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Circular Economy & Industry in 2035

Climate and environmental context

P. BELTRAMELLO, A. PEREIRA PÜNDRICH

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1. Definitions

1.1 Defining the report topic

The climate question

The climate and environmental context is increasingly shaped by climate change, which encompasses the range of possible trajectories of global warming and their consequences for Earth systems and socioeconomic dynamics. These changes create interconnected hazards whose effects can reinforce one another, posing challenges to the organization of transition, adaptation, and mitigation efforts (IPCC, 2022).

The global climate and environmental context evolves through complex relationships among the large-scale systems that sustain life on Earth. Briefly, if Earth is considered a thermodynamically closed system (Georgescu-Roegen, 1971), beyond resource and material depletion, the balance between incoming and outgoing solar energy determines its temperature and climate patterns. The greenhouse effect is thus a natural process essential to a habitable climate on the planet. Anthropogenic CO2 emissions matter because they contribute significantly to altering this balance (SDES, 2023).

Climate change, together with habitat destruction, pollution, and the overexploitation of resources, therefore causes biodiversity loss that affects ecosystem services (IPCC, 2022). Global warming also alters the cycle and management of water, a primary environmental resource for the vital activities that regulate ecosystems and affect animal and human migration (World Bank, 2023).

Finally, climate tipping points refer to critical thresholds in Earth systems that can trigger significant and irreversible changes in the climate and environment. The systemic and interconnected nature of climate change and its impacts involves multiple factors and feedback loops, making the timing and magnitude of these changes chaotic and difficult to predict (IPCC, 2022; IPCC, 2023).

Human impacts on the climate

Climate change is anthropogenic in origin: It results from human activities that alter Earth's climate system (IPCC, 2022, 2023). In light of this evidence, the ecological transition seeks to place major environmental issues—climate change, resource scarcity, biodiversity loss, and environmental health risks—at the center of society's economic and social model (OPCO2i, 2022). Accurate, effective information and, in turn, an appropriate understanding of the complexity of climate change greatly affect social systems' willingness and ability to respond to the associated structural problems (Espargilière, 2022; Quef, 2023; WEF, 2024). Various concepts have been developed to facilitate understanding of this phenomenon and appropriate action, including "planetary boundaries," which refers to the limits within which human activities should remain to maintain a stable and sustainable Earth system. "Overshoot," in turn, concerns exceeding these limits, for example by surpassing acceptable levels of greenhouse gas emissions or depleting resources (Steffen et al., 2015).

1.2 Relevance to the study and key questions for the future

The circular economy and its challenges

The climate and environmental crisis is driving industry to adopt practices that support the transition to a more sustainable development model, influencing regulatory and market dynamics and aligning with societal and ethical values. The circular economy model is thus emerging as a sustainable solution that reduces dependence on virgin resources and minimizes environmental impacts, particularly through technological advances that facilitate this transition, such as improvements in recycling and material recovery processes.

The transition to a circular economy is crucial to achieving the United Nations Sustainable Development Goals (UN SDGs), although empirical evidence of its effectiveness remains limited (D'Amato et al., 2017; Giampietro, 2019; Corvellec et al., 2021). Recent results are rather disappointing: Only 18% of SDG targets

are likely to be achieved globally by 2030 (Sachs et al., 2023). The circular economy helps reduce CO2 emissions, particularly by eliminating waste and conserving the energy embodied in products. Despite doubts about its effectiveness (D'Amato et al., 2017), CE is a key approach to the ecological transition (Hailemariam & Erdiaw-Kwasie, 2023).

The ecological and energy transitions

Because we transform resources into products and services, and each transformation requires energy, economic production is linked to the amount of energy added to the system (Kahraman, 2014). The energy transition is therefore a major component of the ecological transition in the fight against climate disruption. It entails a fundamental change in how energy is produced, distributed, and consumed in order to achieve decarbonization targets (OPCO2i, 2022).

Energy retrofits, in turn, renew the ways we consume, produce, work, and live together to promote the well-being of as many people as possible while preserving that of future generations (OPCO2i, 2022).

2. Retrospective analysis

2.1 Past developments

The Industrial Revolution and the relationship between humans and the environment

Modern climate change originated in the Industrial Revolution, which was characterized by a significant increase in greenhouse gas emissions, mainly from fossil fuel combustion, deforestation, and industrial activities. This era marked a departure from historical climate trends, catalyzing a series of environmental transformations with far-reaching impacts (Lundstad et al., 2023).

The scientific community recognizes the scale of the changes to Earth caused by industrial development as equivalent to a change in geological epoch: from the Holocene, an interglacial geographical period during which humanity developed over the past 12,000 years, to the Anthropocene, a new geological epoch characterized by the emergence of humans as the main force of change on Earth (Gemenne and Denis, 2019). This implies a fundamental change in the relationship between humans and the natural environment because it recognizes humanity's active and disruptive role in determining how the Earth system functions. Economic development models, particularly dependence on a carbon-intensive growth model, have thus played a significant role in the escalation of climate hazards (Crutzen, 2006; Steffen et al., 2011).

Industry's environmental impact

Industrial expansion has a significant environmental impact through its contribution to deforestation, biodiversity loss, and substantial pollution, with greenhouse gas emissions and effluents contaminating air, water, and soil. Industry is also a major water consumer, posing challenges for sustainable water resource management, especially in arid areas. Industrial waste management is another major problem, with toxic waste contamination creating risks to human health and the environment (IPCC, 2022). Trends in recent years show rising material consumption: Global consumption has nearly tripled since 1970, mainly because of industrial expansion (Ritchie et al., 2023).

Since 2000, industrial emissions have increased faster than those of any other sector, mainly because of increased extraction and production of basic materials. In 2019, industrial emissions accounted for 34% of global emissions, making industry one of the largest greenhouse gas emitters. Industrial energy use per metric ton of materials extracted fell by 15% in 2010–19, with the decline accelerated by high energy prices (up 2.4% annually in 2014–19) (Bashmakov et al., 2022).

At the European level, industry's environmental impact has declined in recent decades, particularly because of the introduction of a stricter regulatory framework. For example, the Industrial Emissions Directive (IED) and the Ecodesign Directive impose requirements to minimize polluting emissions and improve the energy

efficiency of appliances. In addition, the EU Emissions Trading System (ETS) seeks to reduce greenhouse gas emissions from industry and aviation, covering around 45% of EU emissions, while the European Pollutant Release and Transfer Register (E-PRTR) increases transparency by providing data on industrial emissions. The EU also encourages environmental management practices through systems such as EMAS and the ISO 14001 standard, as well as initiatives such as Responsible Care and the CSR Europe network. These combined efforts illustrate the EU's sustained commitment to reducing industry's environmental impacts. Despite these improvements, however, industry continues to have a substantial impact on our environment through the pollution and waste it generates (EEA, 2022).

Plastic: A challenge still to be met

Since the advent of plastics in the 1950s, their industrial production has grown exponentially, with a pronounced dependence on fossil fuels. More than 99% of global plastic production currently relies on fossil resources, an unsustainable model that poses serious environmental challenges. This heavy dependence is all the more problematic because plastic production is associated with substantial greenhouse gas emissions, including CO2, methane, and nitrous oxide, owing to the energy intensity of petrochemical processes. Plastic recycling remains inadequate, with only 9%–10% of plastic materials effectively recycled. This low recycling rate reflects the complexity of polymers, contamination of plastic waste, and a lack of appropriate recycling infrastructure. The situation is compounded by waste management systems that are often poorly suited to processing plastics effectively, further limiting opportunities to reduce plastic waste in the environment.

Finally, the authors of the 2022 IPCC report (Bashmakov et al., 2022) show a steady increase in plastic production over recent decades, accompanied by a corresponding increase in associated greenhouse gas emissions. Despite the development of bioplastics made from renewable resources such as plants or microorganisms and growing awareness of environmental impacts, progress is slow and technical and economic challenges remain substantial (Bashmakov et al., 2022).

The mixed impact of innovation and technology on the planet

Since the 1970s, hyperconsumption and innovation have been central to growth and the capitalist model, making modern society heavily dependent on household and business consumption (Lipovetsky, 2003). In what has become an age of abundance, growth is driven by successive waves of innovation, some of which may increase resource use while others may help mitigate the harmful effects of this excessive consumption (Sehnem et al., 2022).

In the first case, for example, digital technologies require enormous data flows, a proliferation of data centers, and the deployment of undersea cables, among other operational needs. They already use 10% of the electricity generated worldwide and accounted for nearly 4% of global CO2 emissions, just under twice the share of global civil aviation (Kahraman, 2018; Tran, 2023). From a perspective more favorable to the planet, innovation can enable different patterns of consumption by addressing the entire life cycle of goods through ecodesign principles, a low-tech approach, or the implementation of circular economy models.

While offering solutions to reduce emissions and adapt to climate impacts, technological progress has also contributed to the problem. Advances in drilling and extraction technologies, for example, have made fossil fuel extraction easier and cheaper while perpetuating fossil fuel use (Nunez, 2022). Thus, although certain innovations support greater energy sufficiency—electric vehicles, renewable energy, and the digitalization of service activities, among others—complex, systematic reasoning is needed to make this work: If the number of electric vehicles increases, electricity generation must also increase substantially (Moreira, 2021; IEA, 2024). This requires consideration of the direct and indirect negative externalities of such measures, which can lead to highly polarized debates, for example over the place of nuclear energy in contemporary society (Pe cout, 2023; IEA, 2024).

Policy action

The adoption of the 2030 Agenda for Sustainable Development by all UN member states in 2015 provides a shared blueprint for peace and prosperity for people and the planet, now and in the future (UN, 2023). Its seventeen Sustainable Development Goals (SDGs) are an urgent call to action for all developed and developing countries to recognize that ending poverty and other forms of deprivation must go hand in hand with strategies to improve health and education, reduce inequality, and stimulate economic growth while addressing climate change and working to preserve oceans and forests (UN, 2015).

At the European level, the European Green Deal, implemented on July 14, 2019, proposes a growth strategy aimed at making Europe carbon neutral by 2050, protecting all forms of life by reducing pollution, helping businesses adopt clean production methods and technologies, and ensuring fair and inclusive integration (CE, 2019).

The emergence of scientific narratives and international environmental movements

Over the past decade, awareness of and engagement with climate change have grown significantly, as shown by evolving climate change narratives, greater interest from the scientific community, and the mobilization of environmental social movements (Diderot, 2020; PRC, 2021). The creation of Earth Overshoot Day, for example, vividly communicates to a broad audience how quickly humanity consumes the planet's natural resources beyond its capacity to regenerate them. To illustrate, in 2010 this day fell on August 8, whereas by 2019 it had moved forward to July 29, revealing an alarming deterioration in our ecological footprint (Earth Science Data Systems, 2024).

At the same time, scientific interest in the ecological transition, the Anthropocene, and the circular economy has surged. The number of scientific articles published on these subjects reflects this trend (Roka, 2020; Eickhoff, 2024). Government and private funding agencies have increased their support for research projects focused on the ecological transition (Lavenier et al., 2023). For example, Horizon 2020, the European Union's framework program for research and innovation, allocated billions of euros to climate, environmental, and energy transition projects, a trend continuing under Horizon Europe (2021–27). This increase reflects both an awareness of the scale of the problem and a growing willingness within the academic community to help find solutions.

In terms of civic mobilization, a growing number of environmental social movements are seeking to influence the evolution of social dynamics surrounding climate change. For example, Fridays for Future, launched by young activist Greta Thunberg, has mobilized millions of young people worldwide, notably through demonstrations and school strikes for the climate (Euronews Green, 2023). Extinction Rebellion,[1] in turn, uses civil disobedience to draw attention to the climate emergency.

The past decade thus marks a turning point in how climate change is perceived and addressed, with mobilization across society reflecting the urgency and complexity of the climate crisis.

2.2 Current developments

Advancing environmental change

Over the past decade, global environmental change has continued to accelerate, as reflected in key indicators of profound changes in the atmosphere, ocean, cryosphere, and biosphere (IPCC, 2023). Global greenhouse gas (GHG) emissions rose significantly from 2010 to 2019: Emissions in 2019 were 12% higher than in 2010 and 54% higher than in 1990.

Temperatures have risen significantly worldwide, intensifying the conditions conducive to extreme events such as heat waves (SDES, 2023) and increasing the frequency of storms, hurricanes, floods, and droughts.

[1] https://extinctionrebellion.fr/

Wildfires have become more frequent and intense, devastating vast areas of land, destroying habitats, and directly affecting air quality and human health. The intensification of the hydrological cycle caused by global warming produces heavier precipitation and more frequent and severe flooding. Flood risks are also increasing, damaging infrastructure and buildings. Over the past two decades, floods and droughts, two of the most devastating consequences of the climate crisis, have affected 3 billion people, causing severe suffering and enormous economic losses (World Bank, 2021). Accelerating glacier melt contributes to rising sea levels, threatening populated coastal areas and affecting freshwater resources for billions of people. Reference glaciers show continuing, significant mass loss, signaling profound changes in global water systems.

Although progress has been made in planning and implementing adaptation measures, tropical, coastal, polar, and mountain ecosystems have reached “hard” adaptation limits beyond which adaptation is no longer possible.

Implementing net-zero strategies for industrial decarbonization

The concept of net zero, centered on achieving net-zero greenhouse gas emissions, has emerged in recent years as a vital response to the urgent challenges of climate change. Initially popularized through the Paris Agreement in 2015, the concept has since guided decarbonization strategies worldwide, emphasizing the need to sharply reduce greenhouse gas emissions to limit global warming to 1.5°C above preindustrial levels. Implementing this net-zero strategy in the industrial sector involves coordinated actions and reforms at the policy, industrial, and financial levels (IEA, 2023a).

At the policy level, governments have adopted legislative frameworks that require emissions reductions and promote renewable energy. These regulations are reinforced by economic incentives and policies supporting technological innovation, such as the development of carbon capture and storage solutions, which are essential for addressing residual emissions from industrial processes (EEA, 2022).

Within this framework, companies are encouraged to transform their operations and adopt cleaner energy technologies, particularly by electrifying production processes, substantially improving energy efficiency, and adopting circular economy practices to minimize resource use and waste (IEA, 2023b). To pursue a net-zero approach, heavy industries such as steel and cement, traditionally among the most polluting, are investing in innovative technologies to reduce their carbon footprints (Bashmakov et al., 2022).

Financing the transition to net zero is also crucial, with financial institutions playing a growing role by incorporating sustainability criteria into their investment decisions. This financial support is supplemented by public funding for research and development of new decarbonization technologies.

Finally, coordinated commitment is essential to transforming industries worldwide and achieving sustainable development goals while combating climate change effectively (IEA, 2023a).

Geopolitical instability and ecological impacts

The war in Ukraine has triggered a global energy crisis. Some 75 million people can no longer afford expanded electricity services, and 100 million face soaring liquefied petroleum gas prices (IEA, 2022). With Russian natural gas supplies disrupted, many European countries have had to seek alternatives to secure their energy supply, relying more heavily on fossil fuels such as coal to offset shortfalls quickly (Kammer et al., 2022). Germany, for example, which had committed to phasing out nuclear power (Energiewende), with the closure of all its nuclear plants scheduled well before the war in Ukraine, has had to reassess its energy strategy amid this crisis. Despite its commitment, Germany temporarily reactivated some coal-fired power plants and reopened the debate over the role of nuclear energy. Although nuclear power is considered a low-carbon energy source, its classification as “green” remains disputed because of safety and radioactive waste management concerns (Livet, 2022). The war in Ukraine and the resulting international tensions have thus realigned global priorities, highlighting energy security challenges in particular and indirectly affecting efforts devoted to environmental issues.

The conflict in Ukraine also starkly illustrates the ecological catastrophe that war represents. The carbon footprint of Russia's invasion of Ukraine is estimated at 150 million metric tons of CO2-equivalent emissions, exceeding Belgium's annual footprint (Meunier & Que nard, 2024). Weapons, ammunition, and military tactics can cause environmental disasters because they leave toxic residues and heavy metals that contaminate soil and water resources. More than 2,400 environmental crimes have been recorded in Ukraine (Meunier & Que nard, 2024).

Erratic environmental policies and global leadership

Halfway to the 2030 deadline, SDG implementation is too slow and is even regressing in certain areas, such as climate action, biodiversity loss, and inequality before the pandemic (Ro, 2022). Humanity risks prolonged periods of crisis and uncertainty triggered by poverty, inequality, hunger, disease, conflict, and disasters unless urgent course corrections are made and implementation of the Millennium Development Goals is accelerated (IGS, 2023).

To this end, the principal role of the Conferences of the Parties (COPs) is to assess the effects of measures taken by different countries—the "Parties"—and progress toward the objectives of the Climate Convention (CCNUCG, n.d.). Despite their contribution to discussions and action on behalf of the planet (CUE, 2023), these meetings have recently generated controversy, particularly over leadership by countries with very specific political and economic interests. This was the case at COP28 in Dubai, chaired by Ahmed al-Jaber, the UAE minister of industry and CEO of the Abu Dhabi National Oil Company, and will also be the case at COP29, to be held in Azerbaijan in November 2024, whose president will likewise be an ecology minister with a long career in the oil sector (Le Monde/AFP, 2024).

These issues prompt criticism and reinforce growing questions in some parts of society about the legitimacy of institutions such as the COPs, as well as science and even democracy (Contessa, 2022; TAP, 2024). Recent years have also seen a rise in climate skepticism, with 36% of the world's population disputing the human origins of climate change (Ipsos, 2023), and in far-right politics (Paillassa, 2024), exemplified by figures such as Jair Bolsonaro in Brazil (Le Monde/AFP, 2024) and Donald Trump in the United States (Courrier International, 2023).

Misinformation and social divisions

Disinformation and misinformation are growing concerns worldwide because they can undermine trust in institutions, influence elections, incite social unrest, and polarize societies (WEF, 2024). This troubling trend is further amplified by technological advances and adapts to the increase in extreme weather events. Facebook, for example, has been criticized for not applying its fact-checking policies to posts classified as opinion or satire, thereby allowing climate disinformation to spread (Turrentine, 2022).

Social divisions in response to ecological transition measures have also become increasingly significant in several European countries in recent years. One example is the Yellow Vest movement, which emerged in France in late 2018 in response to a fuel tax increase presented as a measure to encourage an ecological transition toward less polluting modes of transportation. The movement quickly developed into a broader protest against the cost of living, economic disparities, and government policies perceived as disconnected from middle- and working-class realities (Boussena, 2024). More recently, farmers have protested across Europe, particularly against regulations they consider excessively restrictive and economically unsustainable for their farms (Se mat, 2024). These tensions have revealed the challenges inherent in implementing environmental policies in diverse economic and social contexts (Schlienger and Blombou, 2024).

3. Foresight exploration

3.1 Structural trends

Commitment to the energy transition in France and Europe

For the economy as a whole, the energy transition entails an overall reduction in energy consumption through efficiency and sufficiency, the gradual replacement of fossil fuels with low-carbon energy through diversification of sources, and control over resource consumption (OPCO2i, 2022).

As part of the energy transition, France will have to reduce its consumption by 40% by 2050 (OPCO2i, 2022). This requires diversifying the energy mix to replace fossil fuels, with limited room to maneuver. It entails an energy mix more diversified than today's, allowing carbon-based energy in direct and indirect use to be replaced almost entirely by decarbonized energy, and an energy supply that relies more than 70% on renewables in 2050 (ADEME, 2021). In this context, industry will play a key role in the transition through changes to its processes—electrification and efficiency improvements, among others—its services, such as energy efficiency, and its products, including energy generation, energy-generation equipment, efficient products, and insulation materials (OPCO2i, 2022).

By implementing strict regulations and promoting technological innovation, the EU aims to reshape its industrial landscape to meet contemporary environmental challenges. Central to this transformation, the Industrial Emissions Directive (IED) imposes tighter controls on industrial emissions, encouraging the adoption of best available techniques. This trend toward stringent regulation is also supported by mandatory reductions in major air pollutants imposed by the Medium Combustion Plant Directive.

At the same time, the EU Emissions Trading System (ETS) illustrates a proactive strategy to reduce greenhouse gas emissions, with a target reduction of 43% by 2030. Over the longer term, initiatives such as the Roadmap to a Resource Efficient Europe and the Circular Economy Package outline a vision in which the European economy would be less dependent on natural resources and would pursue substantial greenhouse gas emissions reductions by 2050 (EEA, 2022). This shift toward a less polluting, more resource-efficient industry is both a model for sustainable development in Europe and a standard that other regions could adopt in the future, affirming the EU's leadership in combating climate change and promoting industrial sustainability.

Increasing impacts of climate hazards

Human-induced climate change has increased the frequency and intensity of heat waves since the 1950s, and these will increase further with additional warming (IPCC, 2023). The threshold of 1.5°C above preindustrial temperatures, established in the 2015 Paris Agreement, is expected to be crossed in the early to mid-2030s. Socioeconomic scenarios show that global warming of 1.5°C relative to the preindustrial era will be reached as early as the beginning of the 2030s, regardless of efforts to reduce global CO2 emissions immediately (IPCC, 2023). Although global warming trajectories will be influenced by the speed of decarbonization and the deployment of climate solutions, the degradation of environmental systems could also accelerate estimated trajectories to the point where these systems would contribute "naturally" to global warming and its associated effects (WEF, 2024).

Resilience of the traditional economic model

Despite environmental groups' knowledge of and warnings about the catastrophic effects of a growing, consumption-based global economy on a finite planet (Lacroux, 2023), the dominant economic model is proving resilient. Although environmentally sound and responsible behavior is promoted as a model of social virtue, particularly through the concept of sufficiency, the proposed change in model does not alter the economic logic that drives consumption and individual gain.

Demographic trends and climate migration

Demographic trends are a crucial variable for the years ahead. With the global population exceeding 8 billion, demand for resources, particularly energy, food, and water, has risen, leading to higher greenhouse gas emissions and greater exploitation of natural resources—a situation that worsens environmental degradation and the impacts of climate change. However, population growth is slowing, with a peak of around 10.4 billion expected by the end of the century (Roser and Ritchie, 2023). The demographic divide is widening, with implications for socioeconomic and political systems. Asia dominates population growth, while Africa faces distinctive political challenges, with a population expected to account for 42% of the world's young people by 2030 (WEF, 2024).

The increase in extreme weather events and deteriorating living conditions are forcing more and more people to leave their current homes. Poor populations, which often lack the resources needed to adapt in place, are more likely to be forced to migrate, either within their own countries or to others, in search of better opportunities and safer living conditions. The World Bank estimates that climate change could force 216 million people to migrate within their own countries by 2050 (Clement et al., 2021), while around 21.6 million people are currently displaced each year because of climate hazards (WEF, 2024). Ultimately, climate change is creating increasingly inhospitable environmental conditions, pushing people to migrate to avoid risks and seek better opportunities elsewhere. Such climate migration is likely to be massive in the future.

3.2 Major uncertainties

Effects of global warming on ecological services

Estimates indicate that global warming will reach 1.27°C in February 2024. If the warming trend observed over the past thirty years continues, it will reach 1.5°C in August 2033 (Copernicus, 2023). In this context, the occurrence and spread of pests, weeds, and diseases are expected to increase, amplified by climate-induced extreme events—droughts, floods, heat waves, and wildfires—with negative consequences for ecosystem health, food security, human health, and livelihoods (IPCC, 2023).

In this regard, heat waves increase food security risks in vulnerable regions (IPCC, 2023), while more than 780 million people, or around 11% of the global population, already lack access to clean, safe water (WMO, 2023). Water resources are under strain and rising demand adds pressure, while climate change increases the variability of the water cycle, causing extreme weather events, reducing the predictability of water availability, and affecting water quality (WMO, 2023).

Global leadership and the COPs

Donald Trump's likely reelection in the United States in 2024 (Bickerton, 2024) could adversely affect the progress of discussions and the adoption of measures for a global ecological and energy transition.

Will we follow oil interests, or will this industry adapt to the changes the planet needs? Oil and gas producers account for only 1% of total global investment in clean energy, and more than 60% of that investment comes from just four companies out of the thousands of oil and gas producers operating worldwide today (IEA, 2023). For now, the oil and gas industry as a whole is a marginal force in the global transition to a clean energy system (IEA, 2023).

"Circular" resource use

Nearly 20% of global greenhouse gas (GHG) emissions are associated with hard-to-decarbonize sectors such as iron and cement. However, 40% of GHG emissions from steel, aluminum, cement, and plastics can be reduced through circular measures, requiring a coalition of industries along the value chain. The transition to a circular economy could thus reduce GHG emissions by 39% and pressure on virgin materials by 28%. However, the effect of a circular economy on carbon emissions remains ambiguous, with positive, negative, and statistically insignificant impacts observed (Hailemariam and Erdiaw-Kwasie, 2023). The controversy

surrounding circular economy outcomes may stem from the complex mechanisms through which it influences carbon emissions. Some researchers have observed that cyclical systems consume resources and generate waste and emissions because of the energy required to operate them (Corvellec et al., 2021; Haas et al., 2015; Korhonen et al., 2018; Skene, 2018).

Limited understanding of circular economy effects

The lack of quantifiable data, the emphasis on the post-use phase, and the cross-sector nature of the circular economy could therefore lead to limited understanding and underestimation of its potential benefits for reducing greenhouse gas emissions (EEA, 2024).

The circular economy is an important approach to reducing greenhouse gas emissions through more efficient material flows. However, circular economy actions are underrepresented in national climate policies and measures because of their cross-sector nature and the difficulty of quantifying their impacts (EEA, 2024).

Adopting the three circular economy principles in products, services, and systems makes it possible to begin addressing the remaining 45% of emissions associated with industry, agriculture, and land use that the energy transition cannot tackle. For example, eliminating waste and pollution reduces greenhouse gas emissions throughout the value chain; circulating products and materials conserves their embodied energy; and regenerating nature can sequester carbon in soils and products. In buildings and construction, for instance, eliminating waste, sharing buildings more widely, and reusing and recycling building materials can reduce emissions from building materials by 38% by 2050. Similarly, in agriculture, adopting regenerative production practices, eliminating food waste, and using higher-quality and recycled ingredients in food products could halve food system emissions by 2050 (The Ellen Macarthur Foundation, 2021).

Major global and armed conflicts

A global armed conflict involving major blocs such as NATO/AUKUS against Russia/China would represent a dramatic escalation of international tensions, with profound and potentially catastrophic implications for the climate crisis and ecological transition efforts.

In a large-scale conflict, intensive use of military vehicles and other equipment would massively increase fossil fuel consumption, leading to a significant rise in CO2 and other greenhouse gas emissions. Postconflict reconstruction, particularly in devastated urban areas, would also require considerable resources, further contributing to global emissions.

Furthermore, financial, human, and scientific resources would be redirected toward the war effort at the expense of investment in green technologies and sustainable infrastructure. National budgets for renewable energy research and development would probably be reduced in favor of defense and security.

An armed conflict of this magnitude would fragment international cooperation on climate change, and geopolitical tensions would jeopardize multilateral climate agreements. Moreover, the risk of accidents or attacks targeting critical energy infrastructure, such as nuclear power plants and oil facilities, could lead to large-scale environmental disasters. The war in Ukraine currently provides a glimpse of how armed conflict worsens the environmental crisis (Kammer et al., 2022; Vin uales, 2023).

Net-zero strategies: A major challenge for industry

Achieving carbon neutrality (net zero) in industry is surrounded by several major uncertainties that could jeopardize this objective. First, carbon capture and storage (CCS) technologies, although essential for managing residual emissions, remain expensive and have not been deployed widely enough to affect global emissions significantly. Dependence on emerging technologies that are not yet fully commercialized or widely adopted, such as advances in batteries, hydrogen, and biofuels, adds to the uncertainty. Fluctuating policies and regulations can also affect the decarbonization trajectory: Commitments must be effectively implemented as well as announced. Financing the transition to clean technologies and the necessary infrastructure presents another major challenge, especially in developing economies, where the availability

of funding is uncertain. Market and consumer reactions to new technologies and policy changes are also unpredictable, influencing how quickly innovations are adopted. In addition, geopolitical risks and supply problems involving critical materials needed for clean energy technologies can cause disruptions. Together, these factors make the path to net zero both complex and uncertain (IEA, 2023a, 2023b).

3.3 Controversies

Divergent discourses and approaches to sustainability

The controversy among different approaches to sustainability, particularly environmental (weak) and ecological (strong) approaches, reflects contrasting views of the relationship between human development and environmental conservation, as well as divergent strategies for achieving sustainability.

The environmental approach rests on a belief in the ability of markets and technology to address environmental challenges, while dominating government policy and guiding corporate strategies. Nevertheless, scientists and environmental movements often criticize this approach for its excessive faith in technology and insufficient attention to ecological limits and environmental justice (D'Amato et al., 2017b).

By contrast, the ecological approach emphasizes the inextricable interdependence of human and natural systems and advocates a paradigm shift in how humanity interacts with the environment. This strong sustainability approach stresses the need to reduce resource consumption, promote equity within and across generations, and rebalance the relationship between humans and nature through a thorough understanding of complex systems and planetary boundaries (Beltramello & Bootz, 2022; Dedeurwaerdere, 2014; Schroder et al., 2019).

Justice and responsibility in the face of climate change

Unequal vulnerability and exposure to climate change between developed and developing countries fuel debates over responsibility and climate justice. Less developed countries, which have contributed least to global greenhouse gas emissions, suffer the most severe consequences, such as natural disasters and economic disruption. This disproportion raises questions about the fairness of the mitigation and adaptation efforts required of each country, generating controversy over the distribution of responsibilities and associated costs (Guivarch & Taconet, 2020).

This unequal distribution of the costs and efforts needed to address climate change creates tensions among nations, with developed countries seen as having a greater role to play in providing financial and technological support. The controversy arises from the difficulty of reaching agreement on how resources should be allocated and efforts shared worldwide (Guivarch & Taconet, 2020).

3.4 Seeds of change/developments with future implications

The growing momentum of the energy transition

In 2022, investment in green energy exceeded investment in fossil fuels for the first time, and global coal consumption is expected to begin declining in the coming years. Green energy is now regarded as a growth sector that can create jobs and stimulate economic growth while providing resilience and long-term benefits (IGS, 2023).

The transition to green energy could therefore accelerate. Since 2010, the cost of solar energy and lithium battery technology has fallen by more than 85%, and the cost of wind energy by around 50% (Wiser et al., 2021).

A new directive and its potential positive impact at the European level

Since January 1, 2024, the European Corporate Sustainability Reporting Directive (CSRD) has established new nonfinancial reporting standards and requirements. It applies to large companies and publicly listed SMEs, with the aim of promoting sustainable development within companies and identifying those that act

responsibly in this area. The information collected will allow more accurate assessment of a company's environmental impact and that of its activities. It follows the 2014 Non-Financial Reporting Directive and seeks to harmonize European companies' nonfinancial reporting (DILA, 2024), potentially creating a positive cascade effect on their commitment to sustainable development.

Searching for resources in space and/or the polar regions

Given Earth's limited resources, the Moon, other planets, and asteroids are becoming highly attractive because they contain a wide variety of minerals, gases, and water that could be exploited to provide raw materials, energy, and the elements essential to human life and space exploration (LSA, 20177). Exploitation of these space resources could advance surprisingly quickly, since missions to near-Earth asteroids and the Moon have already yielded remarkable discoveries in this area (LSA, 2017).

On Earth, the Arctic is already experiencing a boom in mineral and fossil fuel exploration and extraction (WWF, 2023). This "extractivist" prospect has recently attracted the attention of mining and mineral exploration companies interested in previously inaccessible frontiers: the seabed, offshore areas, the Far North, and many others (WWF, 2023). If these projects materialize, they will have devastating effects on Indigenous and local communities, fragile Arctic ecosystems, and the global climate (WWF, 2023).

3.5 Disruptions

Reversing the global warming trend

The possibility that, from 2027 onward, climate hazards will become less frequent and global warming will recede, despite the natural disasters observed in recent years and scientific projections, offers hope for the planet. To some scientists, reversing the warming curve does not seem so implausible (Moutot, 2023), and this could influence the development of the circular economy.

Effects of crossing tipping points

The effects and magnitude of climate change, when tipping points are crossed, can cause major disruptions in the planet's climate and ecological systems. These tipping points are critical thresholds beyond which a small change can produce disproportionate and often irreversible consequences. Such disruptions can radically alter ecosystems, hydrological cycles, ice sheets, and other fundamental elements of the planet, with substantial repercussions for society and biodiversity (Potsdam Institute for Climate Impact Research, 2024).

One less likely scenario that could emerge in the coming decades concerns the Arctic regions. As they warm at twice the global average rate, they could cross a critical tipping point with global consequences. In such a scenario, the world would face unprecedented challenges: Millions of people would be forced to migrate because of rising sea levels; global food security would be compromised as droughts, floods, and changing growing seasons affect agricultural production; and socioeconomic and political tensions would arise as nations struggle to adapt to these new climate challenges with increasingly limited resources (Clement et al., 2021).

The importance of the COPs

The COPs provide a forum for discussion and decision-making, allowing progress toward the Paris goals on climate mitigation, adaptation, and financing to be assessed and existing plans to be adjusted (UN, 2023a).

Despite all their shortcomings, the COPs are the only forum on the climate crisis in which the views and concerns of the poorest countries carry as much weight as those of the largest economies, such as the United States and China. Agreement can be reached only by consensus, which can be frustrating and means that some countries—notably Saudi Arabia—can hinder the implementation of more ambitious action, but gives COP decisions global authority (Harvey, 2019). A change in practice could therefore be envisaged whereby

COP decisions would no longer depend on consensus but on a majority vote on a given issue, with the aim of accelerating decisions and the implementation of action.

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