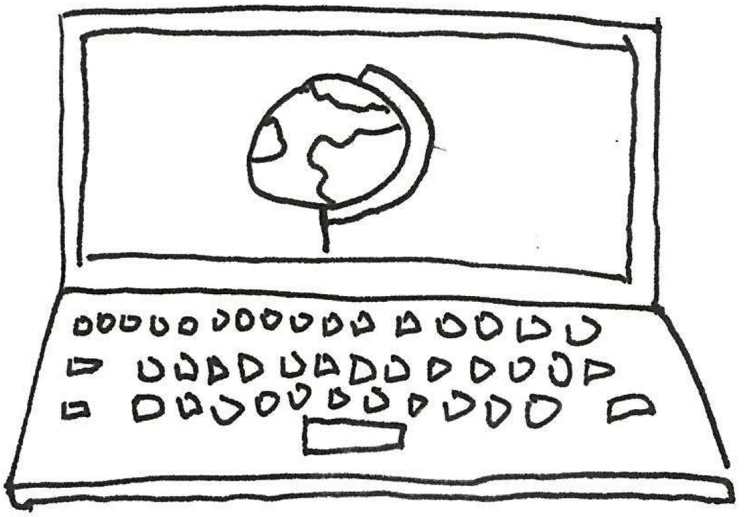
DIGITAL SUSTAINABILITY
FROM CODE TO CLOUD



- Principles and practices

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Digital sustainability from code to cloud

Principles and practices

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Digital development, digital sustainability, twin transition, sustainable digital

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Part one - Why digital sustainability?

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1. Setting the stage: Fundamental concepts of sustainability and digital development

In order to base our work with sustainability on a solid ground, we must first go through some important sustainability concepts. This first chapter covers key ideas and definitions. The goal of the chapter is to give you a glimpse of the complexity which we must be able to handle when working with sustainability. The concepts span many different scientific disciplines, including biology, geology, physics, chemistry, law, economics, and social sciences. Working with sustainability asks of us to navigate in different intertwined disciplines, requiring a holistic approach from those of us working with digital products, solutions and services.

Why is sustainability urgently important right now?

Let's go through some substantial theories that empasize the urgency of taking action for sustainability in all areas, including the digital. Read about:

- The Anthropocene
- Mass extinction
- Great Acceleration
- Planetary boundaries
- Climate change
- Digital transformation
- Your responsibility

🛣️ This is the age of the Anthropocene

The Anthropocene is the name of en epoch, beginning in the 20th century, in which human activities are affecting life on Earth to an extent that they are causing both local and global changes in the global state of the Earth.

In the past, geological processes had the greatest influence on life on Earth and the properties of the planet surface, but our agriculture, buildings, roads, wars, excavations and other activities are changing the landscape.

This change is comparable to the major geological impacts on Earth in the past, such as major volcanic eruptions and meteor impacts. The anthropocene age heralds new times where humanity is not only responsible for its own future, but also holds the future of a livable planet in its hands.

The human emission of greenhouse gases is one example, and the consequences for soil, plant and animal life, and thus for human life, are enormous.

❓ Sixth mass extinction is on the horizon

In biology and ecology, we are also witnessing a historic and global event that scientists describe as the sixth great mass extinction, a process in which a great part of the Earth's different animal species become extinct within decades or centuries. The time we live in can be compared to the time when the dinosaurs went from being the dominant species on Earth to mass extinction.

The sixth mass extinction is expected to be as pervasive for nature as the dinosaur extinction was, with the risk that a third of all animal species could disappear (Urban 2024). As with the anthropocene age, human activity is also the cause of the sixth great mass extinction. This too is happening right now.

📈 We are part of the Great Acceleration

Some scientists theorize, that a global change began with industrialization in the 1800s, and accelerated rapidly after the 1950s. Global change is accelerating and we are accelerating the activities that are changing our planet, such as the release of greenhouse gases and the destruction of various biotopes (Steffen et al. 2015).

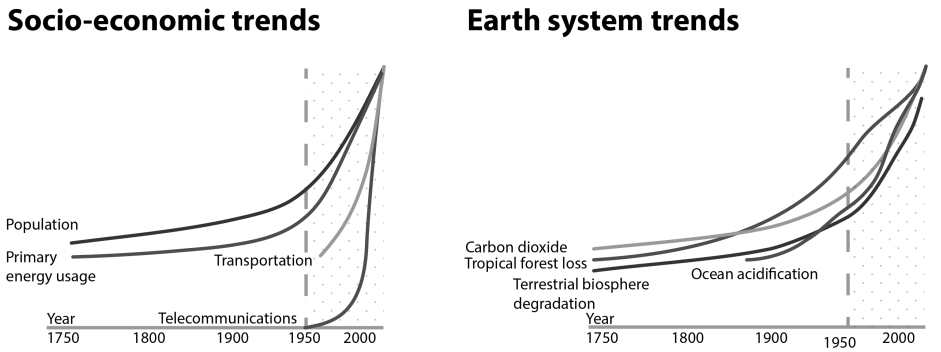

Figure 1. The Great Acceleration is the theory that we live in a time when many different global trends are accelerating at an unprecedented rate. Notice how development takes off after the 1950s. Source: Steffen et al. 2015.

This theory is called the Great Acceleration, and the researchers behind the theory see the Earth as a system where everything is interconnected and one change escalates another, as shown in Figure 1. Over the past thousands of years, the Earth's systems have been able to balance between states that have been mostly favorable to life on Earth, but many fear that the Earth's systems will veer out of balance if we continue to accelerate development.

We are pushing the planets boundaries 🌎

The world's population is growing, our industrial activity and consumption is growing, and economies are also growing year after year - but the planet's size and resources limit this perpetual growth. Planetary boundaries is a concept developed by researchers from Stockholm University, describing the nine major planetary subsystems that regulate Earth's systemic stability and resilience (Stockholm Resilience Centre 2012).

Scientists have estimated limits for Earth's planetary subsystems in which humanity can continue to evolve and thrive for generations to come, without causing irreparable damage to Earth as we know it. If the limits are exceeded, the systems may become unbalanced, leading the planet to a new and different reality.

Developments in recent decades show that, unfortunately, we are increasingly exceeding these limits for sustainable global development, and that there

is a risk of serious global consequences if we do not begin to respect the limits as soon as possible.

We are the climate change 🌪️

Current global development is neither durable nor sustainable. In the coming decades, we must turn all industrial (and digital) development in a sustainable direction to enable people to live a good life.

We must be able to continuously improve and develop our world without fearing the long-term consequences of our actions in the form of droughts, floods, destruction of rainforests and landscapes, major political challenges, migration, and loss of life. We have an ethical obligation to protect nature, which is our origin and our future.

With the help of scientists who continuously monitor global climate change, a number of actions are underway globally that aim to change the trend to something more sustainable (Science Based Targets initiative). But we will need every effort. That's why it's important that we incorporate sustainability into all our activities - including digital ones.

People in information tehcnology and digital services are both the villains and the heros 📡

Information technology and digital transformation are phenomena that surprise us daily with its latest inventions, opportunities and challenges, shedding light on new aspects of our everyday lives - and our existence.

Social media, virtual worlds, sensor networks, autonomous agents, artificial intelligence, generative AI, machine learning, Internet of Things (IoT), data science... All of these IT concepts have emerged in recent years and are still evolving as they change our world.

Modern IT is accelerating some dimensions of science and research, and the computing power of processors and the efficiency of algorithms are increasing every year. It is now the speed of human cognition that limits the speed of development.

Information technology and digital transformation are two sides of the same coin. Digital transformation focuses on people, organizations and their processes, and information technology focuses on the digital technologies themselves.

- Digital transformation is the use of information technology by people and organizations.
- Information technology consists of hardware, software and networks: Electronics, algorithms and systems.

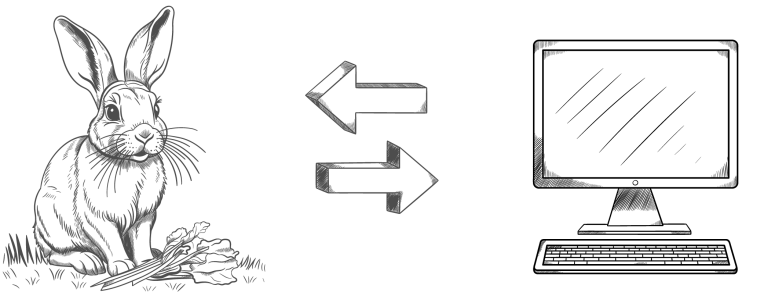

Figure 2. Technology and nature are opposites. But they shouldn't have to be.

There is no digital transformation without technology, and technology also makes the most sense when viewed in the context of the people and organizations that use it. IT (like all technology) is artificial and man-made, and as such is in direct opposition to nature and the environment.

However, technology and nature must be able to coexist in mutual and positive interaction. And this is where sustainability should help create a fruitful balance and exchange between technology, people, nature and the environment.

⛑️ Accept, embrace and live up to your digital responsibility

As an information technology and digital professional, what is your role in this global equation? Can IT and digital development contribute to a better world and a more sustainable future if we use technology with long-term thinking?

You may not be able to solve the sixth mass extinction event and balance nature in the Anthropocene era overnight, but *many small steps - including your professional contribution to the sustainability agenda - will contribute to positive changes in the world.*

Fundamental sustainability concepts

Let's continue by reviewing some key concepts that form the basis for working with sustainable digital development. You may already be familiar with some of the concepts and skip reading about them, but hopefully you can also read up on something new and exciting:

- Definition of sustainability
- Unsustainability
- The hurdles to sustainability
- Uncertainty for a sustainable future
- Green sustainability
- Greenwashing and greenhushing
- Ecology and ecosystems

Definition of sustainability

We can see sustainability as a path towards a brighter and more stable world both on an individual, societal and environmental level. Sustainability is a kind of long-term development where nature and the environment are respected and thrive.

Sustainable development helps us avoid major disasters in the future by addressing problems in the present. That's why sustainability requires action from us today, both for the future, for ourselves and for the world around us.

There are different definitions of sustainability, but one of the newer and more recognized definitions comes from the UN, which in 1983 established a World Commission on Environment and Development headed by the then Norwegian Prime Minister Gro Harlem Brundtland. The Commission's work resulted in a publication entitled Our Common Future - The Brundtland Commission Report on Environment and Development.

The report defines sustainable development as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. This definition is a good starting point for our work, but in the following we will also look at sustainable development from other angles. If sustainability is something that protects the possibilities of future generations, what is the opposite? Let's take a look at "unsustainability".

Unsustainability

Unsustainable products and services are defined by the fact that, despite their useful value in many contexts, often have serious, unintended and far-reaching negative impacts in the long term.

	Short-term (here and now) gain	**Serious problems in the long term**
Pesticides such as glyphosate	Weed-free areas	Poisoned drinking water, destroyed biodiversity
Fossil fuels	Efficient and cheap energy source	Climate change, natural disasters
Plastic materials	Inexpensive and versatile material for many applications	Plastic waste and microplastics are flooding the world's ecosystems
Cryptocurrencies such as Bitcoin	Decentralized, international digital currency	Huge energy consumption and emissions, and available for criminal application
Smartphones	Effective and entertaining communication tool	Environmental and social issues related to the extraction and recycling of materials; addiction-like problems for users

The table above provides some examples of unsustainable products that may create great value in the short term, but have serious negative consequences in the long term, i.e. they are unsustainable (as for now).

For example, herbicides are effective in controlling weeds, but over the years they can leak into the groundwater and poison our drinking water. It may not happen immediately, but over decades they can poison the water we depend on as people and as a society (Faartoft 2024).

The use of fossil fuels is another example of an unsustainable product, partly because we will run out of them at some point in the future, and also because their use contributes to climate change. Climate change does not happen immediately, but over many decades. We may already be feeling the effects, not least as we experience record high temperatures, record rainfall and record wind speeds (Jungersen & Stiesdal 2024). Other examples of unsustainable practices are:

- Using more energy than necessary
- Consuming the earth's resources such as water and minerals without considering alternatives
- Draining nature's resources without ensuring that the equivalent is returned to nature.

Short-term solutions are like taking painkillers for a broken leg without addressing the fracture - they relieve the discomfort for the moment, but the underlying problem remains and may get worse over time. From a holistic point of view, it's makes more sense to make long-term efforts to ensure a good future than to gain short-term benefits. Overall, it is unsustainable to create short-term solutions that have undesirable long-term effects, even if those effects occur much later or in places other than where the solutions work (e.g., when smartphone use in Europe leads to pollution in Africa and Asia).

The hurdles to sustainability

But why aren't we all working sustainably if it's so sensible? There are several reasons - here are four selected examples of obstacles to sustainable development:

1. **It is difficult to predict the long-term and far-reaching consequences of our actions.** Many of the behaviors we have developed throughout history are proving to be fundamentally unsustainable. Innovations that seem groundbreaking and beneficial on the surface - such as pesticides or materials like asbestos - have turned out to be seriously harmful in the long run. Over time, however, we can become better at taking the long view and learning from past mistakes. This accumulated knowledge is valuable and can be actively used and integrated into decision-making processes to promote a sustainable future.

2. **Working sustainably can be more expensive upfront (but in the long term, sustainability can pay off).** Most IT companies build data centers on the existing power grid, which is affordable and straightforward. Other companies base data centers only on renewable energy sources, which means the data center doesn't have any direct greenhouse gas emissions. It's a better solution climate-wise, but it's initially more expensive than connecting the data center to the regular power grid, which doesn't require an investment in its own power plant. Conversely, if the renewable energy plant works well, the data center will get cheap electricity in the future, and the data center's profit will increase over the years as its own wind turbines, solar panels or other renewable sources manage to produce electricity cheaper than the market price.
3. **There are a record number of people on the planet and everyone wants a better standard of living.** This is leading to unprecedented growth in production and consumption, which we can only manage if we can reduce this increased (and still growing) environmental footprint.
4. **Working sustainably requires a degree of altruism**, a respect for the planet and its inhabitants, but not everyone shares this consideration for future generations and the environment. Furthermore, the negative impacts of a company's operations are often distant in time and place from its daily activities, making them easy to overlook.

Let's look at an example from the digital world where these problems can be observed: a smartphone. Using a smartphone has become an everyday occurrence for most people, but this simple everyday device has far-reaching global consequences. Smartphones are made from naturally occurring minerals from different distant places and it's parts are manufactured all around the world.

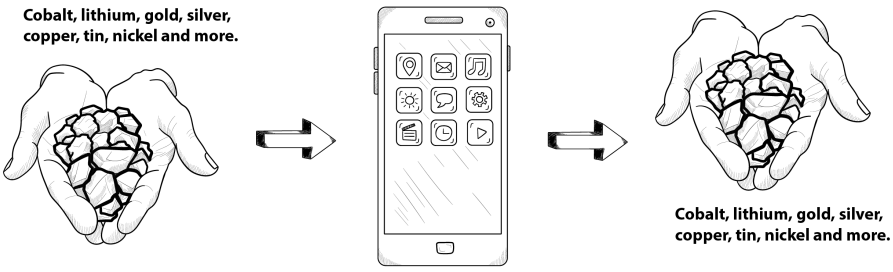

Figure 3. It's fascinating to think that a smartphone is made up of refined stones (minerals) extracted from nature and powered by energy from nature. Ultimately, all technology is a collection of minerals and energy. The more circular the production and use of technology becomes, the more sustainable the future can be.

The extraction of minerals used in smartphones involves pollution, child labor, deforestation, and health problems associated with working in mines in Africa. Assembly line work in Asia may involve poor working conditions. Last but not least, the applications that run on smartphones can have a bad impact on it's users. But this is not something we often think about. Because owning a smartphone has become commonplace, it's hard to think about the long-term and global consequences, because it's relatively vague and far removed from our own reality. So it's easier not to think about it.

In an ideal world, manufacturers and legislators would try to make the resulting problems explicit and do something about them. The Dutch smartphone manufacturer Fairphone, for example, does this by visiting their suppliers cobalt mines and actively improving working conditions in the mines based on their experiences during the visit (Angela 2023). Are they obligated to do this? No, they are not. They are doing it first and foremost for the mineworkers and their environment, and in return Fairphone can position its smartphone as a greener and fairer phone. However, these actions do not come for free and their phones are therefore relatively more expensive compared to the competition.

Embracing uncertainty for a sustainable future

It is clear that we cannot fully guard ourselves against all the unintended future consequences when developing new solutions. By its very nature, it is

impossible to design and develop measures for risks that cannot be foreseen.

However, when it comes to the long-term risks we are able to identify, we have a moral obligation to act. This is especially true in the area of sustainability, where we must accept that we can never fully control the future. Even if we plan and execute our activities carefully, there will always be unforeseen difficulties - such as environmental, social or economic challenges - that can negatively impact the sustainability of our projects.

We must be able to live with the realization that the world around us can be influenced and shaped to some degree, but never completely controlled. This unpredictability should not be seen as an obstacle, but as a fundamental premise for working towards sustainable solutions. Despite our best efforts, the real world can always surprise us - both positively and negatively.

Green sustainability

Sustainability has many facets, e.g technical, economical, social, individual or environmental. Environmental sustainability can also be referred to as *green sustainability*, and because of the climate crisis, this is clearly the most urgent dimension of the overall sustainability field.

It is also the most visible aspect of sustainability at the moment, as climate change is on the agenda in many parts of the world. An example of a company actively working with green sustainability is the Danish window manufacturer Velux. Like most responsible companies, Velux is focused on making its operations greener and more sustainable in the long term.

They announced in 2023 that they will fund forestry projects to capture carbon equivalent to its emissions from its founding in 1941 until 2041 (Petersson 2023). The company also plans to reduce its operational carbon emissions by 100% by improving energy efficiency and switching to renewable energy.

Velux's plan is both forward-thinking and compassionate. There is no law requiring companies to compensate for their past emissions or to become carbon neutral by 2031, but Velux is devoting resources to support this development. Velux is working with external partners to estimate past greenhouse gas emissions and offset equivalent amounts of CO2 in forests in countries such as Uganda, Madagascar and Vietnam.

While the Velux example is not directly related to IT and digital development, the company demonstrates an action that digital companies could ben-

efit from adopting. For example a digital hosting company could compensate for the greenhouse gas emissions they have emitted over time - since their startup.

Are Velux's initiatives genuinely producing an impact on a global scale, or are they merely symbolic gestures with limited effect? While their actions represent an ambitious step in the right direction, the contribution of a single company is insufficient to address the magnitude of the climate crisis. It is only through collective, large-scale efforts across industries and nations that meaningful progress can be achieved. In this regard, Vestas's example may serve as an important point of inspiration, highlighting the potential for global solutions if all stakeholders contribute at a similar scale.

If Velux really succeeds in eliminating 100% of its future greenhouse gas emissions, then the window manufacturer is definitely a climate-friendly company. But that doesn't mean it has become a truly "sustainable company". In order to achieve that, the company needs to go full circular on their activities, and address other dimensions of sustainability before they can call themself truly sustainable.

Greenwashing and greenhushing

When a company sends out marketing communications about its green initiatives, there is always a chance that the company's brand will be portrayed as more green than it actually is. It is not always easy to distinguish between real sustainability achievements and greenwashing, i.e. empty promises with little to no substance behind the communication.

In the case of Velux, is this a genuine environmental initiative with significant impact, or is it greenwashing? We can hope for the first, but only time will tell.

There is no clear line between greenwashing and green marketing, and it can be difficult to tell the difference in practice. The European Comission is working on regulation to hinder companies from making misleading claims about environmental merits of their products and services (Green Claims 2025). There are also companies that deliberately avoid talking about their environmental improvement activities in common terms for fear of being perceived as greenwashers, instead they use synonyms that create positive connotatons in consumers' minds. This behavior is called greenhushing.

How to avoid greenwashing?

Fortunately, there are established benchmarks that help determine whether a company or product is genuinely sustainable or merely engaging in "greenwashing." One such benchmark is the company's documentation of its environmental and social practices, commonly referred to as an ESG report (Environmental, Social, and Governance).

More and more companies embrace ESG reporting, and publish information on how they apply up-to-date (and not outdated) sustainability measures in their operations and development. We have to be critical when reading these ESG reports. It's essential to examine whether the company's environmental actions are in proportion to its activities or products. *Does the scale of the company's sustainability initiatives match the environmental problems caused by the company's operations?* If the initiatives are too vague, frivolous and disproportionate, than the claims can be considered as greenwashing.

A good example of greenwashing is "biofuel ", which you can buy at several gas stations. Here, 5% or 10% ethanol (alcohol) is mixed into the gasoline and called "biogasoline" (biodiesel), even though it is still 90-95% fossil, black gasoline. There is a lack of proportionality between the measure (mixing gasoline with ethanol) and the claim the product makes (i.e. that it is "bio", better than regular, black basoline). "Biofuel" sounds like some kind of environmentally friendly gasoline, but it's not. In reality, it's black, fossil gasoline that has been "masked" with the addition of ethanol.

Detecting and avoiding greenwashing is not easy, and the beforementioned proposals at EU level will hopefully be instrumental in succesfully regulating green marketing. We hope that by the time you read this book, this work will have progressed so that greenwashing becomes less of a problem when consumers want to choose green products over "black" ones.

Ecology and ecosystems

One of the most important concepts in sustainability is ***ecology*** and ***ecosystems***. The word ecology denotes a branch of science that studies "the relationships between living organisms and their environment" (Madsen 2021). Ecology is concerned with systems of living organisms, their interplay, and their surroundings, called *ecosystems*.

Ecosystems are the basis of all life on Earth, and without them we as humans cannot survive. We are part of the ecosystem whether we like it or not. Without the biosphere we cannot exist as humans. Every place on earth has it's more or less unique ecosystem, and we have an obligation to protect it for future generations.

We ourselves are ecosystems: We are hosts for the bacteria that live on us, in us, and without which we cannot live well (if we can live at all). It is essential to be able to think in systems, especially ecological systems, when working with digital sustainability. Ecology and understanding the interconnectedness of ecosystems provides useful knowledge about how our actions affect the environment on a systemic level.

Some of the systemic principles of ecology can be paralleled in information technology as both ecosystems and IT systems can be understood with a systemic approach. In the IT business, we sometimes talk about *digital ecosystems*, where an intertwined network of technology, companies and people thrive together in lously coupled networks.

Just as some plants cannot reproduce without the insects that pollinate them, there are technologies that require cross-pollination. For example, the Android smartphone operating system cannot thrive without its own digital ecosystem. What this means is that Android would not be the same without the many types of phones, phone manufacturers, networks, applications, and users that make up the product's unique ecosystem. Android smartphones would lose essential features without the many developers who provide millions of applications for the phones.

But ecosystems are not unique to Android - the concept can be found in many other successful IT-based products and in many other digital contexts. These include information ecosystems, software ecosystems, knowledge ecosystems, product ecosystems, and media ecosystems. And just as high biodiversity is a sign of a healthy ecosystem in nature, high diversity in a digital ecosystem is a sign of a successful product. Digital ecosystems function as open and dynamic systems that, through self-organization and diversity, can ensure innovation and long-term success for the parts of the system involved.

Environmental aspects of sustainability: energy and materials

If only we had an infinite amount of clean energy at our disposal, we could be more relaxed about the climate. We can for example already build machines, that pull CO2 out of the air, but as we lack clean energy to operate them, their usage is not feasible at a large scale.

As nothing is infinite on earth, we have to innovate circular uses of energy and resources, so instead of continously ingesting "new" energy and "new" materials into our businesses, we have to learn to circulate energy and materials in a sustainable flow. Digital technology paves the way for such a transformation, because it enables us to document, model and undestand the complex systemic consequences of our flows of energy and materials. Let's dig in into the following environmental aspects of sustainability:

- Energy and materials
- Fossil vs renewable energy
- Circular processes
- Greenhouse gases
- Emissions (scope 1-3)
- Climate optimisim and pessimism
- Environmental challenges

A flow of energy and materials

Although our society has access to plenty of energy and materials from many different sources on the planet, all our resources are finite and we are reaching our planetary limits. In the future, we will have no more to extract from the planet, nor can we afford to pollute more. Therefore, in the name of sustainability, we must be efficient and sustainable when using the resources available to us.

But how could that be done? Let's identify some concepts about energy and materials that are essential to our approach to sustainable digital.

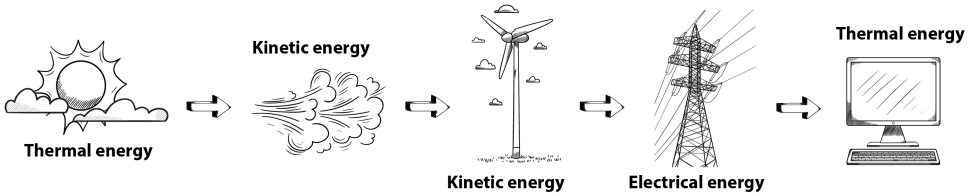

Figure 4. The sun's thermal energy is converted through a chain of processes - the wind's kinetic energy, the wind turbine's mechanical energy and then electrical energy - into calculations and output in the computer. The computer outputs the energy as thermal energy, which often requires additional energy to cool the electronic components. A circular approach to energy consumption can reduce energy waste and improve sustainability.

Energy cannot appear out of nothing, nor can it disappear on its own. However, the energy that exists in the world can be transformed from one form to another. This is one of the fundamental laws of physics: energy cannot disappear – it can only be transformed.

See Figure 4, which illustrates how energy from the sun's rays is transformed into different types of energy that eventually power your computer:

1. The sun's energy heats the air in the atmosphere.
2. This thermal energy causes the air to move, creating wind (kinetic energy or motion energy)
3. The kinetic energy of the wind turns the blades of a wind turbine, which converts it into electrical energy.
4. When you charge your computer's battery, the electrical energy is stored as chemical energy.
5. The stored energy powers the computer's processor—and as a byproduct, releases heat (thermal energy again).

The amount of energy originally provided by the sun is equal to the amount of heat your computer gives off, because energy does not disappear – it is only transformed. (This simplified example ignores the fact that, in practice, we always lose some usable energy at various points in the chain—such as in power lines or generators. This loss should not be understood as energy disappearing, but rather as a small part of the energy is eroding on the way to it's final destination: your computer.)

Fossil energy sources versus renewable energy

The use of fossil fuels such as oil and coal has brought wealth to our society, but the emission of greenhouse gases causes climate change - an unbearable cost in the long run. In addition, we are running out of fossil fuels because they are not renewable.

Renewable energy comes from sources that replenish themselves and do not diminish over time. They include solar, wind, hydro, geothermal, and wave energy. In contrast, fossil fuels such as gas, oil, and coal, which are extracted from the ground, immediately pollute the atmosphere as soon as they are burned, causing irreparable damage to the environment.

Nuclear power does not produce the same greenhouse gas emissions as fossil fuels, but it is expensive to build and maintain. It also poses radiation hazards and produces waste that is difficult to manage and impossible to dispose of. While many countries are investing in nuclear power in the coming years as an alternative to coal and gas, it remains controversial. In the longer term, scientists hope to develop power plants based on fusion energy - a form of nuclear power that promises "inexhaustible" amounts of clean energy without the radiation risks associated with current nuclear technologies. But working fusion reactors may be decades away.

Therefore, when working with sustainability, it is important to remember that the energy and materials we put into a system are transformed - and that transformation creates byproducts. Sustainable companies must take responsibility for these byproducts, for example, by creating circular systems that minimize and recycle energy and materials without damaging the environment. Operating sustainably also means prioritizing renewable energy sources to power digital technologies and infrastructure.

Circularity and circular processes

Nature teaches us that sustainable systems are built on different cycles: cycles of water, cycles of energy and cycles of different elements and materials. One of the most familiar and simple cycles in nature is the water cycle. Water falls from the sky as precipitation and hits the ground. Here it collects in rivers and lakes and organisms absorb the water - and later release it in the form of vapor. Some of the water also seeps underground, only to emerge later in rivers, lakes or the sea.

The amount of water is essentially the same in the system - no new water is added and no water is lost from the system, as vapor forms solid crystals in the cold, higher layers of the atmosphere and falls back to the earth's surface as rain. There is a continuous flow in the global cycle. So when we experience more water in one location than we are used to (e.g. flooding), then there is correspondingly less water elsewhere in the world.

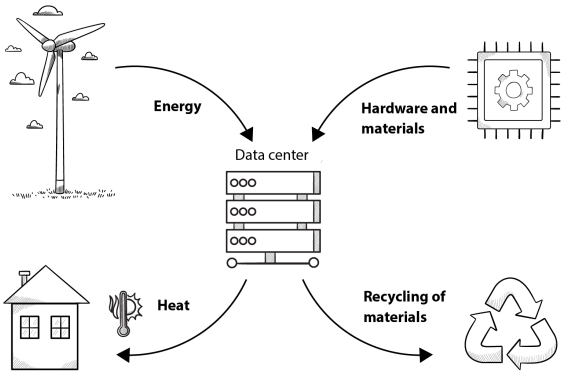

Figure 5. Data centers can operate sustainably by using renewable energy, reusing waste heat and ensuring hardware and materials are recycled. Circular solutions reduce resource consumption and contribute to a more sustainable future.

Life on Earth is based on circular processes, as shown in Figure 5. For thousands of years, our ancestors followed the rhythm of nature: planting, fertilizing, harvesting, and beginning the cycle again year after year. Not all production was circular, but with fewer people on the planet, natural resources such as water, forests, oil, and iron seemed inexhaustible. New supplies could always be found. Today, however, those supplies are under serious pressure. The human population has grown, and we are consuming more of the Earth's resources at a rate that is pushing us toward and past planetary boundaries.

We have good reason to assume that we will run out of more and more resources if we do not improve our ability to develop new technologies and business models based on circular processes, where energy and materials are reused and recycled from raw materials. In digital practice, this could be as simple as using renewable energy or ensuring that all e-waste is sent to companies that can effectively recycle it. In theory, the vast majority of e-waste can be recycled.

Look to nature for inspiration when designing digital products. One of

the most effective ways to create sustainable solutions is to design cyclical systems where energy and materials are repeatedly recycled without being lost or discarded. In other words, sustainable processes are circular, they can be repeated many times without generating significant amounts of waste or wasted energy. Working with sustainability means designing the best possible circular processes.

Greenhouse gases (GHG) and climate change

Fossil fuels (coal, oil, and gas) cannot be considered sustainable energy sources because they are not part of a circular cycle and because they pollute the atmosphere with greenhouse gases. Even before the turn of the millennium, scientists began warning of global warming caused by greenhouse gas emissions from fossil fuels.

Unfortunately, despite these warnings, we continue to extract fossil fuels from the Earth's crust and burn them for energy. This process releases CO2 and other greenhouse gases as a kind of waste that we leave behind in nature. More specifically, we leave CO2 in the air, where it will remain for millennia, forming a kind of "blanket" that warms the Earth. CO2 itself is not toxic - the problem is the increasing volume of emissions that are heating up the planet. If we could simply recycle greenhouse gases and store them underground, we wouldn't be facing the climate crisis we are today (but we may face new problems underground.)

You may have noticed how water starts to swirl, bubble, and move when it boils. A similar phenomenon occurs in our atmosphere as it heats up-the air behaves differently, moving faster and more violently. The same is true of the oceans.

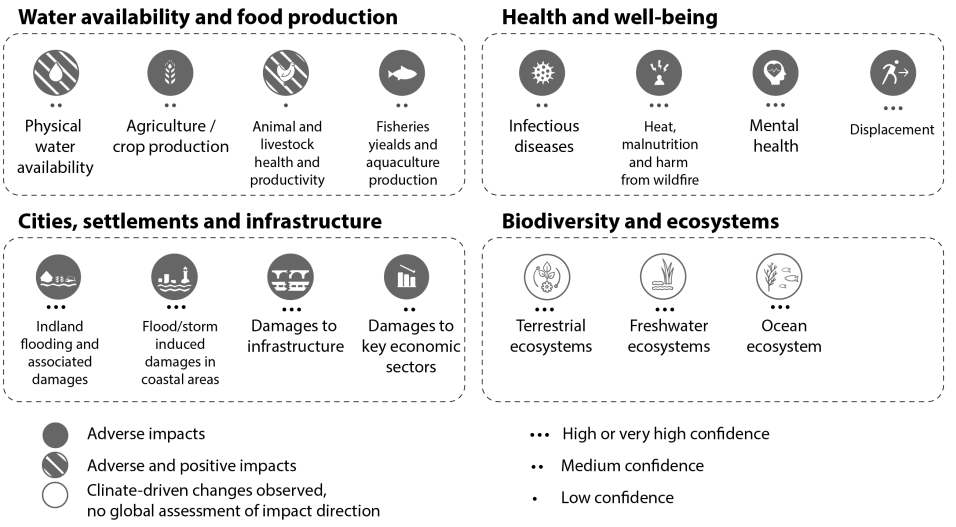

Figure 6. Climate change has far-reaching global consequences. The illustration from IPCC, the Intergovernmental Panel on Climate Change, shows some of the areas expected to be affected by climate change.

Unfortunately, all the evidence points to global warming as a serious threat to the potential for a good life in the future - for everyone on the planet, including humans, plants and animals. Figure 6 illustrates the extent to which climate change is driven by human actions, and the consequences that these changes have already had or may have in the future.

Global warming doesn't just mean higher average temperatures; it also means that weather is becoming more extreme, unpredictable, and unstable. We're already experiencing more frequent and intense weather events because of the excess CO2 we've already released into the atmosphere. If we are to prevent this from getting worse, we must drastically reduce emissions - ideally within the next decade (IPCC, 2023). This urgent goal must influence development in all sectors - including IT.

Fortunately, there is hope and progress on the horizon. Many countries have recognized the problem, and governments and organizations from around the world meet annually under the umbrella of the United Nations at the COP conferences to address climate issues. Work is progressing, albeit slowly, and the UN in 2023 formally recognized greenhouse gas emissions as a global problem requiring global solutions.

Direct and indirect emissions (scope 1, 2 and 3.)

Eliminating the use of fossil fuels and the resulting greenhouse gas emissions is in everyone's best interest. However, this is a difficult task because modern society is built on these energy sources. To understand the green transition, we need a detailed understanding of the processes that emit greenhouse gases, both directly and indirectly.

Take a gasoline-powered car as an example. We can easily observe its direct emissions: we fill the car with fossil fuel, it burns, and CO2 is released along with other gases through the exhaust pipe. But the car is responsible for far more emissions than just those from combustion. Its indirect emissions include those generated during the production, transportation and eventual disposal of the vehicle. In fact, these indirect emissions can account for a significant portion of the car's total environmental impact.

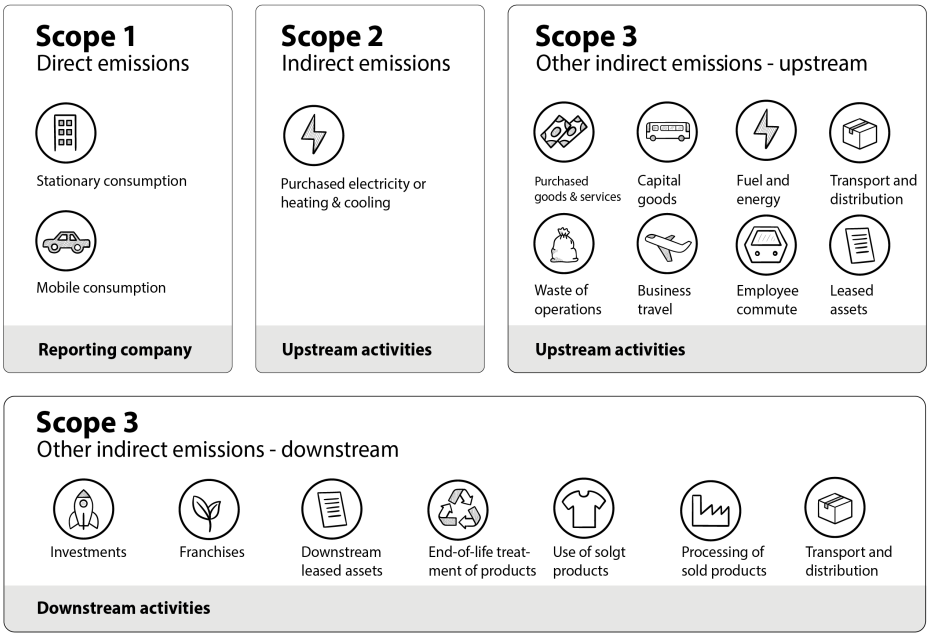

Figure 7. Overview of scope 1, 2 and 3 emissions: direct and indirect greenhouse gas emissions in the company's value chain, as defined by the GHG Protocol. Source: Reproduced with permission from Climaider.com.

When calculating the CO2 emissions of a product, service, or company, we can categorize the emissions using the Greenhouse Gas Protocol (GHG

Protocol). This framework helps quantify both direct and indirect emissions resulting from a company's activities. The GHG Protocol distinguishes between three types of CO2 emissions (Confederation of Danish Industry, 2022), as shown in Figure 7:

- **Scope 1** refers to direct operational emissions that occur at the organization's site. Examples include emissions from buildings, vehicles and machinery.
- **Scope 2** covers indirect emissions that result from the organization's consumption of energy resources such as electricity and heat. Although these emissions are not directly produced by the organization, the organization can influence them by managing its energy consumption.
- **Scope** 3 includes indirect value chain emissions that result from the company's consumption of goods and services throughout its supply chains. These are often the largest contributors to a company's total emissions.

The three scopes of the GHG Protocol are used by organizations and companies to assess and report their direct and indirect contributions to greenhouse gas emissions. These emissions can be tracked over time, and ideally, as shown in Figure 8, there should be a steady decline in emissions year after year.

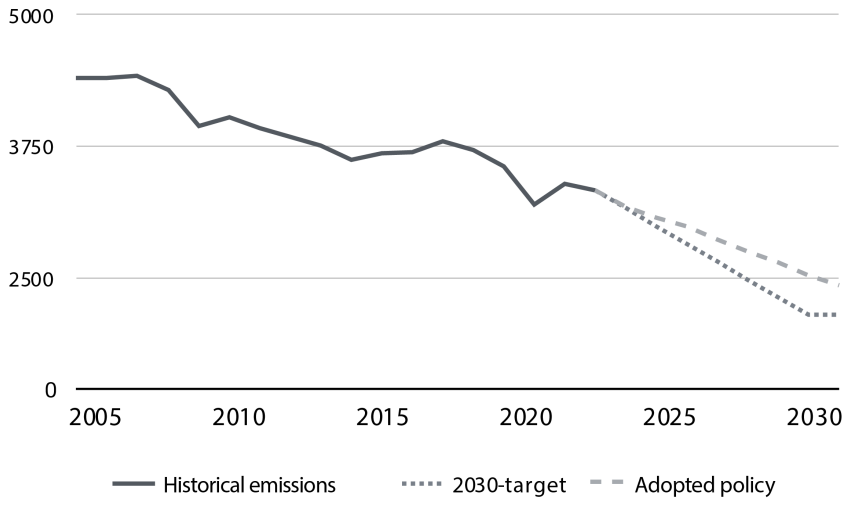

Figure 8. Figure 1.8. The EU must reduce its climate impact by 55% by 2030, and reductions must continue in the future. In 2024, the EU countries' adopted climate policy was four percentage points too low. Source: dr.dk.

The ultimate goal is to reach zero CO2 emissions within a few decades, and even than we might have to bind additional CO2 from the atmosphere. Europe's growth strategy, the European Green Deal has a goal of becoming climate neutral by 2050 (European Commission 2024b), but global ambitions are generally lower. It is worth recalling that the global community has previously succeeded in stopping a global environmental disaster when holes were discovered in the ozone layer around the Earth. This showed the possibility of establishing strong international cooperation.

Climate pessimism and climate optimism

More and more people perceive climate change as a significant threat, but at the same time, most of us find it difficult to assess how much the climate change will affect our own lives and everyday life, and what role we should play in the green transition.

Most of us want to maintain and develop our standard of living as much as possible despite the climate crisis, but we are also happy to support climate-friendly and environmentally friendly initiatives. According to a study by behavioral economist Peter Andre and his colleagues, "69 *percent of the world's population is willing to sacrifice one percent of their income for climate action*"

(Andre et al. 2024), and Myanmar tops the list with 92.80%. Most people are willing to act to combat climate change, but there is uncertainty about what to do.

It is also difficult to point to single actions that can combat the climate crisis, but *climate optimists* would say that it is possible to change the world and implement the green transition for the benefit of most people (Kirkegaard 2024). This would involve phasing out fossil fuels in favor of renewable energy sources and reducing greenhouse gases in the atmosphere to an acceptable level.

The *climate pessimists*, on the other hand, expect that society as we know it today will collapse within a few decades, and that radical global changes will be needed to best weather the catastrophe. Jem Bendell has presented a theory about this scenario, which he calls *deep adaptation* (Bendell 2017). He believes that the global response to climate change is insufficient and that we are heading towards a collapse of society as we know it today. The theory of deep adaptation describes how we ought to manage the transition from our current society to the one that follows. He points to four key themes:

- **Resilience:** Focusing on preserving what we value despite climate change; developing communities that are self-sufficient in energy, food and health.
- **Relinquishment:** Encouragement to give up aspects of our lives that are unsustainable. For example, giving up fossil fuel-dependent lifestyles, abandoning vulnerable coastal infrastructure.
- **Restoration:** Proposing to revive sustainable practices and systems from the past and contribute to more nature and more resilient ecosystems.
- **Reconciliation:** Preparing to make peace with the changes and losses that climate collapse brings.

Although we cannot predict the future with certainty, Bendell's "deep adaptation" scenario seems a plausible possibility. Whether Bendell's theory is pessimistic or realistic is debatable, but the implication is the same as that of climate optimists: *we need to create rapid, fundamental systemic changes in society and the way we live and work.*

Perhaps it is less important to talk about optimism and pessimism than it is to find ways to connect the Danes' climate commitment with Bendell's concrete proposals. This linkage can broaden the scope for action and create the basis

for more effective action. But there is still a gap between Bendell's call for profound change and the limited transition that people are willing to accept so far.

Bendell's work also provides food for thought about digital development and the great risks associated with our dependence on digital systems. These systems are vulnerable to power outages, software failures and cyberattacks, and can be compromised during crises. Therefore, the theory calls for the development of more robust and less technology-dependent solutions, which can also guide the development of new digital technologies.

Environmental challenges in extraction and industry

Whether you are a climate optimist or a climate pessimist, it is essential to keep in mind that environment cannot be reduced to climate only. To achieve truly sustainable information technology and digital services, it's not enough to focus on greenhouse gases alone; we need to address the surrounding environmental challenges as well:

- Air, water and soil pollution (by other contaminants than greenhouse gases)
- Microplastic pollution
- Pollution in space
- (Electronic) waste management
- Protection of ecosystems
- Working and environmental conditions for workers
- The consumers well-being
- And more...

These challenges can often fade into the background because climate is a top priority on a global scale, but responsible organisations should also address the environment in a broader sense. As we'll see in the coming chapters, *in cooperation between companies, organizations and citizens, we can effectively work together to reduce these problems.*

* * *

Organizations shape our sustainable future

It's important to recognize that while sustainability clearly has activistic dimensions - such as Greta Thunberg's work for the climate - it is often the economy and companies that act as the primary driving force in our society. Activists shape our thoughts and the public discourse, but economic considerations shape the strategies and actions of organizations. Although other dimensions of sustainability - such as environmental, social, and cultural concerns - also play a role, they can be difficult to fully integrate into practice without the right economical and financial underpinning. How can organizations ensure that their financial sustainability is aligned with broader sustainability goals?

In the following sections, we explore a range of perspectives and methodologies which aim to reconcile economic priorities with long-term responsibility. We examine alternative ways of measuring performance that go beyond the traditional bottom line, and we highlight principles that emphasize the reuse of resources rather than their depletion. We will also look at mechanisms that show how even well-intentioned actions can sometimes lead to unintended negative consequences:

- Economic growth and sustainability
- Financial and non-financial indicators
- ESG and CSR
- Circular economy
- Rebound effect

Economic growth and sustainability

It is a guiding principle of economics that growth is good. Companies can make more profit, more jobs are created and more taxes are collected when the economy grows. If there is no economic growth in a country, alarm bells go off. It's time to tighten belts, make cuts and shed jobs for lack of funding - and hurry to get out of the downward spiral of recession. And the danger is real, there are many examples in history where a sustained recession has caused countries to go bankrupt, resulting in severe social problems.

Most countries' economic policies aim for the highest possible economic growth year after year, it will make the country richer and there will be more

money to run society. The problem is that if we only think about next year's or next quarter's growth, we're not thinking long-term - and we're not thinking sustainably at all. Instead, we are only amplifying the great acceleration, which leads to us outgrowing the planetary boundaries.

It could be said that the traditional understanding of economic growth stands in the way of sustainable development in society. In a 2021 briefing, the European Environment Agency writes that: "*It is unlikely that a long-lasting, absolute decoupling of economic growth from environmental pressures and impacts can be achieved at the global scale; therefore, societies need to rethink what is meant by growth and progress and their meaning for global sustainability*". (European Environment Agency 2021)

In recent years, digital companies have shown that they can generate huge economic growth. In a relatively short time, software companies like Google, Facebook, and Microsoft were able to grow into some of the world's largest companies by developing powerful software once and generating enormous profits of selling it millions of times over, with minimal additional cost.

It's interesting to consider that people (including the authors) are willing to pay for software licenses for Microsoft Office, even though similar open-source alternatives are freely available. This illustrates a powerful business opportunity: once a company manages to create software with a high perceived value, it can sell the same product repeatedly at virtually no additional production costs, generating enormous profits. The success of companies like Microsoft shows how perceived value, rather than actual cost or uniqueness, often drives successful software and digital solutions.

However, this also highlights the important role that open source software can play in challenging this model. By offering free, transparent, and community-driven alternatives, open-source projects have the potential to disrupt traditional software markets—especially if they can match or exceed perceived value i.e. the quality, usability, or ethical appeal of proprietary solutions. In this sense, open source not only democratizes access to digital tools but also forces commercial vendors to continuously innovate, justify their pricing, and demonstrate real, ongoing value to users.

Financial and non-financial indicators: The triple bottom line

In a holistic approach to business, it's not enough to focus solely on financial metrics; business operations also need to be viewed through broader sus-

tainability lens and in longer terms. *How does the company interact with the environment and society? How will its activities affect future generations?*

In order to promote more sustainable practices, companies would be wise to adopt a comprehensive approach to their operations, one that integrates financial performance with broader sustainability objectives. Some organizations are required to summarize their key financial figures and produce an annual report once a year, which outlines the year's financial performance, including revenues, expenses, and the overall performance of the business. Conventionally, the narrative in an annual report is based on financial figures such as profit, return, solvency, liquidity, and employment. The vast majority of data in these reports are financial figures, describing how capital and financial values flow in and out of the company.

It is imperative for companies to shift their focus beyond **profit** to prioritize **people** and the **planet**. Consequently, sustainable business must consider metrics that cannot be *directly* measured in money. The non-financial indicators provide insight into how energy, materials and human resources flow in and out of a company. These indicators offer insights into aspects of value creation that are not fully captured by traditional financial metrics. Such aspects include, but are not limited to, customer satisfaction, employee well-being, energy efficiency, waste recycling, speed of innovation, and carbon emissions.

As companies endeavor to accentuate the sustainability facets of their operations and disclose information regarding their environmental and social impacts, non-financial indicators assume particular significance.

The concept of the **triple bottom line** refers to a business practice in which performance is evaluated not only in *financial* terms, but also in terms of *social* and *environmental* outcomes. This approach underscores the significance of exerting a beneficial influence on people, the planet, and the bottom line. The triple bottom line can function as a management instrument and is closely aligned with the principles of ESG (Environmental, Social, Governance).

ESG and CSR

Modern companies can no longer focus solely on financial performance; they must also demonstrate positive results across all three dimensions of the triple bottom line: economic, environmental, and social. Adopting a holistic business approach means that financial indicators can no longer stand alone. Instead, companies are increasingly expected, and in some cases legally required, to

provide annual reports that document their efforts and progress in achieving a balanced and responsible triple bottom line.

The table below illustrates a number of examples of themes which can be included in ESG reports to document the development of sustainability practices in a company's activities. The reports should year after year contain comparable indicators which make it possible to monitor and analyze development over time.

Environment	**Social**	**Business Management**
Climate action	Fair working conditions (health, wages, psychological work environment, training)	Business ethics and code of conduct
Responsible sourcing, use and disposal of materials	Equality (e.g. in relation to gender, ethnicity and age)	Composition and independence of the Board of Directors
Water consumption	Inclusion of minorities	Executive salaries
Energy consumption (including renewable energy)	Interaction with society	Whistleblower schemes
Waste, pollution and circular economy	Derived societal effects	Lobbying and political activity
Interaction with ecosystems	Human rights	Risk management
Biodiversity effects	User influence	Collaboration with suppliers and buyers

These non-financial indicators measure the "soft" values of a company, which are often put under the umbrella term ESG (Environment, Social, Governance). The concept of ESG has gained traction as society increasingly

acknowledges that companies carry responsibilities extending beyond profit, growth, and employment. Companies are increasingly being held accountable for their direct and indirect climate and environmental impact, their efforts in relation to working conditions, gender equality and community relations. Not only are their customers making stricter demands, but there is also more and more sustainability regulation both nationally, from the EU and globally. A company's ESG efforts can ensure, that the company can live up to the expectations of the outside world in relation to the environment, society and corporate governance.

- **Environment** covers the company's actions in relation to the environment and climate.
- **Social** refers to social aspects such as gender equality, working conditions and human rights.
- **Governance** refers to responsible, legal and ethical corporate governance, where the company's top management must demonstrate that they can not only manage the company's finances, but also its business ethics, risk management and benefit to society.

Another term that often comes into play in this context is CSR (corporate social responsibility). The term CSR can be used to describe how a company takes responsibility for the society it is part of. It is not only legislation or economic interests that guide a company's actions, and companies can also be motivated by ethical or philanthropic considerations. Interestingly, CSR is a kind of self-regulation of the company, because it is the company itself that identifies the areas it wants to take responsibility for. What ESG and CSR have in common is that they are often part of the company's overall management and operations, and as such these sustainability initiatives are reported annually.

Circular economy: from cradle to grave cradle

As you read earlier in this chapter, sustainability is often linked to various cycles of materials and energy, for example. If we want sustainable organizations, it is necessary to view organizational processes as circular processes. As shown on the figure below, the traditional linear business model for industry and services takes resources from nature and use them in production, and the resources will eventually end up as waste. Unfortunately, this business model is responsible for many of the environmental problems we see today. We can no longer

afford A “use-and-throw-away’ mentality, but must instead aim for a circular economy.

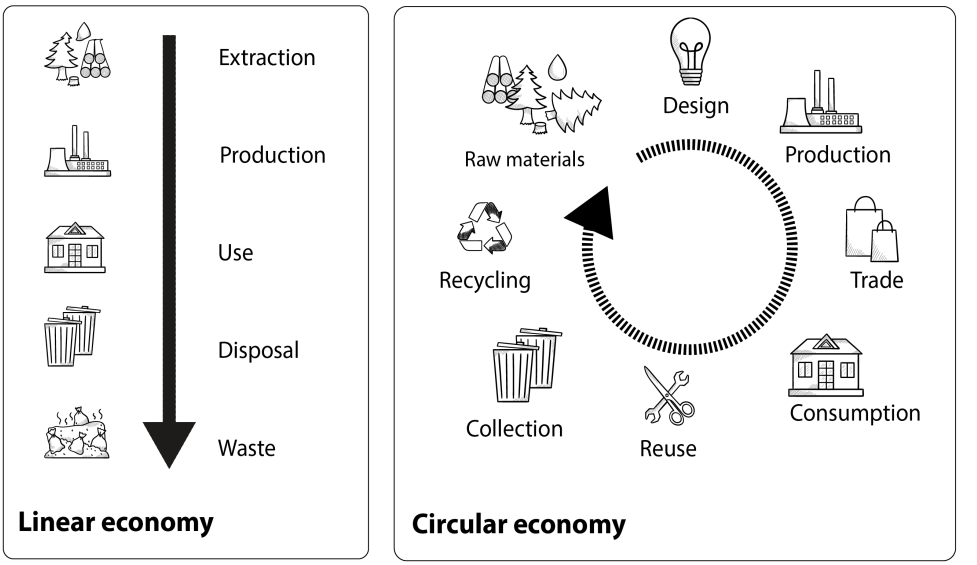

Figure 9. Linear economy creates waste through a ‘use and throw away’ model, while circular economy focuses on the life cycle of resources. By prioritizing design that considers the entire product lifecycle, reuse and recycling, we can reduce environmental impact and make production and consumption more sustainable.

According to the Ellen MacArthur Foundation, circular economy can be defined as a system where “*materials never become waste and nature is regenerated*”. In a circular economy, products and materials are kept in circulation through processes such as maintenance, reuse, refurbishment, remanufacturing, recycling and composting. The circular economy tackles climate change and other global challenges, such as biodiversity loss, waste and pollution, by decoupling economic activity from the consumption of finite resources. (Ellen MacArthur Foundation 2024)

In the coming decades, the production of information technology must become so circular that, in an ideal scenario, the acquisition or disposal of a mobile phone has no greater environmental impact than picking a fruit from a tree or letting it fall to the ground. The life cycle of our IT equipment must be deliberately designed to follow the **cradle-to-cradle** principle. This concept holds that end-of-life products should serve as the foundation for new ones without becoming waste (Hauschild, 2021). Whereas a traditional life cycle

refers to a cradle-to-grave process, the cradle-to-cradle model eliminates the "grave": the end of one product becomes the beginning of another. In other words, the materials used to produce our digital hardware must be recaptured and reused all the way into the creation of new products—closing the loop and eliminating waste.

Beware of the rebound effect

The **rebound effect** refers to the phenomenon where efficiency improvements not only lower the cost of products but also lead to increased consumption. In other words, making a technology more efficient is not necessarily sustainable, as the gains in efficiency often encourage greater use.

Digital development creates tremendous value by streamlining processes. Tasks that once took hours to complete manually can now be accomplished in seconds with the right IT solutions. However, not all optimisations deliver sustainability benefits. A clear example is storage: the dramatic increase in available capacity of storage and cheaper storage options has not reduced our demand for storage space. On the contrary, it has encouraged us to take higher-resolution photos, record more videos, and save more data, ultimately driving up consumption.

The rebound effect is also known as **Jevon's Paradox**. William Stanley Jevon (1835-82) studied energy economics during his time and it was with the increasing availability of coal that he observed that the presence of coal increased energy consumption - instead of replacing previously inefficient energy sources (fires). "*It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth.*" he wrote in The Coal Question in 1865. It's a somewhat frustrating fact that our prowess in developing new sustainable forms of energy has added our consumption instead of replacing less sustainable energy sources. Jevon's paradox or the rebound effect can be a powerful key to interpreting the lack of sustainability effects, even when witnessing impressive digital innovations.

Societal - and individual - aspects of sustainability

We have now covered a wide range of sustainability concepts and explored various aspects of sustainable development. We have examined the foundation for sustainability in terms of energy and material cycles, and we have discussed

the role of companies and organizations through frameworks like ESG and CSR. Now, we turn our attention to the societal and individual dimensions of sustainability.

The challenges related to the environment and climate are so complex that they must be addressed at all levels of society. It is not enough for individuals to live sustainably, or for companies to show consideration for society and the environment. Governments and international partnerships must also create the frameworks for sustainable development through effective legislation and environmental programs. At the same time, companies and individuals should be aligned with and support these efforts in order to reach shared goals:

- UN's Sustainable Development Goals
- Policy, legislation and regulation
- Working conditions, including work-life balance
- Well-being of end users

Sustainable Development Goals

The United Nations (UN) functions as a global umbrella organization, representing nearly all countries worldwide. Over the past few decades, the UN has increasingly prioritized sustainability and has played a leading role in shaping the global agenda for sustainable development.

In 2015, the UN adopted the 17 Sustainable Development Goals (SDGs), which commit all member states to take concrete action toward building a better, fairer, and more sustainable world. These goals offer a unifying and widely accepted framework for understanding sustainable development on a global scale. The 17 global Sustainable Development Goals are:

1. No poverty
2. Zero hunger
3. Good health and well-being
4. Quality education
5. Gender equality
6. Clean water and sanitation
7. Affordable and clean energy
8. Decent work and economic growth

9. Industry, innovation and infrastructure
10. Reduced inequality
11. Sustainable cities and communities
12. Responsible consumption and production
13. Climate action
14. Life below water
15. Life on land
16. Peace, justice and strong Institutions
17. Partnerships for the goals (from UN Sustainable Development Goals)

National governments and their authorities are basically responsible for providing the framework for achieving the SDGs, but both companies, NGO's and individuals are also invited also work towards these specific goals. The motivation for companies to work with the SDGs can be ethical, for example if they want to work for a better future, but working with the SDGs can also benefit the company: It can give the company a better reputation and a more solid ESG foundation, if selected and relevant specific goals and targets are included in the company's operations and development.

It is probably impossible for most companies to work towards all the SDGs at once, but it is a good sustainability practice to *identify one or a few selected SDGs* and specific targets where the company can make a real difference. Here, the company can examine which specific and measurable targets are relevant to the company's sustainability strategy and focus on these targets.

The latest evaluations of the achievement of the UN 's SDGs unfortunately show that, although many have started working with the SDGs, there is still a long way to go to achieve them globally. (SDG Progress Report 2024) Nevertheless, the SDGs provide a guideline for what is meant by sustainable development on a global level, and hence they can be used as guidelines in the digital field as well.

Policy, legislation and regulation

If we really want a lasting and effective change towards a more sustainable society, we need policies and legislation that oblige everyone to follow the necessary sustainability practices.

A notable example of policies advancing the sustainability agenda is the growing requirement in many countries for citizens and companies to sort

waste into separate categories. As a result, waste sorting has become a part of everyday life for most people. The rationale is clear: plastic, metal, and glass can be recycled and reused, ensuring the continued availability of these valuable materials. Food waste can be transformed into biogas, a renewable energy source that substitutes for fossil fuels, while the remaining byproduct is used as fertilizer, feeding into the circular economy.

Despite these evident benefits, resistance to waste sorting still exists. This highlights both the challenge of achieving widespread acceptance of sustainable practices and the difficulty of persuading everyone to consistently "do the right thing."

Scandinavia has a long history of leading the way in soft sustainability values like education, health, decent working conditions, and food safety. The EU also has a wide range of regulations that promote sustainable development (Erhvervsstyrelsen 2024 b). For example, all major EU companies will have to comply with the CSRD (Corporate Sustainability Reporting Directive). This is a set of rules on corporate sustainability reporting. The point of these regulations is to show how companies are doing with their environmental, social, and governance (ESG) commitments and how they are making positive changes. Other EU-level regulations include EcoDesign (Dansk Standard 2024), which sets requirements for environmentally friendly product design, and the Green Claims Directive, which aims to standardize what can be marketed as green products to help companies and consumers avoid greenwashing.

The introduction of sustainability regulation at both national and EU level is positive, because it provides certain guidelines and creates incentives for all companies to adopt more sustainable practices. On the other hand, regulation can feel slow and cumbersome because of the increased bureaucracy and time it takes to comply.

And we must not forget that even in the best-case scenario, where the regulations work as intended and the EU becomes both sustainable and carbon neutral within a few years, there are "only" 448 million Europeans, a small part of the world's total population of eight billion. We can hope to inspire and cooperate with the rest of the world - or learn from the rest of the world should they overtake us in their sustainability efforts.

Working conditions, including work-life balance

Sustainability is not just about the environment and society, it also has many lesser known facets. Individual factors can also have an impact on the sustainability agenda, such as making people (individuals) feel good about their work. "Human resources" is a capitalist approach to business, where people are considered a resource on par with energy, materials and finances. In an unsustainable company where there is no focus on circular processes, human resources can be overexploited, with detrimental consequences for individuals.

In the spirit of sustainability, it is therefore essential that responsible companies also focus on the well-being of their employees, both on a day-to-day basis and in the long term. A sustainable labor market is characterized by parameters such as:

- A salary that allows for a good life.
- Work-life balance.
- Absence of negative health effects from the work itself.
- Meaningful work for the individual employee.
- Opportunities for professional development through continuing education and training.

There can be large geographical differences in what constitutes fair pay or good working conditions in each country, so these need to be determined based on local conditions (Eurofound 2024). While a 37-hour week with flexible hours, free food and beverages and training facilities at work are not uncommon in IT companies, the working hours and benefits vary widely across the globe.

Gender equality is also an important factor in sustainability, as it is important that the most suitable people do the job, regardless of gender, ethnicity, religion or age. Discrimination, whether negative or positive, can lead to tensions and imbalances that are detrimental to long-term development.

Well-being of end users

As digital products become an integral part of daily life, the responsibility of those who design and develop them also increases. They must ensure that their products support, rather than compromise, the health and well-being of users.

At the turn of the millennium, when digital technology was still unfamiliar to most people, a wave of fascination swept through society. Suddenly, the impossible became possible: we could send instant messages, share photos and videos with old friends on social media, and access virtually all the world's information from a device small enough to fit in our pockets.

Over time, we have become increasingly aware of the darker side of digital technologies. Excessive use of screen based digital media has in some cases been shown to be harmful to our mental health, and social media can distort our sense of self and our understanding of the world, and digital agents such as generative AI can influence our thinking for better or worse.

At the same time, there are many positive achievements. Digital technologies can support our health and personal development, think of popular running apps and other digital health tools that actively promote physical and mental well-being.

From a sustainability perspective, it is important to recognize that our interactions with digital products and solutions affect users in many different ways. These interactions should promote well-being rather than encourage harmful patterns or habits. Tools such as *nudging* can help guide user behavior in positive directions. At the same time, we must remain vigilant against unethical design techniques, known as *deceptive patterns*, which manipulate users into choices that are not in their best interest. Even more critically, the rise of AI-generated digital propaganda demonstrates how technology can distort the perspectives of entire populations.

A more sustainable digital future

Information technology, in itself, cannot be called sustainable. It has both dark sides - such as environmental impact and overdependence on social media - and bright sides, in the form of the many opportunities it creates. In fact, there is no such thing (yet) as fully sustainable IT or truly sustainable digital development.

Modern digital technology is not circular; it still relies heavily on the continuous input of new resources, such as rare minerals and fossil fuels, just to keep the Internet and digital infrastructure running. However, we are seeing positive developments: more IT systems are now powered by renewable energy, and material cycles in hardware manufacturing and recycling are

gradually improving. While we already recycle a minor portion of hardware components, current methods still fall short of creating circular systems which allows materials to be reused year after year.

Whether digital development can become a true driving force in solving the climate crisis remains an open question. But as the authors of this book, we remain optimistic. We believe that digital development has the potential to make a positive difference for both people, planet and profit.

This belief is reflected in three key ideas that shape our approach-and the foundation of this book:

- The Karlskrona Manifesto
- Twin transition
- Digitainability

The Karlskrona Manifesto

Sustainable digital development is about developing modern technological solutions and products without compromising the living conditions of future generations. It's a complicated undertaking that we can better address if we can break this goal down into some concrete areas of action.

The Karlskrona Manifesto is a collaboration between researchers and practitioners to inspire both academics and practitioners to integrate sustainability into information technology development processes. The Karlskrona Manifesto's sustainable system design guidelines set out five different dimensions of sustainability (Becker et al. 2015):

- ***Individual sustainability*** *refers to maintaining individual human capital (e.g., health, education, skills, knowledge, leadership, and access to services)*
- ***Social sustainability*** *aims at preserving the societal communities in their solidarity and services.*
- ***Economic sustainability*** *aims at maintaining capital and added value.*
- ***Environmental sustainability*** *refers to improving human welfare by protecting the natural resources: water, land, air, minerals and ecosystem services.*
- ***Technical sustainability*** *refers to longevity of information, systems, and infrastructure and their adequate evolution with changing surrounding conditions.*

The Karlskrona Manifesto defines sustainable information technology as IT solutions that create value for many people and contribute to long-term positive development in areas such as the environment, climate, society, working conditions, and the well-being of individual users. In short: Sustainable digital solutions should not pollute the soil, water, or air, and they must respect and support both the people involved in the design and production, and also those who use the technology. The manifesto (available in full online) presents a set of sustainable design principles intended for software developers, researchers, users, and purchasers.

The ESG criteria and the Karlskrona Manifesto dimensions overlap in their focus on environmental sustainability and social issues, but the Karlskrona Manifesto broadens the ESG perspective by including technical and individual sustainability. The ESG "Governance" element of ESG relates in part to the Karlskrona dimension "Economic Sustainability," especially in relation to responsible governance and long-term economic viability.

Developing, procuring, and operating sustainable IT solutions is essential, but also challenging, because we still lack a clear and widely accepted understanding of how to define and measure sustainability within the IT industry. The Karlskrona Manifesto is broader and is more applicable in digital contexts as it focuses on both technological implications and individual accountability - concepts not directly addressed by the ESG criteria. While the ESG concept targets all kinds of organizations regardless of what they do, the Karlskrona Manifesto guidelines are specifically aimed at the development of digital systems. You can see a comparison between the focus areas of the two concepts in the table below.

ESG criteria	**The dimensions of the Karlskrona Manifesto**
• Environment	• Environmental sustainability
• Society	• Social sustainability • Individual sustainability
• Governance	• Economic sustainability• Technical sustainability

Throughout the whole book, we base much of our discussion on the Karlskrona Manifesto's sustainability dimensions. We believe these provide a thoughtful and nuanced approach to sustainability, which aligns closely with

the ethical, social, and environmental responsibilities of those working in the digital field.

Twin transition

The relationship between sustainability and information technology is captured by the concept of the **twin transition** - the simultaneous move towards digitalization and environmental sustainability. Born out of the EU's ambition to achieve climate neutrality by 2050, the twin transition highlights the close interplay between our transition to a data-driven, connected society and global efforts to address environmental issues such as climate change, biodiversity loss, and resource depletion.

At the same time, the digital transition refers to the ongoing global shift to a more data-driven, automated, and connected society. These two transitions are occurring in parallel and are increasingly influencing each other. An integrated approach is essential to take full advantage of the benefits and potential synergies of both transitions and to mitigate the risks of addressing the two agendas separately (Müller, 2024).

The idea that digital development can help us solve our sustainability challenges in a simultaneous and dual transition is gaining traction both in the EU and internationally. "Twin transition" is thought to have the potential to create positive synergies between digital and green development. For example, a district heating plant can retrieve automatic forecasts for weather, energy prices and heat consumption and can, through digital control, optimize the operation of production so that district heating can be produced in the most efficient way (Dansk Fjernvarme 2023).

The challenge with the twin transition is that all digital development also has a negative climate footprint from the hardware and energy used. So in digital projects with a positive sustainability aim, the positive impact of the project must be significantly greater than the negative effects of the technology used. In the case of the district heating plant, the optimization gains must be significantly greater than the derived negative environmental effects of the new digital control system. In addition, it is also important to take into account the rebound effect and make it likely that increased efficiency will not ultimately lead to even higher consumption.

Digitainability

While twin transition focuses on exploring the connection between green and digital development, the concept of digitainability goes further by presenting the idea that we can combine the development of sustainability and digital development in practice and, in this way, contribute to a more sustainable future.

The term **digitainability** is a contraction of the words digital development and sustainability. The concept was developed by Shivam Gupta et al. in order to support the UN 's Sustainable Development Goals with digital tools (Gupta et al. 2020). The concept of digitainability combines digital innovation and sustainability principles as a tool to create technological solutions that not only promote economic growth, but also protect the environment and support social responsibility.

Gupta is also a climate optimist, arguing, among other things, that the "cross-fertilization" of digital and sustainability strategies can revolutionize the way we develop and use technology. He and his teams proposes a tool called DSM (Digitalization–Sustainability Matrix) that can be used by interdisciplinary groups to explore the digitainability potential of different development scenarios.

Bringing it together: Key insights from this chapter

You've reached the end of the first chapter, take a moment to appreciate your progress! You've explored the fundamental principles of sustainable digital development, learned new concepts, and refreshed your understanding of others.

Hopefully, you've gained an appreciation for the many dimensions of sustainability, spanning from geology and ecology to economics and social sciences. Adopting a holistic perspective is essential if you wish to contribute meaningfully to sustainability.

Your role in the green digital transformation

No single individual can grasp every aspect of the complex digital and sustainable transformations taking place. Fortunately, through international collab-

oration, many skilled professionals and experts continually develop guidelines and recommendations that we all can incorporate into our own practices.

While it's true that individually we can't singlehandedly solve the world's pressing challenges, our collective lifestyle choices and professional decisions can significantly influence global trends. Gandhi summarized this well: "If we could change ourselves, the tendencies in the world would also change. As a man changes his own nature, so does the attitude of the world change towards him." (Quote Investigator 2017).

In your professional role, you have the power to make meaningful choices. For example:

- Select suppliers committed to renewable energy instead of fossil fuels.
- Prioritize hardware solutions that minimize electronic waste.
- Support the Sustainable Development Goals (SDGs) relevant to your field.

Whether your strengths lie in software development, UX design, project management, digital communication, network technology or other fields, *the greatest impact comes from integrating a long-term, sustainability-driven mindset into your daily work.*

Reflect and rethink

To promote sustainability in your everyday decisions in your profession, consider the following questions:

1. Is my work as sustainable as possible?
2. Does my work have a positive impact on the environment, climate, society, working conditions, and the health and well-being of individual users?
3. How do my professional choices today affect future generations?
4. What specific improvements can I make to ensure that my work is climate-neutral and ethically sound?
5. Does my work align with the principles of the Karlskrona Manifesto or relevant sustainable development goals?

The following chapters will provide you with essential tools and knowledge to put these considerations into practice. Next, we'll explore how systems work and how to effectively understand, model, and influence them. After this foundational theory chapter, we'll delve deeper into practical applications, specifically in digital development and information technology.

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Today, systems can also be viewed as complex networks

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6. (Not quite) sustainable hardware and IT operations

The waves of digitalization have - slowly but surely - washed over our everyday lives and society over the past decades. Computers that once took up an entire room have now become small personal devices. Technology is taking up less and less space and becoming more integrated into our lives. We now have laptops, smartphones, smartwatches, smart rings, smart cars and even smart homes where our devices communicate with each other. But we also have huge data centers that take up multiple warehouses and suck energy similar to big cities.

Electrification has transformed our means of transportation, and today our cars can run on electricity from renewable energy sources. Information technology is playing an increasingly important role in virtually every sector and industry, including the automotive industry, where modern cars are now equipped with multiple digital screens and smart features. But it doesn't stop there.

According to long-term forecasts from engineering company DNV, even more industries will be electrified in the coming decades (DNV 2023). When something goes from an internal combustion engine to an electronic mechanism, as we've seen with petrol cars that have become electric cars, digitalization also comes with it. The machines are not only connected to the power grid, they are also connected to data networks (usually the internet). And it's not just cars that are going this way, many other areas of industry are also being electrified. DNV points out that as we electrify more and more technological processes, the connection between them will increase, creating an even more connected world. We are therefore on the threshold of seeing even more waves of development in digitalization.

This digitalization is expected to continue to spread to more and more areas, and there is a huge potential to base this development on a sustainable foundation. The work of designing the digital processes of the future must start now. The more sustainable hardware we can build on, the greater the hope that

future technologies will be responsible and beneficial for both people and the planet.

But how can hardware and networks become sustainable? In the previous two chapters, we explored how digital design is used to create prototypes and blueprints for digital products and how these designs are translated into working software. Now we shift gears and turn our attention to the physical and operational aspects of sustainability in the IT world. This chapter explores how sustainability can be integrated into the more tangible technologies - from the hardware components that power the digital revolution to IT operations and data centers.

(Not quite) sustainable electronics products

Let's start with three concrete examples and see how companies are trying to develop hardware products that are as sustainable as possible.

"The Fair Computer Mouse "

"*Think fair trade coffee, clothing and even tombstones and wedding rings. But what about computers, smartphones and other electronics?*" - Sales text from the Nager IT website

Fortunately, more and more companies are working to drive hardware development in a more sustainable direction. As an experiment, German company Nager IT took a computer mouse and rethought how it could be produced more sustainably. Their product, "Die Faire Computermaus " (which you can see on the figure below), was launched in 2012 with the goal of promoting humane working conditions in hardware production (Nager IT 2024).

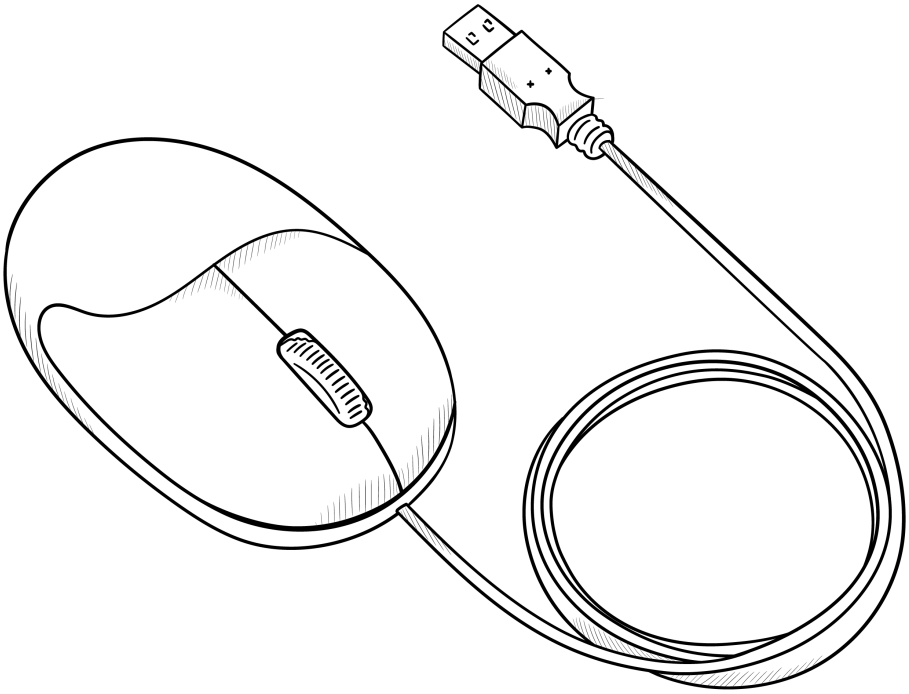

Figure 10. A simple mouse developed by Nager IT, which is more fair and sustainable than competitors' products.

Although the mouse may no longer be a technological marvel and has a slightly old-fashioned design, it is still unique. It is produced in Regensburg, Germany, in a factory where working conditions are good and where they actively employ people with disabilities who would otherwise have difficulty finding work. A special feature of the mouse is that its swivel wheel is made of wood - a symbol of how sustainability can be integrated into technology. In the figure below, you can see Nager IT's overview of how sustainable the mouse components are.

Figure 11. Sustainable, semi-sustainable and unsustainable components of the Nager IT mouse.

Nager IT has put a lot of effort into mapping, optimizing and publishing the entire mouse supply chain. Among other things, they use bioplastics made from sugar cane instead of mineral oil. The solder in the mouse is recycled from electronic waste and all components can be ordered as spare parts, making repair possible.

At the time of writing, the price of the mouse is approximately 35 euros, which is significantly higher than standard mice that can be purchased for a third of the price. The most expensive mouse from a typical Danish IT supplier costs approximately 20 euros today. Furthermore, Die Faire Computermaus is equipped with a cable, and most consumers today prefer wireless mice. On the other hand, the company promises on its website that the mouse is one of the most sustainable on the market: "Considering the entire supply chain, our mouse can in good conscience be labeled as 2/3 fair, which may sound somewhat modest, but it is still by far the most sustainable product currently available in the entire electronics sector."

The supply chain of this small and relatively simple hardware device illustrate how hardware manufacturers can try to understand and control their supply chains. The mouse is assembled at the manufacturer itself in Germany and also shipped from the manufacturer, and this part of the production is sustainable. The packaging and labeling are also green, and here you can also talk about good sustainability in working conditions and local communities. The closer we are to the end product (the mouse) in the supply chain, the more control Nager IT has over sustainability. But the further out in the supply

chain, the less control and the less knowledge the company has in relation to its suppliers. It is uncertain or unknown whether the subcontractor's suppliers are also sustainable. At some points in the chain, there are more and more suppliers who cannot demonstrate the desired level of sustainability. The outermost suppliers in the chain are almost all unsustainable with a few exceptions, which means that Die Faire Computermaus cannot claim to be much more sustainable than its competitors at this level.

Building less unsustainable computers

The case of the fair mouse shows, that it is very difficult to build a simple piece of hardware, which is truly sustainable. Despite great efforts, the current state of technology only allows us to make hardware that is "more sustainable" than the rest, rather than truly green. It will take us decades, if not centuries, to build truly recyclable and fair computing hardware solutions. Nevertheless, there is a strong movement for more sustainable computing, where producents focus on different aspects of challenging the status quo.

Berlin-based MNT Research is "driven by the idea of a digital future that is open source, collaborative, and modular." By emphasizing the importance of open sourcing hardware, they push hardware development into a more collaborative than competitive direction, which could theoretically enable hardware manufacturers to develop better technology by being able to build upon each other's inventions. Unfortunately, this approach has yet to prove its viability at scale. While open source software has taken over the world, and is used at large scale, open source hardware is still a niche. We can only hope, that companies like MNT are pushing the development in this direction.

Nirav Patel, the founder of the company Framework, has set out to create laptops that last longer than most. The goal is not just to prevent them from breaking and being discarded, but to ensure they can be repaired, expanded and upgraded. While the idea that a laptop is made up of components is nothing new, the Framework stands out by enabling users to assemble, repair and upgrade their laptops themselves as technology evolves. See an example of the repairable computer on the figure below.

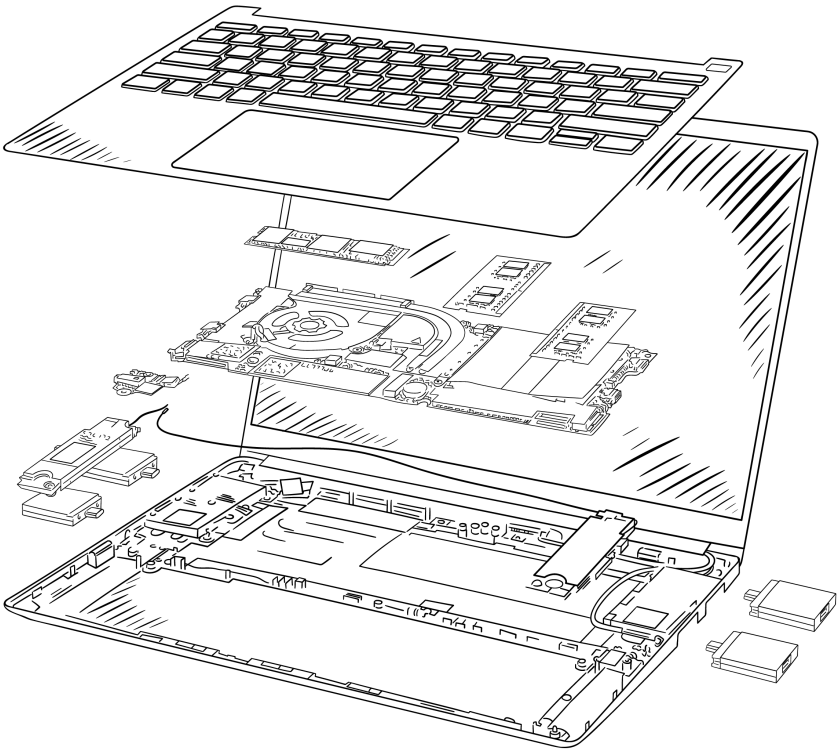

Figure 12. 'In every choice we make, we think through the impact on people and the planet.' Framework's laptop can be easily disassembled and reassembled with a screwdriver. Source: Framework n.d.

This approach, where users can replace components like the motherboard, battery, storage and even ports, stands in stark contrast to the typical trend of non-upgradable, disposable electronics products. Most laptops are difficult to repair because, they are not designed for being repairable. Lack of drawings, tools, documentation and spare parts make repairs cumbersome and costly, often leading to a better financial decision to buy new.

Framework's strategy for upgrades and repairs is expected to significantly extend the life of the devices while reducing electronic waste. The laptop comes with tools and repair manuals so that even users with minimal technical experience can make repairs. Each component of a newer Framework laptop has a QR code that provides access to documentation, repair guides, replacement and upgrade parts, and insights into design and manufacturing data. Furthermore, Framework embraces the open source philosophy and publishes designs and documentation for some of their hardware under open source

licenses on GitHub. Their hardware also supports many different operating systems, including open source systems.

While the challenges of creating a product like Framework are significant, they are not insurmountable. Producing laptops in this way is more expensive, which also makes Framework's products more expensive than comparable laptops. However, it can be argued that the longer lifespan makes the additional cost worth paying. To support the extended lifespan of their laptops, users will be able to buy spare parts for a long time - which can also prove to be costly, both for Framework and for customers. Keeping hardware secure also requires continuous updates of drivers and firmware as well as close collaboration with suppliers and the open source community, which will also be costly in the long run. Framework wants to put a concrete figure on how long they support their hardware with software updates, but they are not yet able to do so because this also depends on their suppliers (Patel 2024).

The company has created an external "Life Cycle Assessment of the Framework Laptop 2022", which explains in detail how Framework tries to minimize environmental impact through recycled materials and energy efficient production. However, their biggest contribution to sustainability lies in extending the lifespan of the laptop through easy repair and upgrades, reducing electronic waste.

Framework is a good example of a hardware brand that wants to differentiate itself on sustainability. In the longer term, we can hope that Framework will also focus on economic and social sustainability. For example, they could implement fairer working conditions with their suppliers or use more ethically sourced materials - and still have a healthy economy in the long run.

Unfortunately, building more sustainable computers is still a niche. The major computer manufacturers are stuck in their traditional and unsustainable workflows, but fortunately, also they are beginning to focus on more sustainable production practices, such as fair use of materials and repairability. But if neither legislation nor customer demand are driving the development of more fair computers, the major manufacturers are not going to move into more sustainable directions. It is than up to smaller, visionary manufacturers to driv the change. Besides MNT Research and Framework, there are a few other laptop manufacturers working for "less unsustainable computers", as for example:

- **Star Labs** laptops are made specifically for Linux, anf they combine

custom chassis designs with open firmware (Coreboot) and a full spare parts shop.
- **System76** engineers and manufactures premium Linux computers and keyboards, and advocates for open ecosystems and offers "Lifetime Support," and highly repairable Linux laptops.
- **Tuxedo Computers** emphasizes fair production and hardware longevity. Their computers offer deep software customization and accessible, user-serviceable internals.
- **NovaCustom's** slogan is "*Own. Your. Tech.*", and the Dutch company focuses on enabling their customers building their own Linux laptops for security & privacy. Their computers are based on open firmware (Dasharo), and they pledge for 5–7 years of spare part availability.

Although these manufacturers are making a great effort for building more fair computers, it is important to keep in mind, that the most sustainable computers are the ones, which do not have to be built from new resources. There are several companies, who are doing great work on refurbishing computers from major vendors, and selling them with support. Refurbishing is saving the earth's resources, because fewer new materials are required for refurbishment, than building new. Not to mention, that refurbished hardware is often cheaper than the new counterparts.

Fairphone, a more fair smartphone

Our third product story is about a fair smartphone, the Fairphone. Designer and entrepreneur Bas van Alber was fascinated by the idea that we can turn pieces of stone into something as complex as a smartphone. In the course of developing a "fairer phone" - a cell phone whose creation is fairer to nature and people - he visited cobalt mines in Congo and electronics factories in China to understand how to design a smartphone that is more sustainable. Consumers are starting to demand green digital products, but the task of designing a "fair phone" is enormous: over 60 minerals from around the world are used in the production of a smartphone and the phone consists of around 1,000 components. This is a picture that characterizes almost all IT hardware.

There are dozens of suppliers in the process, and even the suppliers themselves have dozens of subcontractors, so it is very difficult or even impossible to understand the entire supply chain. Van Alber and his team realized that

the change can't be made in one fell swoop and they can't create a truly sustainable smartphone with the technological possibilities available today. However, they believe that with a pragmatic approach to their work, they can gradually develop smartphones that become more and more sustainable.

Fairphone's efforts in 2023 focused on a few selected areas around material selection, working conditions, climate and e-waste (Monique 2024). Their efforts to create more sustainable smartphones are supported by a circular production model that makes it easier to recycle and repair while cutting down on electronic waste. "If you can't open it, you don't own it" is one of Fairphone's slogans. That's why the smartphone is designed for longevity, modular upgrades and easy repair to ensure that the phone's hardware and software lasts as long as possible. This reduces the number of smartphones produced and the carbon footprint of production and its supply chains. Conversely, it also reduces the company's revenue when it takes longer for customers to change their cell phones. Companies like Fairphone need to think outside the box to generate revenue in new ways, such as services, subscriptions, spare parts and upgrades.

They work closely with their suppliers to ensure responsible use of materials. One example of this is their focus on conditions in Congo's cobalt mines, where child labor and lack of safety are still a problem. Fairphone preferably uses materials that are recycled or sustainably and ethically sourced. They also actively engage in alliances and campaigns to make both industry and consumers more aware of sustainability. All this means that while their products are more sustainable, they also feel a bit more bulky than their competitors in the same price range.

On the social side, Fairphone emphasizes job satisfaction by ensuring fair wages, good working conditions and opportunities for development. They prioritize transparency in everything they do and use smart software tools to manage large amounts of data and tell their sustainability stories in a simple and effective way - both internally and externally.

A cornerstone of Fairphone's business operations is transparency and a high level of information at all levels, so that the company's employees and customers always have up-to-date information about the various aspects of the operation, such as working conditions at subcontractors, drawings and designs of the mobile phone's structure - and insight into the ways in which their products are used. Information is operationalized both internally and externally by telling the *sustainability stories* that drive development. Information is

also used for business management through key performance indicators (KPIs), which are selected measures of company objectives. Some of Fairphone's KPIs are traditional financial metrics such as net profit or turnover of mobile phones, while other KPIs are dedicated sustainability objectives such as "fair factories" and "fair materials" (see figure below).

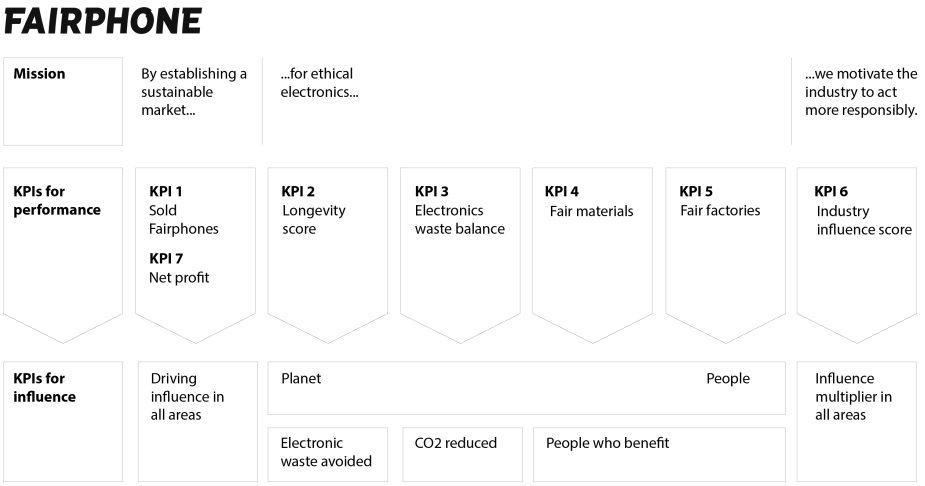

Figure 13. Key performance indicators (KPIs) that reflect Fairphone's sustainability objectives in relation to its mission and positive impact on the industry.

Fairphone assumes that their sustainability focus and stories can attract customers to their business, and they therefore keep their business operations transparent to everyone. They use *activistic storytelling* to tell sustainability stories to their potential customers. The call to action is: "Start a conversation about positive change in your company and join the movement for fair electronics. We need more voices to spread the word - tell the Fairphone story to your colleagues and get your business involved!" To support this initiative, Fairphone is encouraging their customers to take concrete actions such as:

- Sharing facts from their "Fact Sheet" on sustainable initiatives.
- Engagement in workshops and community forums, for example on urban mining.
- To act as ambassadors actively spreading the message of fair electronics (Fairphone Community 2024)

In addition, they also have the ambition to entice competitors in more sustainable directions by, for example, inviting, inspiring and challenging other mobile phone manufacturers. These are strategies that other companies can also use to their advantage when working with sustainability.

Transparency applies not only to key metrics, but also to product design and software. In 2022, the company became the first mobile manufacturer ever to release the blueprints of the electronics in its smartphones to facilitate repair and further development. In addition, the company is working to incorporate the open source mindset into production to support the software part of the phones for as long as possible.

Standards and certifications help Fairphone and many other companies to become more sustainable. In Fairphone's case, the company is helping to both develop new best practices for the mobile phone industry and to comply with various schemes such as the use of Fairtrade certified gold, EcoVadis Rating and B Corporation certification.

EcoVadis Rating (Ecovadis 2024) is a scoring system that ranks companies' environmental, labor, human rights, ethical and sustainable procurement practices, and each company can receive a bronze, silver or gold rating depending on its sustainability practices.

The B Corporation certification (B Corp 2024) is a similar certification that requires a periodic measurement of the company's social and environmental footprint, which is quantified and expressed in an overall score. This score is published after each audit, and the certification can help the company improve its practices in a more sustainable direction year after year.

Fairphone's various reactive and proactive measures can serve as inspiration for companies to work with the different sustainability dimensions of the product: social, individual, environmental, economic and technical.

The case also shows that it takes a lot of time and resources to drive development in the desired direction. There are no quick fixes - there is a long road to circular smartphones. Just as a self-sufficient agriculture could provide society with sustainable livelihoods for many millennia, we have a lot of work to do ahead for sustainable and circular examples of information technology.

On the road to sustainable information technology

Although companies like Nager IT, Framework and Fairphone have made significant efforts to promote sustainability, they still face the challenge that their products cannot fully qualify as sustainable. Unfortunately, the global electronics industry is still mostly operating with unsustainable models, characterized by intensive extraction of raw materials, globalized capitalist structures, use-and-throw-away products and, in some cases, unethical practices.

What the three companies have in common is that they are relatively new and have sustainability as their foundation. The question is whether they can compete financially with the less sustainable competitors in the long term. We hope so, but there is a risk that these companies will not be able to sustain themselves in the long run. Sustainable hardware can only thrive if there is an incentive for consumers to pay a higher price for these products.

When innovation is focused on sustainability, there are fewer resources to develop new features, which means that sustainable products can often be a step behind technologically - yet they have the potential to catch up. And as seen with the mouse, which has yet to go wireless, it can take longer for these companies to incorporate new technologies as their development resources are used for sustainability initiatives such as lifetime extension or cradle-to-cradle design. Nevertheless, Nager IT, Framework and Fairphone have managed to create products that have gained some popularity, showing that there is a sustainability narrative and quality that appeals to consumers.

The examples we have discussed focus on consumer electronics, and we have not touched on server products, networking equipment or other types of hardware such as IoT and embedded systems. This is because it is mainly individual consumers who are increasingly demanding sustainable electronics, while businesses are not yet doing so. Businesses are still driven by a profit-oriented logic and are not ready to pay a premium price for sustainable hardware components. This is an obvious area where *you* can make the world a better place: demand more sustainable hardware solutions in your company - and from your suppliers.

We are also seeing positive signs across the electronics industry, with more companies trying to improve their sustainability profile. Large chip manufacturers such as Nvidia, Intel and AMD have taken steps to promote sustainability, but their efforts are often limited. As these companies are

primarily profit-driven, they will only embrace sustainable practices as the market requires and the regulation dictates. The difference between these larger companies and the smaller, more sustainability-oriented manufacturers lies in the approach: the big players often continue with a traditional business model and only occasionally try reactive sustainability initiatives, while the smaller companies have integrated a proactive approach to sustainability into all their processes.

We hope that the future will bring more companies that fully commit to producing sustainable hardware products and that these companies will achieve long-term financial success. If this does not happen, it may indicate the need for (global) action and regulation to curb unsustainable production practices and promote fully sustainable solutions.

Thought experiment - real, sustainable computers

When considering what has proven to be sustainable in the long term, we can take inspiration from farming systems that have worked for millennia, such as the cultivation of dates, figs and grapes. These crops have been cultivated for generations in the right climate zones without depleting natural resources. In this spirit, we can imagine what a fully sustainable smartphone could look like in the future - as a thought experiment for circular hardware production.

For a computer to be truly sustainable, the raw materials used must be renewable in a continuous cycle, year after year. An ideal sustainable phone could be biodegradable, which would ensure that it does not become waste even if left in nature. Alternatively, an effective deposit system could be implemented, like we know from bottles, where a deposit on phones would create an incentive to return and reuse all components. This would ensure that raw materials are recycled efficiently and reduce the need for new extraction.

The production process would have to be based entirely on renewable energy sources and all resources such as raw materials and water would have to be recycled with high efficiency. Today, a cell phone requires over 60 different minerals that are transported globally before being assembled into a finished product. Unfortunately, these raw materials are rarely recycled and often end up as waste in landfills around the world.

A fully sustainable phone could potentially consist of components that can be grown and recycled locally. While this may seem utopian, there is

already research underway aimed at developing organic computers. These research projects are exploring the possibility of creating computers based on organic materials such as fungi, DNA or cultured nerve cells. Although these "computers" are still at a very early stage, comparable to the first primitive calculators, they show that it is possible to implement basic computational and logic circuits with organic materials (Hu 2023).

It is clear that we must evolve our current technology and direct future information technology towards sustainable hardware solutions. If we continue with our current approach, we risk running out of the essential raw materials that our current technology relies on.

Lo-fi computing, low carbon computing, collapse informatics

"*What we are truly asking is whether or not there can be a place for computer and network technology in a world where humans contribute to the well-being of the biosphere rather than destroy it? And if yes, how?*" (*Permacomputing* 2024)

There must be room for information technology in a sustainable future. The discussion about the sustainability of IT itself has long been overshadowed by notions of the sustainability benefits that IT is thought to be a prerequisite or guarantor of.

Let's dicuss movements in IT and computer science that focus on the sustainability of technology itself. There are many terms for the class of movements that focus on this; *permacomputing*, *lo-fi computing*, *junkyard computing*, *collapse informatics*, *etc.* They are at a different end of the spectrum than, for example, Microsoft and OpenAI's plans for the $100 billion "Stargaze" supercomputer (Moss 2024). That computer is planned to be powered by nuclear energy, will rely on an advanced social structure and will of course be built by elite engineers with modern and innovative materials. Lo-fi computing is a completely different story.

Low carbon computing is a response to the high energy consumption of IT and the projected energy consumption of information technology in the future. It is estimated to be about twice as high as it is now, and three to four times higher by 2040. The only thing to do is to start "treating computational resources as finite and precious, to be used only when necessary and as efficiently as possible. As we have also seen in the GREENER principles, we

need frugal computing , where we can achieve comparable results for less energy." (Vanderbauwhede 2023)

The vision for low carbon computing is to increase the durability of future IT, so that future IT uses virtually no energy. In practice, this means:

- That we need to design systems to extend the lifetime of devices.
- That we need software development strategies that address the above - especially technical debt - i.e. expenses created by complex approaches that are likely to add costs in the future. The answer to this is simpler, but more robust, software.
- Increased focus on information security.
- Increased focus on data science efficiency across the entire system.

These visions do not only depend on engineering expertise. Permacomputing.net - a wiki on digitization using permaculture principles - describes a number of digital principles that show care for the earth and people. These include repair, reuse and "design for disassembly", i.e. planning for technical artifacts to be disassembled at the end of their life. There is also a focus on limiting the number of dependencies and minimizing the use of "pseudo-simplicity", i.e. avoiding features that hide complexity from the user (hiding complexity does not make it disappear).

There are a number of ethical principles for permacomputing: being transparent about the code you use, avoiding centralization, recognizing diversity and avoiding monocultures, and not taking infrastructure for granted! The guiding principles are: availability, compatibility, efficiency, flexibility and robustness. Robustness means that the machine can handle power outages, an offline-first approach that requires little maintenance.

The interesting thing about permacomputing is that it is both a utopian notion of digitalization, but with many practical directions. Another utopian (and perhaps dystopian) approach to information technology is collapse informatics or disaster informatics . As the name suggests, collapse informatics is a research and development approach to digitalization that focuses on the ability of digital solutions to survive in collapsed environments: What does digital infrastructure look like that can withstand water surges, droughts and floods - and how to minimize catastrophic effects with computing power?

More sustainable IT operations

If it is not yet technologically possible to produce sustainable hardware, does that mean we can't make the operation of digital systems sustainable either? The answer depends on how we define the system boundaries in IT operations. If we assume that the responsibilities of IT operations include both the use of ethical hardware and responsible disposal and recycling, then sustainable IT operations may seem unattainable as we do not yet have the necessary technological solutions.

However, if we look at IT operations in a more limited context, where the responsibility is to use the most sustainable technology available and ensure that electronic waste is handled by companies that take responsibility for recycling, then you can actually work towards sustainable IT operations. We believe that IT operations can be very much based on sustainable principles that both secure the future of digital solutions and meet the requirements for sustainable system development.

The most pressing challenges for sustainable IT operations are carbon neutrality, responsible hardware recycling, efficient software development, energy efficiency and cybersecurity. Carbon neutrality is crucial as energy consumption in the IT sector is expected to continue to rise, requiring green data centers powered by renewable energy sources.

Efficient recycling of the hardware and all its components can both reduce pollution and reduce the risk of running out of minerals and raw materials. Efficient software development optimizes resource consumption, and energy efficiency ensures that we use every watt to the maximum. Cybersecurity is also a critical factor; robust security solutions not only protect data and systems, but also minimize the risk of security incidents, which can lead to major resource losses and disruption to sustainable IT initiatives.

To avoid reinventing the wheel, IT operations can be based on well-defined and proven approaches to sustainable IT. There are several guidelines and standards that aim to support the work with sustainable IT, and in the next sections you can read about two concrete examples:

- The danish IT-Branchens's 9 recommendations for companies' green IT transition.
- SustainableIT 's IT standards for environmental, social and corporate sustainability.

9 recommendations for companies' green IT transition

IT-Branchen is a trade organization that brings together Danish IT companies with the goal of promoting their agenda both politically and internationally. The organization works to "harness technology for the benefit of the climate, the economy and the individual" and create "a better future" (IT-Branchen 2024b). In recent years, it has had an increasing focus on sustainable operations and in 2020 launched the first recommendations for sustainable IT. This publication was last updated in 2024 and is now presented as nine recommendations for companies' green IT transformation . The nine recommendations offer an easily accessible starting point for companies that want to get started with sustainable IT operations.

1. **Start small and build on it** It is recommended to start with the simple, affordable steps when embarking on the development of a green IT strategy. You can then increase the complexity and difficulty as your business evolves.
2. **Involve key employees from all relevant areas of the business** An organizational strategy can only work if all relevant employees buy into it. That's why the green transition must engage the entire organization, from management to IT.
3. **Create greener digital behavior** Ultimately, it's the behavior of employees that is key to successfully transitioning to greener ways of working. Initiatives such as digital cleanup and optimizing energy consumption are some examples of how employees can embrace more sustainable digital workflows on a daily basis.
4. **Extend the life of IT equipment and switch to circular consumption** The longer IT equipment can be used, the less it needs to be purchased and remanufactured. Businesses should create a circular approach to IT equipment by repairing, reusing and extending the life of their devices.
5. **Journey towards IT climate neutrality and set green requirements for IT suppliers** The climate crisis is our burning platform for transition, which can create an incentive to set green and climate requirements for IT suppliers and consider solutions that can reduce the climate footprint of IT operations.
6. **Shop green** Establish purchasing policies that choose climate neutral products with ethical production, low resource consumption and longevity .

7. **Offer new green skills to your IT managers** Investing in your employees is good sustainability practice, and training IT staff in sustainability and green IT practices can make a big difference.
8. **Stay on top of data and reporting** Sustainability efforts should be based on data rather than hunches as much as possible, and mapping and reporting the company's IT consumption and CO2 emissions can form the basis for informed action.
9. **Leverage technology to accelerate your company's green transition** Consider using modern technology such as IoT and AI to accelerate your company's green transition.

It is our impression that several companies have benefited from these recommendations as a supplement to their sustainability work. The recommendations can be used by companies that are just getting started, as well as by experienced companies working with green IT. The publication can be read in its entirety on the Internet, as it contains many practical recommendations for the green IT transition (IT-Branchen 2024a).

SustainableIT : standards for environmental, social and corporate sustainability

IT-branchens recommendations represent a simple collection of best practices as a starting point, but these are not necessary operational at larger scale. The american non-profit, Sustainable IT has developed a set of comprehensive standards, which have been developed in international working groups to provide a uniform framework for measuring and quantifying sustainable IT.

The SustainableIT standards (SustainableIT.org) are designed to provide IT departments with a comparable basis for sustainability work. Companies can chose relevant metrics from a comprehensive list of topics, and integrate environmental, social and governance focus areas into their green transformation. The standard includes over 100 quantitative and qualitative ESG standards (topics, metrics and KPIs) that can provide insight into a company's IT sustainability. That said, the standard does not offer concrete goals for sustainability (such as 90% of hardware to be recycled), but instead encourages you to take stock of selected areas where you can then strengthen your efforts in the long term.

SustainableIT: Examples of the standard's focus areas

The table below illustrates, that the SustainableIT standard includes several ESG parameters that can inspire and engage IT departments to deliver measurable sustainability efforts.

Environment	Social	Governance
1. Energy consumption (kWh, % renewable energy)	1. Health and safety impact of IT	1. Sustainability management and accountability
2. Lifecycle energy consumption of IT	2. Ease of use	2. Funding and incentives for sustainability
3. Emissions from IT infrastructure	3. Inclusive design	3. Education and talent development in sustainability
4. Life cycle emissions	4. Diversity, equality and inclusion in the workforce	4. Responsible technological innovation
5. Circularity in devices (hardware lifecycle)	5. Diversity in the supplier ecosystem	5. The future of work strategy for sustainability
6. Recycling rate	6. Digital community engagement	6. Retraining of workers
7. Replacement cycle for IT devices	7. Reducing digital inequality	7. Data usage, security and privacy management
8. Virtual meetings	8. Supplier requirements for compliance with human rights	8. Business continuity and resilience strategy
9. Eco-friendly business travel	9. Human rights requirements in the supply chain	9. Risk management with a focus on ESG risks
10. Paperless business		10. Precautions against fraud and corruption

Environment	Social	Governance
11. Water consumption and discharge		11. AI management
12. Sustainability impact of procurement		
13. Sustainability criteria for technology meetings		
14. Environmental impact assessment in IT procurement processes		

Most larger companies can benefit from implementing parts of SustainableIT, because they can feed directly into the company's overall ESG reporting. It may seem overwhelming to implement all the standards from SustainableIT, and fortunately, it is possible to start working with a smaller selection of standards.

Once an organisation have set their sustainability goals, they can identify and prioritize the metrics that are most relevant to their business. The first evaluation will serve as a baseline evaluation, mapping the company's current practices. This provides a clear picture of the status and possible areas for action.

After establishing a baseline, new targets should then be set, based on industry standards or benchmarks. These targets should be concrete and achievable, such as a reduction in energy consumption per user or a higher share of renewable energy within a given timeframe. In the implementation phase of the standard is a good opportunity to identify potential problems and bottlenecks, such as lack of energy management systems, organizational resistance to change or incomplete contracts with suppliers. These challenges can be addressed along the way in order to reach the goal of better ESG metrics.

Finally, organisations should focus on integrating sustainability into its their core digital activities. By using the standards' metrics as a starting point, companies can target and systematize their work towards more sustainable

operations, while meeting ESG reporting requirements and creating value both for the company and also for society.

For example, energy efficiency metrics can help understand energy consumption in data centers, while monitoring water consumption can help minimize water use in IT manufacturing, and waste management standards can promote responsible recycling of electronic waste. On the social side, standards can help improve occupational safety in technology manufacturing facilities, while metrics for fair labor practices and community engagement can strengthen corporate social responsibility. Managerially, cybersecurity standards are important to protect against data theft or data loss, and ethical AI standards contribute to the responsible development and use of artificial intelligence. Finally, compliance reporting helps to systematically document the company's adherence to international standards.

As the SustainableIT standards are based on ESG , they lack some essential sustainability aspects for IT systems that we know from the Karlskrona Manifesto. This means that SustainableIT cannot cover the broad sustainability criteria alone. Therefore, IT organizations should consider supplementing SustainableIT with additional focus areas relevant to aspects such as individual and financial sustainability as well as sustainable digital design. This ensures a more holistic approach to sustainable IT operations.

Summary: What can you take away from this chapter?

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7. Wellness, well-being and digitalization

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