

CIRCULAR CONSTRUCTION AND CIRCULAR ECONOMY

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Felix Heisel, Dirk E. Hebel
with Ken Webster



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In 2019, the European Union outlined its ambitious Green Deal to be the first continent to become climate neutral by 2050. It requires that we reduce net emissions of greenhouse gases to zero by 2050. Not only that: it also stipulates that Europe must transition to a functioning circular economy by 2050 and thus establish a statutory basis for a metabolic approach to thinking about physical goods and commodities, their reuse, recycling and natural composting. While sustainability is to become the guiding principle of social action and economic activity, the ways and means by which we will achieve this are far from clear. As a holistic praxis, sustainability must combine technical and material as well as social, economic, ecological and also ethical strategies, which have multiple complex interactions and all too often also conflicting goals and priorities. In no other field can these be better observed, addressed and influenced than in architecture and building, because in the organisation, design and construction of the built environment we encounter the complexities of sustainable action including all its various experiences, problems and potential solutions. At the same time, sustainable action cannot only look forward towards a – hopefully – better future but must also address the enormous existing stock built long before the guidelines and targets of the Green Deal. The need to adapt and convert this stock is a formidable but necessary task, given that the building sector is responsible for 50 % of primary raw material consumption globally and at least 40 % of all greenhouse gas emissions.

The series of publications, of which this is the first issue, aims to help guide us along this path and examines the central topics of the process and its interactions and dependencies from both a scientific and practical perspective. Each volume of *Building Better – Less – Different* details two fundamental areas of sustainability and explores their respective dynamics and interactions. After introductory overviews, each book presents established methods and current developments along with analyses of potential conflict points and relevant international case studies. The sustainability criteria of efficiency (“better”), sufficiency (“less”) and consistency (“different”) form the framework for each book. Together, the volumes will provide a systematic and up-to-date compendium of sustainable building.

This first volume presents concepts, methods and examples of circularity in construction and the economy. Here, the focus is on the question of resources: where will raw materials for future construction activity come from, given the increasing bottlenecks in supplies and depleting reserves? What role will the bio-economy play? Which methods and processes do we need to trial, implement and politically establish for us to achieve the goals of a circular economy? Urban mining and circular construction are two approaches to the challenges that architecture and urban design are facing, using techniques such as mono-material constructions and design for disassembly, and tools such as materials passports and databases. The circular economy is not solely about recycling but also encompasses a wide range of strategies from local community projects to new ownership and service models and steering mechanisms such as carbon fees and dividends. We must learn to understand the respective dynamics and interdependencies to avoid the pitfalls of blinkered silo thinking.

This book rises to this challenge by providing multiple ways of linking interrelated topics to one another. As such, it is more than just a linear sequence of articles, case studies and commentaries; it is also a field of relationships defined by the categories “better”, “less” and “different” as well as construction and economy. A corresponding visual table of the contents (see p. 9) aims to encourage a variety of ways of accessing the topics within. Further references at the end of each contribution help readers broaden their perspective and establish links between the different subject areas. After all, each area can learn from one another: how can we apply and incorporate economic models and ideas from the energy and resources sector to the construction industry, and vice versa? As such, a building is not just an architectural or constructional challenge but also a vehicle for adopting and discussing relevant economic models and contexts. For this, we must learn to work and act in cycles within a metabolic economic model.

PREFACE

Accordingly, the various  introductions,  articles,   case studies and  commentaries in this book highlight – and introduce – the inherent relationships within this field to further vital discourse on implementing and establishing circular models. The third decade of the 21st century will be crucial to whether we succeed in finding ways to live and act consistently, i.e., in harmony with the environment and its natural cycles and processes. Only then will we be able to dispense with the man-conceived and man-made distinction between the built and natural environment, so that we may exist together in dignity on this planet without exploiting one or the other.

Felix Heisel and Dirk E. Hebel, August 2022



SUSTAINABILITY – THE IMPORTANCE OF A HOLISTIC APPROACH

Introduction by Dirk E. Hebel and
Felix Heisel

A CONSIDERATION OF UNSUSTAINABILITY

To discuss the principle of sustainability, it can help to first consider the opposite: a situation that we would describe and classify as “unsustainable” so that we may derive principles and methods of sustainable action from it. A particularly striking example of unsustainable behaviour is the fate of Easter Island in the South Pacific Ocean and the events long ago that led to its demise. The island was first discovered by an exploration party on behalf of the Dutch West India Company under the command of Admiral Jacob Roggeveen on 5 April 1722 – an Easter Sunday, which explains its modern European name (Paasch Eyland). The crew of the three-ship expedition, which was actually searching for “Terra Australis”, was astonished and shocked by the living conditions of the few remaining people on the island. Many housed in caves, and the canoes the natives used to paddle to meet them were small, leaky and barely seaworthy. The island was dry and scorched by the sun, with mostly grasses and shrubs as vegetation and no plant higher than two metres. On a visit in 1774, Captain James Cook wrote in his logbook: “Nature has been exceedingly sparing of her favours to this spot.”¹

That this cannot have always been the case was evidenced by the large rectangular stone ceremonial platforms (*ahu*) and huge stone statues (*moai*) scattered across the island, which were an impressive and imposing sight, then as now. There are a total of 887 statues, the tallest of which is 21 m high and weighs 270 tonnes (metric tons). These upright abstract male figures with large heads but no legs or arms were probably created as ancestral representations and direct their gaze towards the interior of the island, towards their descendants. The question was: how could these statues have been created, moved into place and erected when there were no trees for making scaffolding with and not enough vegetation for making ropes?

More recent findings suggest that the island was originally settled as early as the 9th century AD by travellers from other Polynesian Islands to the west. At that time, the settlers brought plants and domestic animals from their homeland, including the sweet potato, yam, taro, banana, sugar cane and chicken. In addition, the inhabitants’ diet comprised dolphins, mussels and land and sea birds, which had thrived due to a lack of natural predators. Well provided for by agriculture, small animal husbandry, fishing and bird catching, the population grew steadily into a sizeable society of ten tribes spread across the island. Although one of the driest (a product of its predominantly flat geography), windiest and coolest of all the Polynesian islands, it was originally fully covered by a mixed forest with many species (21 such species have been identified from charcoal remains). Of these, the most impressive species was certainly the genus *Jubaea*. This Easter Island palm could grow to a trunk diameter of 2 m and was also the largest species of palm tree on the Polynesian Islands at that time. It is estimated that the island was originally home to some 10 million palm trees and other tree species covering an area of about 172 km².

The trunks of the trees and their fibres would therefore have provided the raw materials for constructing the statues, and it is probable that significant quantities of the wood were used to build the cultural-religious representations. However, the palms and other tree species were also an important resource for the lives of the people, for example for building shelters and boats, and as a source of sweet sap and firewood. From the 13th century onwards, however, deforestation advanced considerably for several reasons. The island’s geographical location and climate did not provide conditions conducive to rapid reforestation and the problem was compounded by rats that had arrived with the settlers. Without natural predators, they were able to multiply rapidly and feed on the shoots of the palm trees, as bite marks on palm nuts have shown. But it was mainly the islanders themselves who were responsible for the demise of their own livelihood through the progressive over-exploitation of natural resources.

The dry and windy climate soon caused erosion of the deforested areas. Although the inhabitants adopted measures to try and protect the land by building stone walls or laying so-called lithic mulching (placing stones on exposed soil to trap moisture, act as mineral fertiliser and compensate for diurnal temperature fluctuations), they were increasingly

1 James Cook, *A Voyage Towards the South Pole and Round the World*, Volume 1 (1777). Tredition Classics, 2011.

forced to abandon their farmland and settlements. Without larger trees, they were unable to build larger canoes for hunting dolphins out at sea. Only the rather meagre stocks of smaller fish species near the shore remained as a source of food. As the forests disappeared and the rats multiplied, safe habitats for land and sea birds disappeared resulting in the gradual loss of a further source of food. As wood reserves for firewood, for building dwellings and boats and for providing nourishment depleted, the population probably retreated more and more to the stone caves in the centre of the island. Between the 17th century and the arrival of the first Europeans, social coexistence gradually broke down, resulting in violent conflicts and ultimately also cannibalism. With the conflicts came a loss in the belief in the protective powers of the ancestors, and rival groups began toppling each other's stone statues. While it is estimated that up to 15,000 or more people lived on the island in the 16th and 17th centuries, by the end of the 18th century there were just 2,000 inhabitants, and in the middle of the 19th century probably only several hundred left, mainly also due to political reasons (e.g., deportation as forced labourers) and diseases introduced by outsiders.

This theory of Easter Island's collapse as a consequence of ecological overexploitation was put forward by Jared Diamond in his book *Collapse: How Societies Choose to Fail or Succeed*.² It is particularly distressing because the remote location in the middle of the Pacific and the impossibility of the inhabitants to interact with other people paints a picture of complete isolation and hopelessness. But there are also doubts about the complete ecological demise of the island. The ecosystem researcher Hans-Rudolf Bork of the University of Kiel does not assume a complete collapse of the food supply due to deforestation, arguing that the application of stone mulching prevented a complete breakdown. And yet, as with a laboratory experiment, excluding other influencing variables and parameters, a systemic view can be described and evaluated.

Were the island's inhabitants particularly ruthless in the way they exploited their natural environment? There is no reason to presume that. It is more likely that they behaved just as their ancestors had done in the centuries before them. The narrow boundaries, the insular geographic situation and specific climatic conditions were key reasons why it was not possible to sustainably replenish the resources they had increasingly consumed. And, as with our own planet, there was no exchange with outside systems that might have been able to compensate for the deficit. Today, the island, which now belongs to Chile, numbers some 8,000 inhabitants, most of whom live from tourism and supplies imported from other areas of the Pacific region. Even today, the island is largely without significant vegetation – the consequences of the disaster are still visible.

REFLECTIONS ON ECOLOGICAL AND ECONOMIC SUSTAINABILITY

What would have been a more sustainable approach on Easter Island? Did the inhabitants understand the consequences of their actions for their livelihood? Surprisingly, around the same time as the deforestation of Easter Island began, there were similar examples of unreflected action in many regions of the world, for example in the German Erzgebirge, the Ore Mountains. Here, the motivation was profit maximisation for silver and ore mining. While mining for metals had been common since the Middle Ages, the practice of "fire-setting" produced greater yields. Large wood fires were lit in cavities to induce stress cracks in the rock and often the heated rock was cooled with water to accelerate the effect. Wooden wedges were driven into the cracks and doused with water to cause them to swell. Both these practices required vast quantities of wood, which was sourced from the surrounding forests. The more successful the mine, the greater the degree of logging of the natural environment. At that time, a certain Hans Carl von Carlowitz (actually Johann "Hannß" Carl von Carlowitz) was the Royal Polish and electoral Saxon Chamberlain and Mountain Councillor, as well as chief mining administrator of the Ore Mountains. The Carlowitz family, a long-standing aristocratic family in Saxony, owned and managed large areas of forest in the region. Carlowitz realised that once the forest was gone there would be nothing left to manage, and that the only way to ensure their own ongoing financial security, as well as that of the mining community in the Ore Mountains, was to protect the forests – especially as

² Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed*. New York and London: Viking Penguin, 2005.

there were no rules or laws governing forestry at the time. In 1713, only a few years before the arrival of the Europeans on Easter Island, he wrote a treatise entitled *Sylvicultura oeconomica oder haußwirthliche Nachricht und Naturmäßige Anweisung zur wilden Baum-Zucht* [*Sylvicultura oeconomica – Forest Economy or Guide to Tree Cultivation Conforming with Nature*].³ In it he describes in detail the connection between the valuable natural raw material and the desire for profit maximisation. Today, one would speak of an energy crisis caused by the unchecked felling of woodland to supply a rapidly growing population. And so, he declared: “For this reason, the greatest art/science/labour and management of our lands will be based on how such conservation and cultivation of wood can be arranged so as to make possible a continuous, steady and sustaining use, as this is an indispensable necessity, without which the country cannot maintain its being.” Although the expression “sustaining use” occurs only once in the 432-page treatise, the *Sylvicultura oeconomica* is considered the origin of – at least the European – terminology and awareness of sustainability.

The Ore Mountains was not the only region to be affected by deforestation. Other areas, such as the Black Forest, experienced a similar period of persistent unsustainable use in the late 18th century, though there it was not a consequence of silver and ore mining but instead the result of the forest grazing of livestock. While the intention was that they would feed on beechnuts and acorns, the animals also ate most of the young tree shoots, preventing the natural regeneration of the forest (much as the rats had done on Easter Island). In addition, the felling of large trees for timber rafting down the Rhine to the Netherlands had become a profitable business. Sturdy timber was highly prized for building foundations for dikes and settlements in the soft marshland of the Netherlands and accordingly was exported in large quantities from the Black Forest and Upper Rhine Graben. The Kinzigtal raftsmen were famed for their skill and craftsmanship in binding and steering exceedingly long rafts down the Rhine. But such was their avarice that wood became so scarce in the Black Forest towards the end of the 18th century that in some places fence posts, stairs, carts and other wooden objects had to be burned to ensure the inhabitants’ survival over winter. The ensuing hardship led to the realisation that the natural resource of the forest had to be protected and preserved and that felling must be limited to an extent that permitted the forest to regrow naturally. By then, however, the majority of the Black Forest had already been cleared and some bare, eroded mountaintops one sees today bear silent testimony to the tragedy of bygone times.

Laws were subsequently passed regulating the amount of felling and prohibiting forest grazing and fire setting in forests, and most of these still apply today. Ironically, what saved the Black Forest was not primarily the realisation of the need for sustainability but a technical advancement that would become a new problem for later generations: the invention of the steam engine and the advent of the Industrial Revolution caused wood to be displaced by coal as the primary source of energy – a development that soon spread the world over and is now a global challenge.

The examples discussed here show that we must understand the links and interdependencies between economic goals and prevailing ecological, social and societal conditions, both locally as well as for the planet as a whole. Only then can we take sustainable action that does not lead to the destruction of our own livelihood.

SOCIAL SUSTAINABILITY

In 1962, the US-American biologist Rachel Carson published the book *Silent Spring*,⁴ which today is regarded as marking the beginning of a socially driven environmental movement. It was one of the first non-fiction books written for a broad audience to make clear the connections between the release of toxic substances such as DDT and other pesticides and herbicides into the environment and its consequences for animals and humans within the food chain. To give the topic a sense of specific relatability, she astutely chose to set it in a fictional small town in America. The book links the principle of ecological balance with the human and social perspective, right down to the premature death of the bald eagle, which as the heraldic animal of the USA was no doubt chosen to represent American Society, though

³ Hanns Carl von Carlowitz, *Sylvicultura Oeconomica oder haußwirthliche Nachricht und Naturmäßige Anweisung zur Wilden Baum-Zucht*, ed. Norbert Kessel. Reprint of the first edition from 1713. Leipzig: J. F. Braun, 2011.

⁴ Rachel Carson, *Silent Spring*. Boston: Houghton Mifflin, 1962.

Carson only mentions this in passing. And so it transpired that this bird of prey went on to become the symbol of the fight against DDT in the years that followed. Carson's book therefore adds a third dimension to the topic of sustainability alongside the ecological (Easter Island) and the economic (Carlowitz): the ethical responsibility of a socially oriented society.

These three dimensions are seen to this day as the three primary pillars of sustainability: ecology, economy and sociology. Like the principle of communicating vessels, a balance needs to be found between these three aspects and their interactions. The process of weighing these up against each other, and the inevitable prioritisation this entails, has a dynamic socio-political dimension, and Rachel Carson's book helped bring about a broad social awareness of this collective responsibility.

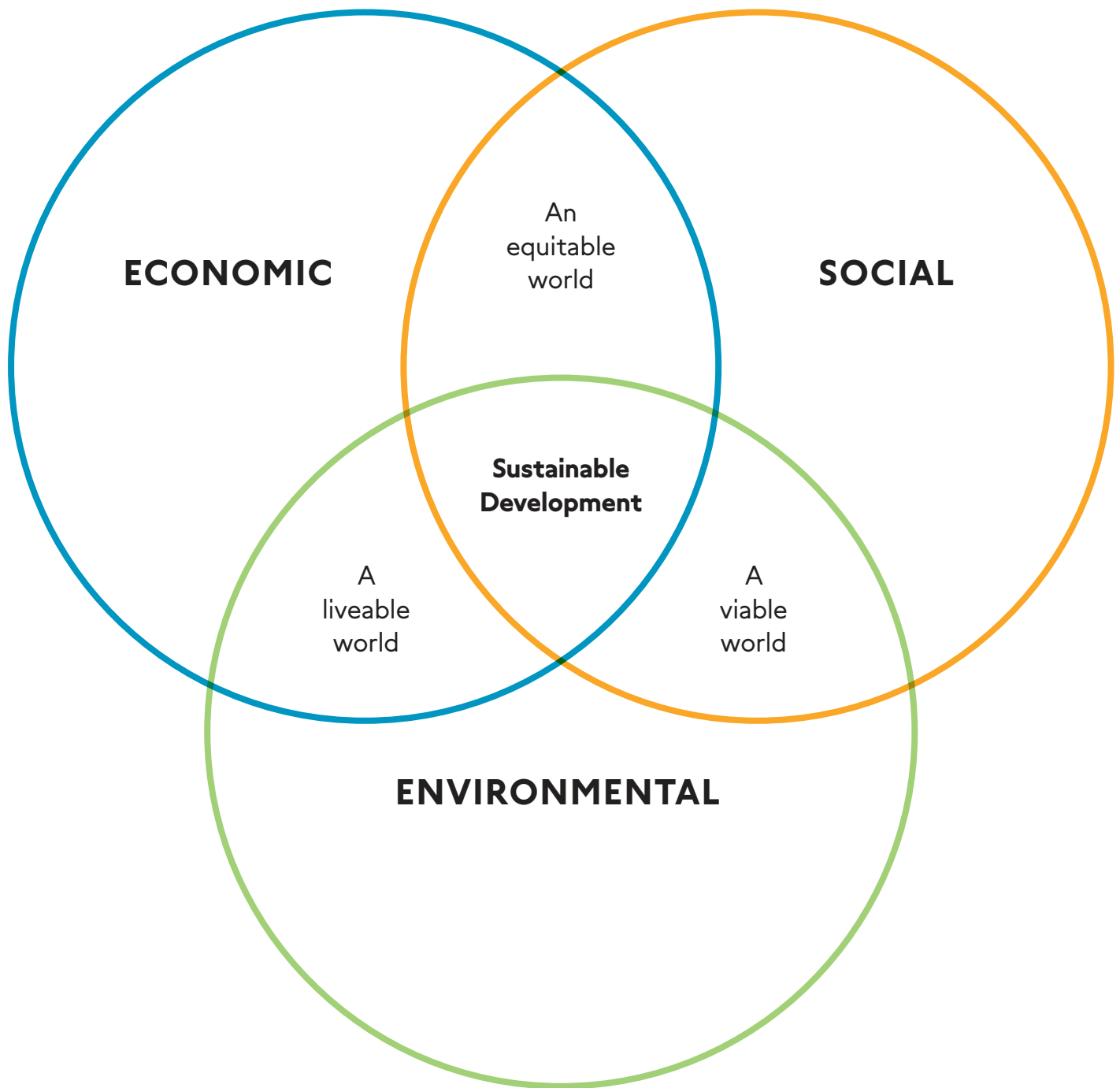
In 1972, Harrison Schmitt, an astronaut on the Apollo 17 mission, took what is still one of the most iconic photographs in the world: *Blue Marble*, as it is titled (the official designation is AS17-148-22727), shows a view of the Earth from 45,000 km away, perfectly illuminated by the sun behind the photographer. It depicts the earth against a background of black nothingness, isolated, frail and vulnerable, and we see just how thin, fragile and ephemeral the atmosphere around the Earth is. As an impression of an organism in need of protection, it evoked a sense of collective unity, and since then the image has been printed on countless T-shirts, flags and other items and has become a symbol of the emerging environmental protection and sustainability movement. It is frightening to think what could happen to a population of billions of people on this one planet if we are not able to learn from the examples of the past and adapt our behaviour to the situation at hand and act accordingly.

CALCULATING (UN)SUSTAINABILITY

A few years earlier, in 1968, two other protagonists of this movement, the Italian industrialist Aurelio Peccei, then a member of the boards of Fiat and Olivetti, and the Scotsman Alexander King, then Director of Science, Technology and Education at the Paris-based Organisation for Economic Co-operation and Development (OECD), organised a conference to try and raise awareness of the future of humanity against the background of global population growth, emerging reports of resource depletion and the need to engender a sense of ecological responsibility towards the planet. To the organisers' dismay, however, the conference at the Accademia dei Lincei in Rome failed to bring about the hoped-for awakening of a global awareness of the issues. Only many years later did this finally come about under the auspices of the United Nations.

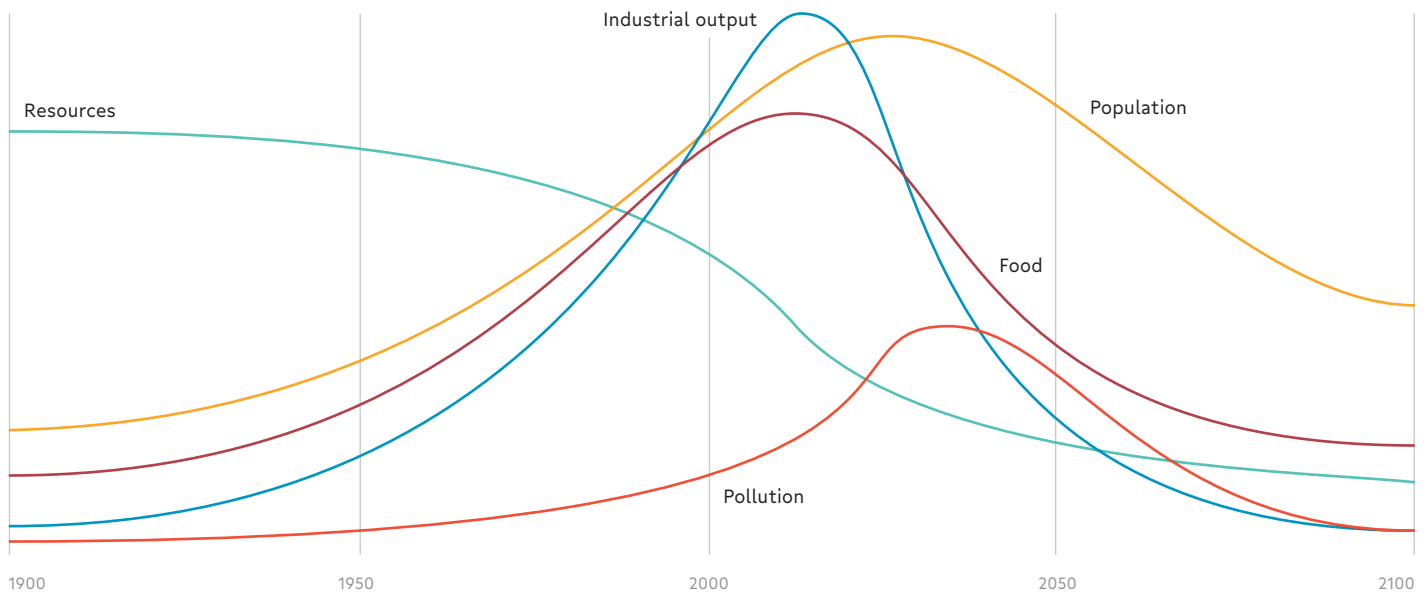
Six of the attendees – Erich Jantsch, Alexander King, Max Kohnstamm, Aurelio Peccei, Jean Saint-Geours and Hugo Thiemann – did, however, agree to work together to pursue the issues further as a collective that they called the "Club of Rome". Dennis L. Meadows, a computer scientist at MIT, later recalled: *"It was a circle of intellectuals, scientists, industrialists and other public figures [...]. In 1970, the club met for its first official annual meeting in Switzerland. The members debated at length, including how they could conduct research on the future of the world. One of the members had a concrete idea. That was Jay Forrester, a professor at MIT, the Massachusetts Institute of Technology [...] who was already famous at the time. He suggested that his computer models could help simulate the future development of world population, industrialisation and resource consumption. [...] I was already at MIT at that time and put forward a proposal on how to improve Forrester's models using the computer language Dynamo in such a way that you could develop a so-called 'world model' from them. The idea was to simulate the systemic behaviour of the Earth as an economic model according to different scenarios. And to see how long the world's resources would last. [...] Computer programmes that could simulate so-called systems, i.e. mutual dependencies between different variables, was one of MIT's major achievements at the time."*⁵ Taking up this suggestion, the Club of Rome commissioned a group of scientists to conduct a study based on Jay Forrester's preliminary work and make an estimate of how long the system Earth could remain viable – assuming global population growth and increasing economic activity, while also taking into account the limited availability of natural reserves and their increasing exploitation.

5 Frankfurter Allgemeine Zeitung, "Dennis Meadows im Gespräch: 'Wir haben die Welt nicht gerettet'", <https://www.faz.net/aktuell/wirtschaft/dennis-meadows-im-gespraech-wir-haben-die-welt-nicht-gerettet-11671491.html>, published 3 March 2020 (accessed 3 January 2022).



1

Sustainability is often described as the holistic synergy of social, economic and environmental concerns. The intersection of and interaction between these individual aspects allow us to better understand their interdependencies and identify corresponding objectives. The isolated consideration or predominant emphasis of a single aspect results in an imbalance in the system.



In 1972, the book *The Limits to Growth*⁶ was published, which presented the results of these simulations to the public. Its authors were Donella H. Meadows, Dennis L. Meadows, Jørgen Randers and William W. Behrens III, representing a team of 17 scientists. The findings of the study were devastating: if global society fails to make more sustainable use of natural resources and does not radically reduce its levels of consumption, the study predicted that the global system of the earth would collapse in the first half of the 21st century. The causes cited included the pollution of the environment through solid and gaseous emissions, the depletion of natural resources (or an end to their viable extraction) and a decreasing productivity of agricultural land, which together with the pollution of natural flora and fauna ecosystems would lead to a decrease in food supply. This would, in turn, lead to a steep decline of the birth rate, the aging of society and, above all, a sharp decrease in industrial production and services. Given the unthinkable outlook it predicted, the book came in for heavy criticism. Several attempts were made to recalculate the models with updated data and better software and hardware, most notably in 1992⁷ and in 2004,⁸ but the overall results remained unchanged. For the authors and initiators, it was important to show the interdependencies of the individual systems and the influencing variables. As such, their work represents a continuation of the earlier approaches by Carl von Carlowitz and Rachel Carson, albeit at a much higher level of complexity.

SOCIO-POLITICAL DEMANDS FOR SUSTAINABILITY

During the 1970s and 1980s, a strong global social movement emerged that aimed to make sustainability issues a central concern of politics. Various initiatives were formed, partly driven by anti-war and peace campaigners or other green and alternative groups who opposed the civil and military use of nuclear power and the exploitation of natural resources. In 1980, Germany's first green party was founded in Karlsruhe, which from then on advanced this agenda, initially at a municipal level, and later in government. Since then, these issues have gained broad support in society. Internationally, similar calls for a responsible and sustainable use of resources grew increasingly vocal and in 1983, the United Nations established the World Commission on Environment and Development,⁹ based in Geneva, as an independent expert commission. It was tasked with developing a study on how the global community could establish long-term environmental strategies for sustainable development while reconciling these with economic and social aspects. When it was founded, it comprised 19 members from 18 nations and was chaired by Gro Harlem Brundtland, former Minister of the Environment and then Prime Minister of Norway.

2

State of the World: In *The Limits to Growth*, published in 1972, scientists modelled how long the planet can maintain various existing systems before increasing imbalances will inevitably result in radical shifts in the world order.

Based on: Donella H. Meadows, Dennis L. Meadows, Jørgen Randers and William W. Behrens III, *The Limits to Growth; A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books, 1972.

⁶ Donella H. Meadows, Dennis L. Meadows, Jørgen Randers and William W. Behrens III, *The Limits to Growth; A Report for the Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books, 1972.

⁷ Donella H. Meadows, Jørgen Randers and Dennis L. Meadows, *Beyond the Limits*. White River Junction, VT: Chelsea Green Publishing, 1992.

⁸ Donella H. Meadows, Jørgen Randers and Dennis L. Meadows, *The Limits to Growth: The 30-Year Update*. White River Junction, VT: Chelsea Green Publishing, 2004.

⁹ World Commission on Environment and Development (WCED).

Its first report was published in 1987 and provided a concise definition of sustainability that is still widely acknowledged today: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*¹⁰ – a simple, succinct but also unequivocal description of the responsibility we all bear, individually and collectively. Anticipating that professional circles would not find this adequate, the report offered a second, more detailed definition: *"In essence, sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development; and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations."*¹¹ This second definition adds several noteworthy aspects: Firstly, the report recognises that sustainability is a dynamic system that is constantly being renegotiated, and secondly, it expands the framework of the communicating vessels system to include not just the three aforementioned pillars of ecology, economy and sociology but also the concepts of technology and politics (institutions) and explicitly addresses the question of resources.

DEFINITIONS OF SUSTAINABILITY

However, even this second definition was not scientific enough for some experts. In 1989, Swedish cancer researcher Karl-Henrik Robèrt and a group of 50 scientists formulated a more far-reaching approach that draws on the laws of thermodynamics: *"The Earth's biosphere is a system open to energy, which enters the atmosphere in the form of sunlight, generates winds and ocean currents and partially leaves as heat radiation. The Earth's biosphere is a relatively closed system in terms of matter, due to gravity as well as slow geological processes that put and keep minerals, metals and fossil fuels underground."*¹² Within the biosphere there are established cycles that form the basis for life on earth and ensure its ongoing survival. For example, plants produce oxygen and food through photosynthesis, which humans and animals absorb, producing carbon dioxide and natural fertilisers (from excretions and composted organic material) that promote plant growth. The biosphere is also dependent on the earth's crust, the lithosphere. Materials enter the biosphere, for example through volcanic eruptions, which with the help of biosynthesis are transformed into other material compositions. Similarly, materials also enter the lithosphere from the biosphere through mineralisation or sedimentation. *"These natural processes have evolved over billions of years. Humans are an adaptive, self-organising social species with fundamental needs to be fulfilled. [...] Humans depend on each other and on these systems to sustain them. The challenge is that these natural and social systems are being influenced more and more by humans, up to a point where we are degrading these systems on a global scale. In a nutshell, the root causes of unsustainability are: 1) Extraction of a relatively large flow of materials from the earth's crust. 2) Introduction and concentration of persistent chemical compounds foreign to nature. 3) Physical inhibition of nature's ability to run cycles. And 4) Allowing the existence of obstacles to people's health, influence, competence, impartiality or meaning-making."*¹³

Following these principles, and by preventing and opposing these four causes, Robèrt, together with public institutions, private companies, government bodies and environmental associations in Sweden, went on to design a framework of sustainable development, which was made available to all schools in Sweden and is used as a teaching aid to this day. By its own account, it has greatly influenced the country's agricultural, energy and forestry policies. Generally speaking, this predominantly scientific approach aims to lend greater consistency to our actions within the existing natural cycles, which must be protected at all costs.

MEASUREMENTS OF SUSTAINABILITY

In 1997, Mathis Wackernagel and William Rees published the book *Our Ecological Footprint. Reducing Human Impact on the Earth*.¹⁴ In it, they describe a systematic attempt to quantify the unsustainable behaviour of humankind and present a tool that any individual, community or country can use as a basis for comparison. The approach measures patterns

10 World Commission on Environment and Development, *Our Common Future*. Oxford: Oxford University Press, 1987. Chapter 2, §1.

11 Ibid., Chapter 2, Section I §15.

12 The Natural Step Germany, <https://www.thenaturalstep.de/approach/> (accessed 5 January 2022).

13 Ibid.

14 Mathis Wackernagel and William Rees, *Our Ecological Footprint. Reducing Human Impact on the Earth*. Gabriola Island, B.C.: New Society Publishers, 1996.