Schmidt, et al. “Temporal and Spatial Distribution of Health, Labor, and Crop

Benefits of Climate Change Mitigation in the United States." *Proceedings of the National Academy of Sciences* 118, no. 46 (2021). https://doi.org/10.1073/pnas.2104061118.

Spirina, Katrine. "Top 12 AI Trends in Retail and E-Commerce in 2021," July 7, 2021. https://indatalabs.com/blog/ai-ecommerce-trends.

Stokel-Walker, Chris. "Data Centers Are Facing a Climate Crisis," August 1, 2022. https://www.wired.com/story/data-centers-climate-change/.

Stone, Leilah. "Hunters Point Library Called out over Accessibility Issues," October 8, 2019. https://www.archpaper.com/2019/10/hunters-point-library-called-out-over-accessibility-issues/.

Stone, P., Brooks, R., Brynjolfsson, E., Calo, R., Etzioni, O., Hager, G., Hirschberg, J., Kalyanakrishnan, S., Kamar, E., Kraus, S., Leyton-Brown, K., Parkes, D., Press, W., Saxenian, A. L., Shah, J., Tambe, M., & Teller, A. (2016). Artificial Intelligence and Life in 2030: One Hundred Year Study on Artificial Intelligence: Report of the 2015-2016 Study Panel, Stanford University, Stanford, CA, Doc: http://ai100.stanford.edu/2016-report.

Strubell, Emma, Ananya Ganesh, and Andrew McCallum. "Energy and Policy Considerations for Deep Learning in NLP." *Proceedings of the 57th Annual Meeting of the Association for Computational Linguistics*, 2019, 3645–50. https://doi.org/10.18653/v1/p19-1355.

"Sustainability Commitment." H&M Group. Accessed June 22, 2022. https://hmgroup.com/sustainability/standards-and-policies/sustainability-commitment/.

Sætra, Henrik Skaug. "AI in Context and the Sustainable Development Goals: Factoring in the Unsustainability of the Sociotechnical System." *Sustainability* 13, no. 4 (2021): 1738. https://doi.org/10.3390/su13041738.

"Taking Sustainable Fashion to a New Level with Tech," June 2, 2021. https://hmgroup.com/our-stories/taking-sustainable-fashion-to-a-new-level-with-tech/.

Tang, Ming, and Huchang Liao. "Multiple Criteria Group Decision-Making Based on Hesitant Fuzzy Linguistic Consensus Model for Fashion Sales Forecasting." Essay. In

*Artificial Intelligence on Fashion and Textile: Proceedings of the Artificial Intelligence on Fashion and Textiles (AIFT) Conference 2018, Hong Kong, July 3-6, 2018*, edited by W. K. Wong, 329–36. Cham, Switzerland: Springer, 2019.

TextileGenesis, "Creating traceable supply Chains," accessed June 22, 2022, https://textilegenesis.com/.

Thiele, Leslie Paul. *Sustainabiltiy*. Polity Press, 2013.

Thompson, N. C., Greenewald, K., Lee, K., & Manso, G. F. (2020). The computational limits of deep learning. arXiv preprint arXiv:2007.05558.

Tromp, Nynke, Paul Hekkert, and Peter-Paul Verbeek. "Design for Socially Responsible Behavior: A Classification of Influence Based on Intended User Experience." *Design Issues* 27, no. 3 (2011): 3–19. https://doi.org/10.1162/desi_a_00087.

UCLG (United Cities and Global Governance) 2010. 'Culture: fourth pillar of sustain- able development', policy document. Available at: http://www.agenda21culture. net/sites/default/files/files/documents/en/zz_culture4pillarsd_eng.pdf (accessed 10. September 2022).

"UN Helps Fashion Industry Shift to Low Carbon," September 6, 2018. https://unfccc.int/news/un-helps-fashion-industry-shift-to-low-carbon.

van Wynsberghe, Aimee. "Sustainable AI: AI for Sustainability and the Sustainability of Ai." *AI and Ethics* 1, no. 3 (2021): 213–18. https://doi.org/10.1007/s43681-021-00043-6.

Vinuesa, Ricardo, Hossein Azizpour, Iolanda Leite, Madeline Balaam, Virginia Dignum, Sami Domisch, Anna Felländer, Simone Daniela Langhans, Max Tegmark, and Francesco Fuso Nerini. "The Role of Artificial Intelligence in Achieving the Sustainable Development Goals." *Nature Communications* 11, no. 1 (2020). https://doi.org/10.1038/s41467-019-14108-y.

Vos, Robert O. "Defining Sustainability: A Conceptual Orientation." *Journal of Chemical Technology & Biotechnology* 82, no. 4 (2007): 334–39. https://doi.org/10.1002/jctb.1675.

Vucetich, John A., and Michael P. Nelson. “Sustainability: Virtuous or Vulgar?” *BioScience* 60, no. 7 (2010): 539–44. https://doi.org/10.1525/bio.2010.60.7.9.

Vue.ai, and Diesel. Rep. *Image Attribute Extraction Using VueTag - Vue.ai's Automated Tagging Solution: An Impact Study*, n.d..

Vue.ai. Rep. *A.I. in Retail 2022*, n.d..

“Wages.” Accessed July 7, 2022. https://hmgroup.com/sustainability/fair-and-equal/wages/.

Wang, Xibo, Wendong Wei, Jianping Ge, Bin Wu, Wei Bu, Jiashuo Li, Mingtao Yao, and Qing Guan. “Embodied Rare Earths Flow between Industrial Sectors in China: A Complex Network Approach.” *Resources, Conservation and Recycling* 125 (2017): 363–74. https://doi.org/10.1016/j.resconrec.2017.07.006.

Watson, Emma, Andres Chang, Alberto Carrillo Pineda, Christa Anderson, Cynthia Cummis, and Martha Stevenson. “SBTi Corporate Net-Zero Standard. Version 1.0,” October 2021.

Wolff Anthony, L. F., Kanding, B., & Selvan, R. (2020). Carbontracker: Tracking and Predicting the Carbon Footprint of Training Deep Learning Models. ICML Workshop on " Challenges in Deploying and Monitoring Machine Learning Systems".

Wong, Pak-Hang. “Democratizing Algorithmic Fairness.” *Philosophy & Technology* 33, no. 2 (2019): 225–44. https://doi.org/10.1007/s13347-019-00355-w.

Wong, W. K., Zhaoxia Guo, and Yung-sun Leung. *Optimizing Decision Making in the Apparel Supply Chain Using Artificial Intelligence (AI): From Production to Retail*. Cambridge: Woodhead Publishing Ltd, 2013.

World Commission on Environment and Development. Rep. *"Our Common Future"*, 1987.

# Appendices

## Appendix A: Physicality vs. Materiality

When I started this project, I usually spoke about the 'physicality' of AI meaning servers and their related infrastructure necessary to run the programs. Using the term physicality, it also felt natural to use 'physical form' of AI to refer to the required servers. But along the way, a discussion arose about whether 'material' and therefore materiality would be the better terms, as they seem more common in engineering sciences. Following this initial remark, I had several discussions with other people. I also received reactions to my survey, which suggested people were uncertain about how to interpret the term physical form of AI. It appears, that many people associate robots with the combination of AI and physical form. This made me question my choice of words and I began to reflect on what I intended with my word choice.

In all honesty, I think it was the first term that came to my mind, when I began exploring the relationship between AI and its environmental impact. I knew it might not be the ideal term and that I might have to change it along the way. But I liked the idea of servers being the bodies of AIs and never thought of a better term myself, so it became the right fit in my opinion. Looking back and after some research, I can substantiate my choice.

Physical and material can be used synonymously but differ in their etymology and intricacies of their meaning. Physicality and Materiality on the other hand are more distinct. According to the Oxford English Dictionary physicality describes the "fact, state or condition of being physical (as opposed to mental, spiritual, etc.), the "awareness of the body or of bodily sensation, a bodily function or experience" or the "quality of being physically demanding; physical intensity; strong physical presence or appeal". Furthermore, it was previously used to describe medicine or medical practice. The term is a derivative of the adjective physical which likely stems from the post-classical Latin physicalis translating to physical or medical.

Materiality, on the other hand, means the "quality of being composed of matter; material; existence; solidity", that "which is material […] material things", or "[m]aterial or physical aspect or character; outward appearance or externality". The term is probably a derivative of material which stems from the post-classical Latin word materialis meaning formed of matter. In Aristotle's work, this is one of the four causes necessary to achieve explanatory adequacy.

Considering the meaning of the terms both materiality and physicality are suitable descriptions, but I think that physicality and therefore physical form is better suited to express my ideas. One could argue that servers are the material AIs are built from, but this obscures all the materials and processes necessary to create servers, conflating them into one material. This could lead to a less thorough assessment of the physical impacts AI has on the environment. Physicality, on the other hand, suggests a body, something that takes up space and acts upon its environment. This might lead to confusion initially but describes servers well. Servers are physical representations of AIs, especially if they are only used for online purposes. It is not necessary for an AI to be linked to a robot or other machine to have a physical impact and form, although this seems to be assumed by some people. Using physicality and physical form to reference servers, data centres and everything else to create and use an AI could change the understanding of physical AI and make the connection more visible. Servers, or more broadly data centres, are the form in which AIs will always influence their environment. Many of the positive effects such as the reduction of overproduction, only happen if the recommendations of a forecasting AI are followed and executed well. But even if recommendations are not followed the impact of the servers remains, which is a physical effect on the environment. Therefore, I am using the terms physicality and physical form to refer to the servers and other infrastructure necessary to produce and maintain AIs. Other authors might use materiality and material form to refer to the same aspects of AI.