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Revisiting Competitiveness Acknowledging the Economic Benefits of Climate Mitigation and Circularity

As part of the special edition: Earth4All Germany

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List of Abbreviations, Units and Symbols

Abbreviations

AI	Artificial Intelligence
BAU	Business as usual
BDI	Federation of German Industries
BEV	Battery Electric Vehicle
CE	Circular Economy
CHP	Combined heat and power
CMUR	Circular material use rate
EE1st	Energy Efficiency First/Energy Efficiency First Fuel
EEG	Renewable Energy Sources Act
EV	Electric Vehicle
GVA	Gross value added
HDI	Human Development Index
ICT	Information and communication technology
IEA	International Energy Agency
MAGA	Make America great again
NDC	National determined contributions
OECD	Organization for Economic Co-operation and development
SDG	Sustainable Development Goals
SME	Small and medium sized enterprises
SVIK	Special fund for infrastructure and climate neutrality
UBA	German Environment Agency
UNDP	United Nations Development Program

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1 Introduction

Competitiveness is a seemingly straightforward objective that is present in many national and supranational economic programs, both in Europe and in many countries worldwide. However, deeper analysis reveals that the concept of competitiveness requires clarification regarding the embeddedness into broader societal objectives (e.g. climate mitigation), potential conflicts of objectives, and different socio-technical perspectives from which it is viewed. Following a systemic approach this paper contrasts the narrow economic understanding of competitiveness with a broader and sustainable concept of competition, from which more future-proof and transformative recommendations can be derived. We consider "green" competitiveness – in our sense – to be a key indicator of current economic and ecological opportunities and of promising prospects of a circular economy and climate-friendly society in comparison to business as usual in linear economies.

To capture the relationship between competitiveness, climate mitigation, resource use, and the circular economy (CE) as quantitatively as possible—both in physical and monetary terms—we focus in the following on Germany. The reasons for this are the availability of data and studies, as well as the potential transferability of the results to other countries.

Measured by GDP, Germany is the world's third-largest economy and, within the OECD, has an above-average, resource-intensive industrial base. It therefore appears plausible to hypothesize that Germany is a suitable case for demonstrating to what extent (absolute) decoupling processes between economic growth and natural resource use are, in principle, achievable in a highly industrialized country, and what economic implications (e.g., for a country's international competitiveness) ambitious national CE strategies may entail. In addition, the 'black-red' coalition government of CDU/CSU and SPD, in office since 5 May 2025, has declared the implementation of the National Circular Economy Strategy a key priority of its environmental, climate and economic policy.

Environment Minister Carsten Schneider (SPD) explains that "… the circular economy offers solutions to many of the most pressing problems:

- It can make the German economy more competitive and resilient,
- ensure the long-term security of raw material supply,
- and open up new areas of growth.
- Particularly compelling from the minister's perspective: the circular economy can prevent further environmental pollution and reduce greenhouse gas emissions (own translation)."[1]

We examine the evidence for this statement and the relevance of "competitiveness" by discussing the following conceptual topics, objectives, indicators and strategic fields:

1 | Clarification: how to understand "competitiveness"?

1 Cf. Scheider, C. (2025): Rede beim Tag der Kreislaufwirtschaft. Available at: https://www.bundesumweltministerium.de/rede/rede-von-carsten-schneider-beim-tag-der-kreislaufwirtschaft-2025

We start the clarification in Chapter 2 demonstrating the necessity to broaden the concept of the too narrow and short run understanding of economic competitiveness.

2 | Political objectives and rationale for a national circular economy strategy.[2]
In Chapter 3 we focus on the challenging role of competitiveness in view of long run transformation and structural economic change heading towards a circular economy. Interestingly by analyzing circular economy strategies the keyword is no more *competitiveness*, but horizontal and vertical *cooperation*. There remains a research challenge how this new perspective of cooperation within a Circular Economy relates to the traditional understanding of competitiveness. Chapter 4 broadens the analysis to the systemic perspective of staying within planetary boundaries. With this perspective it becomes evident that ultimately competitiveness must contribute to reduce the current overshoot of seven planetary boundaries and must be understood as a means to an end and not as an end itself.

3 | Share of material costs in the gross production value of industry.[3]
Chapter 5 investigates a key variable for international competitiveness of industry: The *average* share of material costs of the gross production value is more than 40%, demonstrated for the German manufacturing industry as an example. As the share of labor costs amounts to only about half of the material cost share it raced the questions whether reducing the unit material cost could be economically, ecologically and socially much more benign than – in the name of a narrow understanding of competitiveness - putting pressure on wages and trade unions to reduce the unit labor costs.

4 | Physical development of RMC, GDP, labor and material productivity [4]
In Chapter 7 the developments of labor-and material productivity as main drivers of economic growth and raw material consumption are analyzed. The increase in resource or labor productivity is assumed to enhance competitiveness. Competitiveness, in turn, is seen as contributing to the preservation or growth of prosperity. In the ex post, empirical analysis of chapter 7 - based on now available more comprehensive data - these seemingly self-evident observations is analyzed in more detail, especially by comparing countries of different development stages.

5 | The specific impact of energy efficiency on competitiveness.
Chapter 6 focusses on the share of energy costs in industry, which is included as a minor part within the material costs. Nevertheless, due to the global trend to electrification, the energy price crisis and the raising energy cost burden for energy intensive industries it is important for competitiveness to foster energy efficiency by removing barriers and harvesting the still enormous energy savings potentials, not only for heat but for electricity as well.

2 BMUKN (2025): Nationale Kreislaufwirtschaftsstrategie. Available at: https://www.bundesumweltministerium.de/download/nationale-kreislaufwirtschaftsstrategie-nkws

3 Cf. Acatech (2021): Circular Economy Roadmap for Germany. Available at: https://en.acatech.de/publication/circular-economy-roadmap-for-germany/; and STATISTA (2013/2022): Kostenstruktur im Produzierenden Gewerbe

4 Cf. Dittrich M. & Dierk J., forthcoming, 2026: Empirical relevance of productivity – an explorative analysis covering all countries in two decades. Wuppertal Paper.

6 | Competitiveness and global GreenTech lead markets.[5]
In Chapter 8 the technological drivers of competitiveness and innovation - the global markets for GreenTech - are investigated in more detail. This technological supply side perspective of competitiveness is interesting, because technological innovation and the growing share of green branches in GDP-growth can be powerful drivers of frontrunner countries for (absolute) decoupling GDP from the use of nature and raising the national competitiveness in relation to incumbents.

7 | Competitiveness, financing and climate cost-benefit analysis.
Finally, chapter 9 and 10 look into financing topics. The argument, often raised against the undoubtedly substantial public start-up funding for investment programs pursuing ambitious societal goals (such as climate neutrality by 2045/2050), is that it harms competitiveness. However, as numerous studies show, the future costs of failing to take ambitious climate action are an order of magnitude higher. Furthermore, the energy cost savings or the macroeconomic multiplier and self-financing effects of climate mitigation investments are often not factored in, and the “anyway”-costs are not presented separately from the climate-relevant additional costs. Therefore, with regard to financing issues, the narrow, short-term, economic concept of competitiveness is particularly counterproductive and is thus addressed in conclusion here.

To sum up, this paper focuses on the macroeconomic implications and the critique of a too narrowly defined category of competitiveness, as expressed in usual statements such as “increasing the competitiveness of Europe.” Typically, the short-, medium-, or long-term goals that are to be achieved through competitiveness are not further addressed, let alone potentially serious conflicts of objectives (for example, competitiveness in relation to increased climate protection or backward refossilization of the energy system) being analyzed in sufficient detail. Therefore, this paper aims not only to critically examine the seemingly unambiguous tool of increasing competitiveness against the backdrop of different goals and perspectives, but also to propose a broader concept of “green” and “systemic” competitiveness for use in scientific policy advice.

5 Cf. UBA (2025): GreenTech made in Germany 2025. Available at: https://www.umweltbundesamt.de/publikationen/greentech-made-in-germany-2025-0

2 Understanding Competitiveness

"Competitiveness" is a buzzword of many current studies and policy programs. Defending or better increasing competitiveness seems to be a clear objective for businesses or countries. But what does competitiveness mean for the current apparently unsustainable development in comparison to a future economic system within planetary boundaries? How do we frame and encourage competitiveness today regarding the decided transition to net zero, dematerialization and CE-strategies in 2030, 2040 or 2050?

Maintaining or increasing competitiveness appears in economic discourses as a seemingly self-evident economic policy objective. The Draghi Report[6] has, not least, placed "competitiveness" at the center of attention. A closer analysis, however, reveals that the term is anything but clear, and its economic policy consequences are often (mis-)understood in an extremely one-sided manner; here are some typical observations:

Economic policy demands for competitiveness often simply boil down to a forced implementation of lower labor costs, reduced social and environmental standards and social public budgets – a policy design which sharply contradicts a "just transition" to climate neutrality (net zero GHG emissions).

In international competition, it is repeatedly downplayed that increasing national competitiveness might be a *relative* concept in a zero-sum game and in a "race to the bottom" (in terms of wages and standards), where it implies a relative gain in strength at the expense of others.

Joining Presidents Trump`s "Drill Baby Drill"-policy and the fueling of international competitiveness through a backward-oriented fossil fuel strategy can, at current price and cost ratios and by neglecting completely external environmental and social costs, very effectively promote catastrophic climate change and the destruction of biodiversity. Relying on cheap US fracking gas – currently three times cheaper than in Europe - raises "competitiveness" not only at the expense of nature and climate protection, but also increases supply dependencies and reduces incentives for technological alternatives and innovations concerning energy efficiency and renewables.

The plea for "competitiveness" is called into question even more fundamentally by the needs of a truly circular economy in contrast to the current linear "take,make,waste"-economies. The global consensus for promoting the circular economy has so far often ignored the fact that *the most extensive possible cooperation horizontally and vertically (along the value chain)* between companies, producers, consumers, as well as states and not unbridled competition is a crucial prerequisite for enforcing circularity.

6 Cf. EC (2024): The future of European competitiveness. Available at: https://commission.europa.eu/document/download/97e481fd-2dc3-412d-be4c-f152a8232961_en

"Obsession with Competitiveness"[7] is therefore an apt observation, which we will critically examine below, primarily from various ecological and economic perspectives. It becomes clear that the demand for "greater competitiveness"

- should at least differentiate between macroeconomic competitiveness of an economy and the competitiveness of special sectors like e.g. automotive or renewables within a static or dynamic economic setting,
- must contribute to a predefined societal target system (e.g., climate neutrality) and within the framework of a comprehensive policy mix, e.g. including more regulation through sustainable and forward-looking industrial policy,
- should be promoted in particular by increasing energy and material productivity, but also – while safeguarding social protection rights – labor productivity and through appropriate green investment activities,
- must acknowledge the differences in competitiveness of countries with different development and resources status e.g. by comparing high-income with low-income countries
- must within countries include the social dimension and distributional issues, because a socio-ecological transformation to net zero is inconceivable without social acceptance and a broad perception of "just transition" and last but not least
- cannot be a seemingly self-evident *goal*, but merely *a means* for sustainable economic activity within planetary boundaries; short-, medium-, and long-term, and above all, systemic perspectives must therefore be considered.

7 Cf. Kaczmarczyk, Patrick (2025): Obsession with Competitiveness: A Growth Promise Put to the Test (own translation). Available at: https://library.fes.de/pdf-files/a-p-b/22330.pdf. This thought-provoking article rightly calls for "not more, but better competition." The challenge remains, however, to incorporate the ecological dimension and economic rationale into this "better" economic and competitive system within planetary boundaries.

3 The National Circular Economy Strategy in Germany

We start our analysis by discussing the vision and objectives of Germany's National Circular Economy Strategy. It aligns with the Environment Minister's previously cited positive assessment and reinforces it with an ambitious material reduction target of 6-8 tons per capita until 2045: "The circular economy is central to achieving our climate and environmental policy goals, while at the same time opening up significant opportunities for growth, employment, and competitiveness" (own translation).[8] In addition to contributing to raw material supply security, strengthening supply chain resilience, and increasing the use of secondary raw materials, "[…]the circular economy offers considerable additional and cost-effective opportunities for industrial decarbonization based on technologies already available today. The circular economy has the potential to stimulate new technologies and business models, thereby increasing value creation and productivity across the entire economy" (own translation; ibid., p. i).

As evidence for this favorable socio-economic and environmental assessment, the National Circular Economy Strategy refers to studies reporting, for example, that "circular economy measures in industry have the potential to reduce greenhouse gas emissions by approximately 30–50% by 2050, while simultaneously increasing value creation. An integrated approach to climate protection and the circular economy offers the opportunity to reduce the abatement costs per ton of CO_2 by 2045 for steel, concrete, cement, and plastics by 45%" (own translation; ibid., p. ii). The Federation of German Industries (BDI) and the consultancy Deloitte likewise "[…] project an annual increase in gross value added of the German economy by €12 billion by 2030, accompanied by an increase of 117,000 jobs. McKinsey estimates the medium-term (2030) global market potential for circular economy consumer goods at €650 billion per year" (own translation; ibid., p. ii).

On the basis of this promising macroeconomic outlook, the then federal government ("traffic light coalition" of CDU/CSU, SPD, GRÜNE, FDP) decided—after extensive debate—to adopt an ambitious target for reducing total primary raw material use. Germany's raw material footprint, which is currently high in international comparison at 15.3 tons per capita and year (measured as RMC = Raw Material Consumption, i.e., primary raw materials used for consumption and investment, including the raw material equivalents of foreign trade), is to be roughly halved by 2050. The strategy explains: "In doing so, the proposal of the International Resource Panel of UNEP for operationalizing the UN Sustainable Development Goals—namely, to achieve a global average raw material consumption intensity of 6–8 tons per capita per year by 2050—serves as a guiding benchmark. The guiding framework will be evaluated every five years, starting in 2030, with the participation of industry, and adjusted if necessary" (own translation; ibid., p. i).

8 BMUKN (2025): Nationale Kreislaufwirtschaftsstrategie. Available at: https://www.bundesumweltministerium.de/download/nationale-kreislaufwirtschaftsstrategie-nkws

In a series of studies and scenarios, the German Environment Agency (UBA) has demonstrated the fundamental feasibility of achieving both ambitious material reduction and near-complete climate neutrality in Germany by 2050. As shown in the following figure 1, under the most ambitious scenario, GreenSupreme[9] ("**G**ermany- **r**esource **e**fficient and greenhouse gas **n**eutral"), greenhouse gas emissions could be reduced by 97% and material use (RMC) by 70% between 1990 and 2050. In addition to defossilization (i.e., the elimination of the "fossil fuels" from material flows), RMC in this scenario declines through circular strategies, improvements in resource efficiency, lifestyle changes, and the assumption of zero economic growth from 2030 onwards: "Improvements in material efficiency across all technologies and economic sectors, combined with high product quality and long product lifetimes, lead to goods and products that are resource-saving [...] People are also changing their consumption habits. For example, they eat less meat and overall healthier, live in smaller spaces and make greater use of bicycles, public transport and sharing services for their journeys. In addition, they are increasingly demanding sustainable, durable and repairable products, so that the overall demand for goods is decreasing [...]. In contrast to other Green scenarios, which assume an annual GDP growth of 0.7%, GreenSupreme assumes a growth exemption in Germany, i.e. zero annual GDP growth, from 2030 onwards."[10] A more recent study[11], building on the GreenSupreme scenario—specifically accounting for the raw material requirements and environmental impacts of Germany's energy transition in the EU and global context—identifies a feasible reduction target of 7.9 tons RME[12] per capita by 2050.

[9] Umweltbundesamt (2020): RESCUE – Wege in eine ressourcenschonende Treibhausgasneutralität. Available at: https://www.umweltbundesamt.de/themen/klima-energie/klimaschutz-energiepolitik-in-deutschland/szenarien-konzepte-fuer-die-klimaschutz/rescue-wege-in-eine-ressourcenschonende#hintergrund sowie Lutter, S. et al (2022): Die Nutzung natürlicher Ressourcen. Bericht für Deutschland 2022. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/fb_die_nutzung_natuerlicher_ressourcen_2022.pdf

[10] Umweltbundesamt (2024): Limits to Consumption: Sustainable Consumption Considering Planetary Boundaries. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/165_2024_texte.pdf

[11] Cf. Umweltbundesamt (2024): REFINE: Betrachtung von Rohstoffaufwendungen und Umweltauswirkungen für die Energiewende in einem ressourcenschonenden und treibhausgasneutralen Deutschland. Available at: https://www.umweltbundesamt.de/publikationen/refine-betrachtung-von-rohstoffaufwendungen-0

12 Cf. Umweltbundesamt (2024): REFINE: Betrachtung von Rohstoffaufwendungen und Umweltauswirkungen für die Energiewende in einem ressourcenschonenden und treibhausgasneutralen Deutschland. Available at: https://www.umweltbundesamt.de/publikationen/refine-betrachtung-von-rohstoffaufwendungen-0

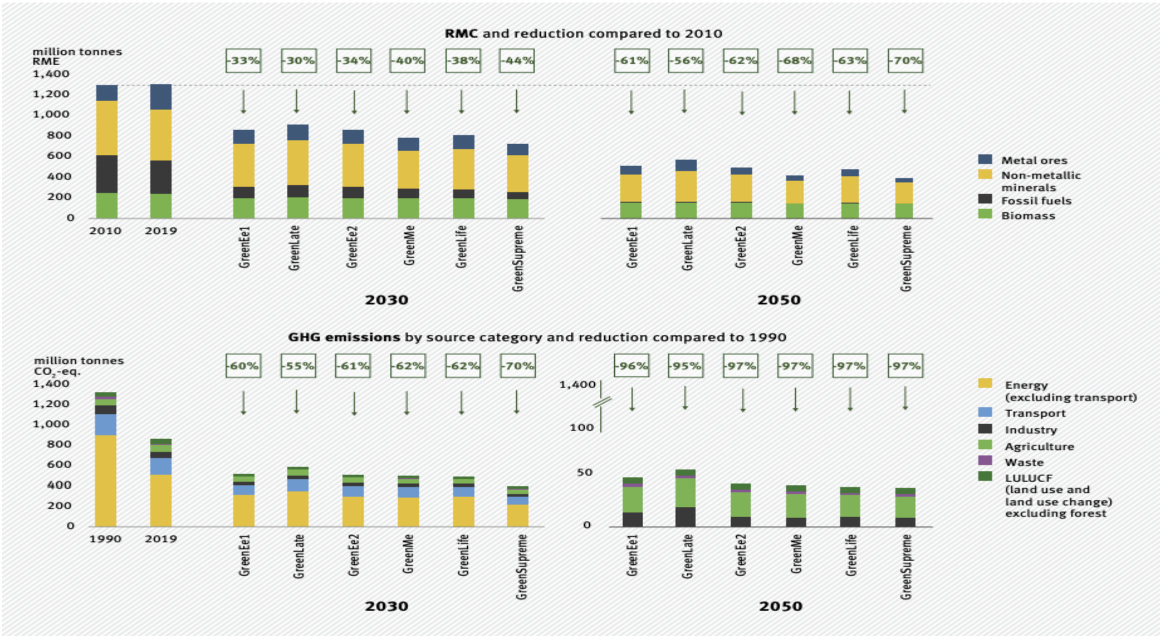

Figure 1: Reduction of GHG-Emissions and of RMC in Scenarios of the German Environment Agency Source: (UBA Rescue (2022); Lutter, S. et al (2022))

As an interim conclusion, it can be stated that the physical feasibility of achieving climate neutrality and halving per capita annual RMC by 2050 has been demonstrated for an industrialized country such as Germany through scenario analyses. This is associated with a pronounced absolute decoupling of GDP from greenhouse gas emissions and resource use. The underlying assumptions for these analyses and results are rigorous (e.g., zero economic growth from 2030 onwards), yet—taking into account the positive social, ecological, and distributional effects—can be regarded as, in principle, capable of achieving majority public support. Furthermore, even in the most ambitious scenario, GreenSupreme, the ten R-strategies 13 are by no means fully exploited. It should be emphasized that “recycling”, though often falsely perceived as the strategy of CE, is by far not the most important option for an advanced Circular Economy and e.g. in the EU not sufficient to double the still low circular material use rate[14] (CMUR) from 11,7% to 23,2% by 2030[15].

[13] 1. Refuse: Avoiding products or materials that are not sustainable or cause unnecessary resource consumption. 2. Rethink: Reviewing business models and product development to minimize resource requirements. 3. Reduce: Minimizing material use and waste generation through efficient product design and production processes.4. Reuse: Reusing products or components in their original or a similar function. 5. Repair: Repairing defective products to extend their lifespan. 6. Refurbish: Restoring products to a near-new condition, often by replacing components. 7. Remanufacture: Completely overhauling products to bring them to a condition comparable to that of a new product. 8. Repurpose: Using products or materials for a purpose other than their original one. 9. Recycle: Recovery and reuse of materials from used products. 10. Recover: Recovery of energy or materials from waste that can no longer be recycled. See also https://efs.consulting/insight/r-grundsaetze-kreislaufwirtschaft/#:~:text=Diese%20Ma%C3%9Fnahmen%20sind%20besonders%20effektiv%2C%20da%20sie,(%C3%9Cberdenken)%20*%20Remanufacture%20(Wiederaufarbeiten)%20*%20Repurpose%20.

14 The CMUR is defined as share of secondary materials in overall used materials (primary and secondary). For more details Eurostat, 2018.

15 EEA (2023): How far is Europe from reaching its ambition to double the circular use of materials? Available at: https://www.eea.europa.eu/en/analysis/publications/how-far-is-europe-from

However, no comprehensive strategy mix (including more R-strategies) or macroeconomic cost–benefit analysis for GreenSupreme is until now available, nor have the questions of how to finance the required investments been addressed. Likewise, the employment and distributional effects of the underlying socio-economic structural transformation have not been sufficiently examined. Yet, the maintenance or enhancement of competitiveness is an economic objective that, in principle, presupposes answers to these questions. In the absence of a comprehensive economy-wide cost–benefit analysis, we will therefore turn, in the following, to selected aspects that are particularly informative with regard to the question of competitiveness.

4 Competitiveness within Planetary Boundaries

The government's official assessments and guiding visions will, in the following, be examined in greater depth on the basis of existing studies and scenarios for Germany. The official assessment (cf. p. 2) can, in principle, be confirmed; however, only under the condition that the often ambitious assumptions of the scenarios are also implemented in practice by policymakers and the business sector, and proactively translated into politically, economically, and socially viable majority-supported action.

It becomes evident that only a *three-pillar model (see below) of integrated resource and climate protection policy*—one that strictly avoids further negative distributional effects at the expense of low-income households and SMEs—can succeed. Put simply: technology (efficiency and consistency/renewable energy/agriculture) must be combined with sufficiency policies, embedded in a socially grounded policy mix that enables the necessary transformation for low-income households and vulnerable SMEs ("just transition"). A socio-ecological transformation to net zero by mid-century, combined with the goal of absolute per-capita material reduction, entails a policy-driven, time-critical economic structural transformation oriented towards quantified guiding targets—one unprecedented in industrial history and also in contradiction to linear, Neoclassical or Keynesian economic (growth) theories.

From an economy-wide perspective, existing studies (see below) confirm that such an accelerated socio-ecological structural change yields (net) positive qualitative growth and employment effects—provided that the negative value-added and employment effects inherent to any structural change are anticipated and mitigated through accompanying policy measures (e.g., retraining, business relocation).

The term "Green Deal" has, in the European context, become the common designation for this process, even though it insufficiently conveys the implicit radical nature of the economic structural transformation and the social distributional effects involved. Put simply, this targeted transformation means that "brown" risk sectors (e.g., fossil-fuel-based industries) must be drastically reduced, while "green" future sectors (e.g., resource-efficient GreenTech industries—see below) must be vigorously promoted. Such a state-driven structural transformation can only secure majority support if negative distributional effects are anticipated and proactively limited through socially supportive policies, while positive innovation and growth effects are actively encouraged.

The initially necessary massive start-up financing for a "Green Deal," through a transformative future investment program, places particular demands on both public and private financing. In addition to the budget funded by the current level of tax revenues, three additional sources can be considered for this extraordinary public expenditure: 1. The phasing out of environmentally harmful subsidies[16], 2. The expansion of the tax base through a progressive financing responsibility of the wealthy, 3. Crisis-related, temporary large-scale public borrowing for a future

16 The Federal Environment Agency estimates the environmentally harmful and generally distribution-critical subsidies at €65.4 billion annually; Cf. UBA (2021): Umweltschädliche Subventionen in Deutschland. Available at: https://www.umweltbundesamt.de/daten/umwelt-wirtschaft/umweltschaedliche-subventionen-in-deutschland

investment program. This crisis-induced deficit spending—in line with the maxim "whatever it takes"—is not a typical Keynesian counter-cyclical fiscal policy (as per the so-called "golden rule"[17]), but rather an ultimately survival-critical pre-financing measure to contain an existentially threatening polycrisis. It requires special justification in terms of eligibility criteria and management, as well as in terms of refinancing from additional tax revenues through qualitative growth and from progressive taxes on ultra rich wealth

In socio-economic terms, the following general observation seems to be important: The state-driven, goal-oriented structural change required to achieve climate neutrality calls for a new, long-term, and integrative political style. Government policy-making and the establishment of a framework for a forced Green Deal, as well as the necessary forward-looking eco-social industrial and service policies, must also take concrete responsibility for ensuring that no one is left behind as a result of government-driven intervention. The technical and economic transformation to net zero therefore also requires overcoming inhibiting social inequalities as a prerequisite and equivalent goal.

Therefore, it is essential to simultaneously implement a turnaround in inequality, not only with regard to the extremely unequal causes of natural resource consumption (measured in terms of income-related CO_2 and material footprints) , but also, in particular, to strengthen public financial power through progressive tax reform.[18] Comprehensive financing, targeted social support, and quality improvement of previously neglected common goods, such as affordable mobility and housing for all, are essential prerequisites for acceptance by a majority of the population who cannot afford transformative protective measures and technologies such as individual e-mobility, heat pumps, or energy-efficient renovation of housing without policy support.

In this context, the universally desired goal of "strengthening competitiveness" must also be discussed in a more differentiated manner. Competitiveness in relation to social objectives such as climate neutrality and absolute per capita material reduction must obviously ensure and promote the development of a sustainable industry structure, more sustainable processes and product qualities, and a circular innovation dynamic. As has been mentioned above: This stands in stark contrast to the backward-looking preservation and expansion of a fossil fuel-based economy, as favored by the current Trump administration. However, the temporary competitive advantages of this backward strategy (e.g., by promoting the extraction and export of shale oil and fracking gas) at the expense of the environment, health, and human rights are built on shaky ground, because technical and economic megatrends in green tech markets[19] will sooner or later force them out of the market. For example, the share of renewable electricity capacity has been growing steadily worldwide for

17 Cf. Federal Ministry of Finance (2022): Kompendium zur Schuldenregel des Bundes (Schuldenbremse). Available at: https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Themen/Oeffentliche_Finanzen/Schuldenbremse/kompendium-zur-schuldenbremse-des-bundes.pdf?__blob=publicationFile&v=9

18 Cf. Fischedick et al. (2024): Earth for All Deutschland – Aufbruch in eine Zukunft für Alle. Available at: https://www.oekom.de/buch/earth-for-all-deutschland-9783987261114;

19 Cf. the section below on GreenTech made in Germany

two decades and by 2024 it had already reached 91.1% of annual capacity growth[20]. Falling prices and massive global promotion of batteries[21] as well as the unstoppable advance of e-mobility[22] are also global megatrends.

Thus, observers assume that Trump`s MAGA economic and energy policy will cause economic and social counterproductive slash backs especially for the US. It is true that currently gross value added in the US rose significantly, e.g. faster than in Germany, but this was primarily because "[...] high-growth, knowledge-intensive, and productive sectors such as the tech sector are driving dynamic growth in the service sector" (ibid., p. 5). What is grouped together here as "tech sector" are the so-called "high-tech" giants such as Nvidia, Alphabet/Google, Amazon, Apple, Microsoft, Tesla, and the associated service industries. However, the growth boom of these "high-tech" giants coincides with *an apparent industrial weakness in the US*. [23] One observer puts it bluntly: "USA: Tech giant, industrial dwarf? A surprising economy contrast (own translation)"[24]. Judged by traditional economic standards, the future growth potential and competitiveness of the US economy hinges on the hope of "reindustrialization," which the Trump administration believes it can force through tariffs and (direct) investment deals.

There is evidence that the Trump administration's fossil fuel and nuclear-based energy policy is damaging the competitiveness of the US economy in the medium and long term and may dampen the level of ambition in global climate policy, but the future exponentially growing trends of GreenTech are unstoppable.

The demand to "strengthen competitiveness" therefore does not follow a criterion that preserves the status quo, but rather concerns competitiveness in relation to the key objective of a sustainable economy and welfare society within planetary boundaries.[25] Inevitable conflicts of interest, such as temporary competitive advantages through seemingly "cheap" fracking gas or fossil-fuel-fired steel, chemical, and cement production, and carbon leakage in general, must be compensated for and limited by appropriate countermeasures.[26]

20 Cf. IRENA (2025): Renewable energy highlights. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Jul/IRENA_DAT_Renewable_energy_highlights_2025.pdf; see also IRENA (2025): GLOBAL LANDSCAPE OF ENERGY TRANSITION FINANCE. Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2025/Nov/IRENA_CPI_FIN_Global_landscape_energy_transition_finance_2025.pdf

21 Cf. e.g. for Germany: BMWK (formerly BMWi), available at: https://www.bmwk.de/Redaktion/DE/Artikel/Industrie/batteriezellfertigung.html

22 Cf. e.g. VDA (2025): Die Elektromobilität weltweit auf dem Vormarsch. Available at: https://www.vda.de/de/themen/elektromobilitaet/marktentwicklung-europa-international

23 See e.g. Deloitte (2025): 2026 Manufacturing Industry Outlook. Available at: https://www.deloitte.com/us/en/insights/industry/manufacturing-industrial-products/manufacturing-industry-outlook.html; and CNN (2025): America's job market flashes yet another warning sign about the economy. Available at: https://edition.cnn.com/business/live-news/us-jobs-report-august-2025; and The Conference Board (2026): Us Consumer Confidence Inched Up in February. Available at: https://www.conference-board.org/topics/consumer-confidence/ ; and CEPS (2025): Defying gravity… or not? Here are seven weaknesses to look out for in the US economy. Available at: https://www.ceps.eu/defying-gravity-or-not-here-are-seven-weaknesses-to-look-out-for-in-the-us-economy/

24 Xpert (2025): USA: Tech-Gigant, Industrie-Zwerg?. Available at: https://xpert.digital/usa-ein-ueberraschender-wirtschaftskontrast/

25 Cf. PIK (2026), Planetary Boundaries. Available at: https://www.pik-potsdam.de/en/news/latest-news/seven-of-nine-planetary-boundaries-now-breached-2013-ocean-acidification-joins-the-danger-zone

26Cf. OECD (2025): EU Carbon Border Adjustment Mechanism: What is it, how does it work and what are the effects?. Available at: https://www.oecd.org/en/blogs/2025/03/eu-carbon-border-adjustment-mechanism-what-is-it-how-does-it-work-and-what-are-the-effects.html; and European Council (2024): Electricity market reform. Available at: https://www.consilium.europa.eu/-en/policies/electricity-market-reform/

5 Material Costs of Manufacturing Industry as a Crucial Factor for Competitiveness

International competitiveness of the industry sector does not only depend on the prices of material, energy and labor but also on the labor/material cost relations and cost reduction potentials and their social distributional and ecological effects. The statistics on costs for the manufacturing industry in Germany show a distribution of material and labor costs that is surprising to many: According to these statistics, the share of average material costs between 1993 and 2013 was between approximately 38% and 47%, with a slight upward trend. The share of labor costs during the same period was between approximately 17% and 27%, with a strong downward trend.

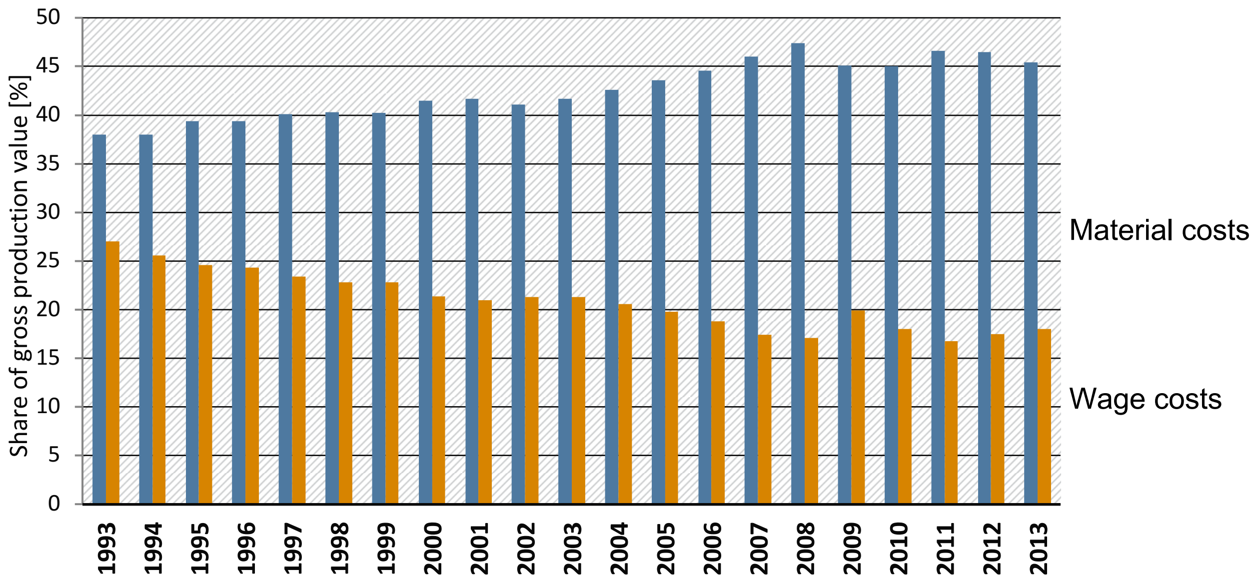

Figure 2: The Share of Material Costs (blue) and Wage Cost (brown) of Gross Production Value in the Manufacturing Industry. Source: DESTATIS (2019), FS 4, Reihe 4.3. Kostenstruktu im Produzierendem Gewerbe 2013/2022. Material costs are defined as: raw materials and other externally procured preliminary products, auxiliary and operating materials including third-party components, energy and water, fuels, office and advertising materials as well as non-capitalized low-value assets

Unfortunately, this report series (Fachserie 4, Reihe 4.3) was only continued until 2017. The most recent value for the share of material costs stood at 43.2% in 2017, approximately at the average level of the past 24 years. Sector-specific variations in the material cost share are considerable, of course. However, on average, it can be assumed that a cost-effective significant reduction in material costs through intensified improvements in material efficiency and circular economy strategies can contribute far more to overall economic competitiveness than the socially and macroeconomically problematic attempt to reduce labor costs e.g. by wage dumping or dismissal of workers.

Noteworthy here is that the average share of energy costs (as part of material costs) in the manufacturing sector is only around 2.5% (2021)[27], with energy-intensive industries such as steel, cement, and chemicals having significantly higher energy cost shares of between 10% and 30% of production costs. Competitiveness in terms of energy costs must therefore also be discussed in a sector-specific manner.

Whereas many competition-oriented analyses and discussions on energy and labor costs are available, cost-benefit analyses of potential savings in material costs are still rare. This is partly because the analysis is considerably more complex and the cost-benefit considerations more demanding. Nevertheless, on the macroeconomic level, there are potential and cost estimates available that plausibly substantiate the argument that a substantial opportunity for environmental and cost relief is yet to be realized in this domain.

In estimating the total material cost savings in the German manufacturing sector by 2030, Wilts et al.[28] base their assumptions on the following: The total costs associated with resource consumption in Germany's manufacturing industry were estimated at approximately €941 billion (2018). CE levers beyond recycling are projected to enable cost savings of up to 33% by 2023. This corresponds to around €310 billion in savings, a figure that exceeds the cumulative cost savings from the use of secondary materials (such as metals and plastics) by a factor of ten by 2030 (ibid, p 14). Realizing these broader savings potentials will require investments in new recycling capacities and circular production processes, though the report does not provide details on these investments. Crucially, the study emphasizes that an early implementation of R-strategies within the value chain and circular business models offers substantial ecological and economic benefits compared to relying solely on end-of-life recycling of products and processes.

A considerably more sector- and product-differentiated cost-benefit analysis of the transition to a CE has been presented by Prakash et al.[29] This study provides detailed impact assessments for nine sectors (product groups)[30], characterized by high environmental burdens during production and use. However, the value added in these sectors accounts for only about 15% of total German economic output and approximately 20% of the workforce. Therefore, the results can only partially be extrapolated to a comprehensive macroeconomic impact assessment of Germany's CE transition. Nevertheless, the study represents a methodological milestone, as it

[27] Cf. Destatis (2021): Energieverbrauch und Energiekosten im Verarbeitenden Gewerbe. Available at: https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Energie/_Grafik/_Interaktiv/energieverbrauch-verarbeitendes-gewerbe.html

28 Wilts,H./Steger,S./Hopfensack,L./Arjomandi,T., (2021): Ressourcenperspektive auf die Circular Economy in Deutschland. Available at: https://wupperinst.org/p/wi/p/s/pd/2001/

29 Öko-Institut, Fraunhofer, Freie Universität Berlin (2023): Modell Deutschland Circular Economy, Feasibility study commissioned by WWF Germany. Available at: https://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/Unternehmen/Machbarkeitsstudie-Modell-Deutschland-CE-Endbericht.pdf; and Öko-Institut, Fraunhofer, Freie Universität Berlin (2023): Modell Deutschland Circular Economy, Politik-Blueprint. Available at: https://www.oeko.de/fileadmin/oekodoc/MDCE_Blueprint.pdf

[30] Vehicles and batteries, civil engineering, ICT and household appliances, food and nutrition, textiles, furniture, lighting, and packaging

exemplarily estimates the following potential benefits of CE strategies within these nine sectors up to 2045:

- "Potentials for climate, resource, and biodiversity protection, thereby avoiding macroeconomic external costs. These are considered societal benefits of the Circular Economy.
- Potentials for industrial transformation in Germany on the path to greenhouse gas neutrality by 2045. These also represent societal benefits.
- Potentials of CE measures to secure raw material supply as well as to reduce the ecological impacts associated with raw material extraction — representing both societal and economic benefits.
- Impacts of CE measures on socio-economic indicators such as gross value added and labor demand, including structural effects. These will be included in the cost-benefit assessment.

It is important to note that these are potential costs and potential benefits that will arise or change depending on how policymakers shape structural change. The task of policymakers is to reduce negative costs through targeted interventions in order to achieve a net benefit for society" (own translation; ibid., p. 172).

Based on this highly differentiated sector and product analysis, the study also arrives at a positive assessment of the overall economic benefits of a CE strategy: "From a broader perspective, the question is not when it becomes worthwhile to begin the ecological transformation. It can be assumed that taking action is definitely profitable and that 'doing nothing' is in any case more expensive. The overall societal benefits of a circular economy are significantly higher than the associated costs [...]" (own translation; ibid., p. 182). Another interesting methodological aspect is that the study quantifies the rebound effects resulting from the alternative use of freed-up income (cost savings in consumption or investment) and concludes: "Overall, positive socioeconomic effects in terms of gross value added and labor demand occur when the income freed up by the implementation of CE measures is spent in areas with low environmental intensity, e.g., in the service sector. The [...] project thus highlights the need for political action, also with regard to directing the income freed up towards economic sectors with low environmental intensity" (own translation, ibid., p.182).

6 Fostering Energy Efficiency integrated into CE Strategies

Unlike materials, energy cannot be "circulated" in a closed loop. When utilizing waste heat in electricity production, for example, for combined heat and power (CHP) and district heating systems, or when using biowaste for biogas production, the term "cascaded energy use" is more accurate. At each conversion stage, some of the usable energy is lost as heat (law of conservation of energy). Therefore, a continuous supply of new and affordable energy is essential for the sustainable and economical use in production processes, machinery, transportation, buildings, communication and data processing, and household appliances.

This is why the price of energy plays such a crucial role in international discussions on competitiveness, alongside the quality and sources of energy (fossil, nuclear, renewable). However, what is repeatedly forgotten in energy and climate policy programs is the following simple point: For competitiveness, it is not energy prices, but energy bills, or, to put it technically, the unit cost of energy,[31] that is decisive. By using highly efficient conversion technologies, unit costs of energy can decrease despite high or even rising energy prices.

Even though the absolute reduction of material consumption, and especially of fossil fuels, automatically lowers energy consumption for extraction, processing, and disposal, and renewable energies support climate and resource protection, there are many ecological, social, and economic reasons to prioritize *the avoidance of all forms of energy* when the desired level of energy services can be achieved more cost-effectively through more efficient conversion technologies. This is the reason why, for example, the IEA[32] and the EU have been actively promoting the "Energy Efficiency First" (EE1st or "Energy Efficiency First Fuel") principle since several years.

133 countries, including the EU and Germany, committed at the Conference of the Parties (COP28 in Dubai 2023) to "[...]cooperate to triple the world's installed renewable energy generation capacity to at least 11,000 GW by 2030, taking into account different starting points and national circumstances;[...]cooperate to jointly double the global average annual rate of energy efficiency improvements from around 2% to over 4% by 2030;[...]place the principle of energy efficiency as 'first fuel' at the heart of policymaking, planning and key investment decisions." (COP 28, 2023, own translation).

While the market introduction of renewable energy needs to be further accelerated to achieve the agreed-upon "tripling" by 2030[33], both the continuing decline in producer prices for solar and wind power (including falling battery storage costs) and the expansion of capacity are progressing well – not least due to China's impressive expansion policy. Since renewable energies are calculated with 100% efficiency, their

[31] Energy unit prices are the relation of the costs for heat/cold and electricity to gross added value.

[32] The IEA World Energy Outlook (2013) coined the phrase "Energy Efficiency is the First Fuel," positioning efficiency as a core energy resource, influencing later EU policy and wording. The Regulation (EU) 2018/1999 (Governance Regulation) formally defined EE1st in Article 2(18) and made it a guiding principle for National Energy and Climate Plans (NECPs). The Energy Efficiency Directive (EED) (Recast 2019/2023) further embeds the principle, requiring Member States to consider EE1st in policy and planning. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023L1791

33 See IRENA, 2025

expansion substituting fossil or nuclear sources alone reduces future primary energy consumption.

However, the foreseeable energy demand in all countries remains too high[34], the avoidance of unnecessary energy consumption according to the EE1st principle is nowhere ambitious enough, and the increase in the annual energy efficiency rate is still far from doubling by 2030. Even more critical is the fact that energy efficiency policy is, at best, given secondary consideration in the practical implementation of climate and competition policies: “(The) Draghi Report, The Future of Europe’s Competitiveness, in September 2024, followed by the Competitiveness Compass and the Clean Industrial Deal in early 2025 […] state that future European competitiveness must be built upon innovation, a joint plan for decarbonization, and enhanced energy security. However, within this crucial policy architecture, the unique and indispensable role of improved energy efficiency as a structural, long-term driver of competitiveness requires far greater recognition and proactive prioritization than currently afforded.”[35]

The neglect of ambitious energy efficiency implementation is all the more astonishing because significant energy-saving potential exists that is, in principle, economically viable: “The potential for additional energy efficiency remains substantial: By 2030, cost-effective energy efficiency measures could reduce industrial energy demand by 25%. Electrification of industry is still in its infancy and can leverage large efficiency gains. Best-practice adoption alone reduces energy intensity in industry by an additional 20% in the near term.” (ibid)

Studies for Germany provide more concrete information on which sectors and technologies can unlock these savings potentials for heat (primarily natural gas) and electricity, and which energy-saving measures best address the very different energy cost burdens in the individual sectors. We assume that these structural characteristics of German industry also apply, in principle, to other EU member states with a high proportion of industry.

Interestingly, in Germany between 2008 and 2020, unit energy costs remained largely constant in industrial sectors with medium and low energy demands, and even decreased considerably in sectors with high energy demands. However, with the energy price crisis of 2021/2022, unit energy costs increased by approximately 10-20 percentage points, particularly in energy-intensive sectors (glass/ceramics, chemicals, pulp/paper and metal production/processing).

The intensive debate in Germany about reducing energy prices for everyone (e.g., through federal subsidies for network costs, incorporating the former EEG surcharge for renewable energies into the budget, and abolishing the gas storage surcharge)

34In reality, also the primary energy consumption is therefore not decreasing to the extent projected in net-zero scenarios, as necessary and - both technically and economically - feasible for achieving climate neutrality by mid-century. This applies, for example, to the IEA's Net Zero Roadmap (2021) as well as to all climate protection scenarios for Germany aiming for climate neutrality by 2045.Compare IEA (2021), https://iea.blob.core.windows.net/assets/8ad619b9-17aa-473d-8a2f-4b90846f5c19/NetZeroRoadmap_AGlobalPathwaytoKeepthe1.5CGoalinReach-2023Update.pdf and Hennicke, P., Die Energiewende in Earth4All Deutschland, https://epub.wupperinst.org/frontdoor/deliver/index/docId/8751/file/WP204.pdf

35 Cf. Rosenow, J., Schlomann,B., Eichhammer, Borg,N. (2026): Europe’s competitive edge: Industrial energy efficiency as a structural game-changer. Available at: https://journals.plos.org/climate/article?id=10.1371/journal.pclm.0000809

became particularly controversial because, in addition, the electricity tax for 600,000 companies was reduced and a reduction in the industrial electricity price is planned.[36] Handelsblatt reports: "The German government will subsidize electricity prices with €29.5 billion in 2026. The government is spending significantly more money than in previous years to keep electricity prices at a level acceptable for consumers. Experts consider this unsustainable." [37]

This massive subsidization of energy/electricity prices not only raises questions about distortion of competition across the EU, but it is also counterproductive because the price incentive for energy-saving measures drastically decreases, and the more effective energy policy focus—namely, a structural and lasting reduction in energy demand through harvesting existing energy-saving potentials—threatens to be completely overlooked.

A short study has identified the existing "market-oriented" and „economically viable" energy-saving potential for Germany as follows: "By implementing economically viable final energy saving measures (i.e., measures with a positive net present value), 263 TWh/a of the 635.4 TWh/a final energy demand of German industry (as of [date missing]) can be saved." As of 2023, potential savings of approximately 40% are estimated. This amounts to 209 TWh/a in the heating sector and 54 TWh/a in electricity applications. A large portion of the economically viable final energy savings measures are even "market-oriented measures," meaning they have payback periods of less than three years. The corresponding savings are approximately 28% (176 TWh/a), divided into 134 TWh/a in the heating sector and 42 TWh/a for electricity applications outside the heating sector. The economically viable final energy savings from all measures would translate into cost savings of approximately €29 billion/a in 2025. The necessary investment is estimated at a total of €104 billion, resulting in an average payback period of 3.6 years." [38]

It is obvious that the planned energy price subsidies will make it more difficult to tap into these energy efficiency potentials, which at current price levels are attractive from both a national and business perspective. This is especially true if structural market barriers are not addressed through enhanced energy conservation governance: "Despite its high potential, energy efficiency is often given little consideration in discussions about a cost-effective energy transition. Obstacles to implementing energy efficiency measures in companies include liquidity constraints, a lack of personnel (skilled worker shortage), and the desire for short amortization periods. Furthermore, investments in energy efficiency are hampered by other obstacles that are outside the control of individual companies or even the entire

36 Cf. Federal Government of Germany (2026): Energiepreis-Entlastungen wirken. Available at: https://www.bundesregierung.de/breg-de/aktuelles/senkung-energiepreise-haushalt-2358526#:~:text=Die%20Energiepreise%20sinken%20ab%20dem,Ein%20%C3%9Cberblick

37 Handelsblatt (2025): Bund subventioniert Strompreise 2026 mit 29,5 Milliarden Euro. Available at: https://www.handelsblatt.com/politik/deutschland/energiewende-bund-subventioniert-strompreise-2026-mit-295-milliarden-euro/100182362.html

38 Meyer, J. et al (2025): Volkswirtschaftliche und betriebswirtschaftliche Bewertung der Energieeffizienz in der Industrie: Marktnahe und wirtschaftliche Energieeinsparpotentiale in der Industrie. Available at: https://www.duh.de/fileadmin/user_upload/download/Projektinformation/Energieeffizienz/UmInM%C3%BCn01-Kurzstudie-2025-10-02.pdf

industry. The political regulatory framework is a particularly important factor here. Another obstacle can lie in ownership structures. If the buildings are not owned by the company but only leased, this complicates all such investments related to the building.” Furthermore: “Since there is clearly a market failure in the energy efficiency market, meaning that an efficient market outcome has not yet been achieved, an open discussion should be held on how additional government support could promote energy efficiency. Various instruments and levels of intervention are possible.” The short study (as of March 2023) also pointed out that the proven energy-saving potential “does not yet take into account the significant potential from resource efficiency and the circular economy.”

The interim conclusion is therefore: A more ambitious and proactive energy-saving policy is necessary to remove obstacles and realize the large, in principle economically viable potentials. Without an enhanced energy-saving governance, these attractive potentials for competitiveness, resilience, innovation, and climate protection cannot be realized through market-driven mechanisms alone. The ultimate aim should be to integrate those enhanced energy efficiency policies into CE-strategies to maximize the reduction of energy and materials.

7 Labor and Material Productivity and the Development of GDP and RMC

7.1 General Observations on Relations between Productivity and Income

The increase in resource or labor productivity is assumed to enhance competitiveness. Competitiveness, in turn, is seen as contributing to the preservation or growth of prosperity. In the following ex post, empirical analysis - based on now available more comprehensive data - we examine these seemingly self-evident observations in more detail.

Regarding competitiveness, the argument so far proceeds as follows: raw materials are mobile goods and thus internationally tradable; there is a global market price, resulting in no substantial differences between countries. Thus, a competitive edge of a country can typically not be based on price advantages but only on technologically induced cost reductions and material productivity increase. By contrast, labor is far less mobile across borders, and the competitiveness of countries is perceived to differ primarily due to variations in unit labor cost, which might be differentiated by labor productivity.

Unfortunately, examining the relevance of resource productivity for competitiveness has, to date, remained largely unexplored. This often causes biased competitive policies putting high pressure on the reduction of labor costs instead of material costs. This raises the question from a social and ecological perspective: Wouldn`t it be much more convenient and innovative "to make tons or kilowatt-hours redundant than labor"? (referring to a citation by Ernst von Weizsäcker)

For centuries, the resource question was neglected, with the consequence that no long-term data series on resource productivity were available[39]. This situation has changed only recently probably by price and security concerns and owing to the efforts of individuals who succeeded in placing the issue on the political agenda and undertook the largely underfunded task of compiling the relevant data. Drawing on the datasets now available, we conducted an exploratory ex post analysis of the relationship between various productivity variables for all countries worldwide over the period 2000–2018. This comprehensive analysis lays beyond the scope of this paper; the empirical results will be presented in detail elsewhere[40].

As there is no clear indicator for competitiveness of a country as such (only for competitiveness of specific branches or products), we examine in this preliminary assessment the share of exports in GDP as a proxy for competitiveness in relation to labor (GDP/L; L as amount of workers) or material use (GDP/RMC; RMC as tons) - on the assumption that a higher export share reflects greater national competitiveness. We also explored the relationship between material productivity (GDP/RMC) and GDP, as well as GDP per capita with RMC per capita on absolute and growth levels of these indicators. It should be kept in mind, while GDP is a

39E.g. Immler, H. (1990): Vom Wert der Natur; and Daly, H. (1999): Ecological Economics and the Ecology of Economics; and Bleischwitz, R. (2001): Rethinking productivity: why has productivity focused on labor instead of natural resources?

40 Dittrich, M. and Dierk, J. (2026), forthcoming: Empirical relevance of productivity – an explorative analysis covering all countries in two decades. Wuppertal Paper.

highly problematic indicator related to well-being and distributional effects, it remains widely used as a measure of monetary economic activity, not least because comparable data are available for all countries.

Our first empirical finding based on ex post analysis for the period 2000 to 2018 can be summarized as follows: In general, and for all countries there is no significant statistical relationship between the share of exports in GDP and material productivity. The findings on the relationship between GDP and labour productivity however, seem to be more self-evident. The analysis shows in general that growth in GDP per capita and growth in labor productivity (GDP/ L) are highly correlated, as expected. These two variables are linked through a multitude of mechanisms and additional factors that are fundamental to the current understanding of our economic system.

This, however, does not hold true in any case for the relationship between the growth rates of material productivity and GDP when *comparing countries at different development stages* in a certain period. We observed: on average, more productive work is typically correlated with higher incomes/cap and vice versa. But we don´t find that average per-capita income rises everywhere in step with rising resource productivity (and vice versa). While at the firm level, increasing efficient use of materials directly increases profitability—reflecting a competitive advantage relative to other firms in the same sector—the aggregate relationship across sectors and countries does not appear to hold in the same straightforward way.

For all countries, quite different shares of material flows (e.g. biomass, fossil fuels, metal ores, non-metallic minerals) related to different stages of economic development, infrastructures and built environment can be observed (see Fig.3 below) and this has an impact on material productivity and economic growth as explained further below.

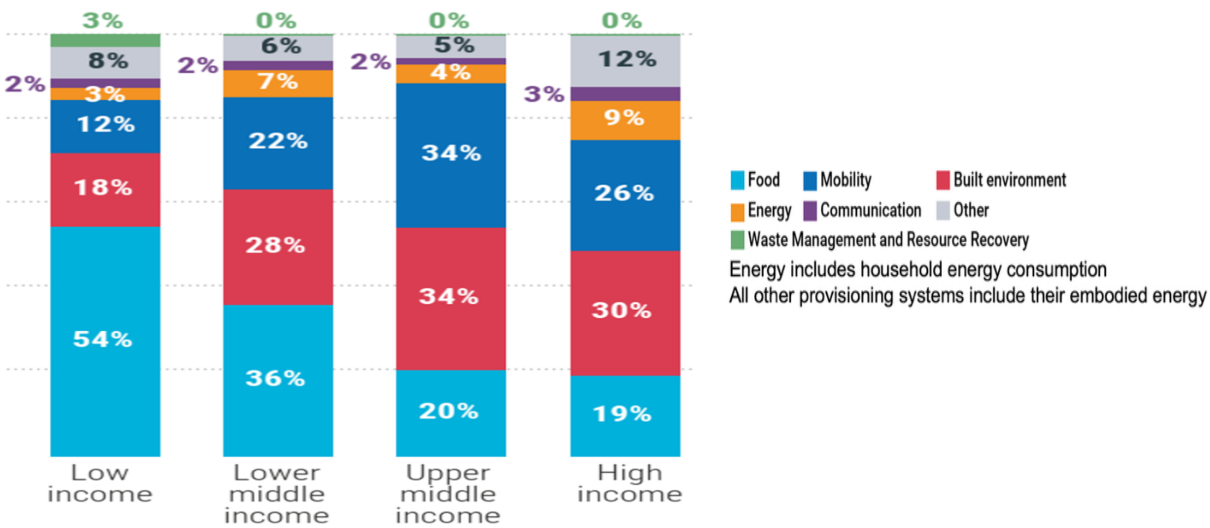

Figure 3: Material use according to different Development/Income Status (2020). Source: International Resource Panel (2024)

Additionally, we can summarize some selected findings and then draw preliminary conclusions:

- It can be shown empirically that high material productivity (measured as GDP/RMC) correlates (on an absolute indicator level) almost as strongly as high labor productivity with high per capita income when considering all countries. It is important to note that correlation does not indicate directionality or causation. This means it may be the case that wealthier and material intensive countries are able to use their often imported resources more productively than poorer countries and/or that more productive countries are wealthier than less productive ones. The relationship is likely influenced by various contextual factors including technological development, institutional frameworks, resource endowments, investments etc., that this explorative analyses can´t depict.
- Clustering countries by level of income in high, medium and low-income countries, significant differences can be demonstrated. The results are displayed in Table 1: While in high-income countries resource productivity is highly correlated with income/capita, it is lesser the case in low-income countries and there is no relation between both indicators in medium-income countries. Again, these differences are connected with different development stages, status of infrastructures (e.g roads, railways, harbours, ICT) and the built environment (see below)
- There is no correlation between material productivity and RMC/cap in the group of high-income and low-income countries, but there is a medium-strong negative correlation in the group of medium-income countries.

Country Income Tercile[41]	Material Productivity & GDP per Capita	Labor Productivity & GDP per Capita	Material Productivity & RMC per Capita
High-income tercile	0,74	0,96	0,05
Middle-income tercile	0,48	0,80	-0,36
Low-income tercile	0,66	0,82	-0,18

Table 1: Pearson Correlation Coefficients across Countries sorted by Income Terciles. Source: Dittrich M. & Dierk J., forthcoming, Data derived from different sources: UNEP IRP Global Material Flows Database (2026); Penn World Table (PWT 10.0) by Feenstra et al. (2015).

How can we explain this and what can we conclude from this? Since material productivity in this analysis is calculated as GDP/RMC—and thus includes the full upstream material flows embodied in traded goods—the observed relationship between material productivity and economic activity cannot only be explained by the outsourcing of environmental burdens to poorer countries[42].

[41] The income terciles were defined based on each country's average GDP per capita.

[42] This would only be the case if the underlying data were inaccurate, for example due to the use of inadequate price estimates, as noted above – a deeper analysis should be taken in another paper.

The differences between the country groups points especially to the role of infrastructure: The construction and maintenance of shared infrastructures are disproportionately material-intensive and operate under a different economic logic than companies heading for productivity maximization. Poor countries don't have the money for investing in public infrastructure. We estimate the share for infrastructure in total country specific RMC less than 15%. Thus, the material-intensive infrastructure is not an important factor influencing resource productivity in these countries. This is different in medium-income countries: they generate money to invest and build up infrastructures, the share of materials (in RMC) used in public infrastructure rises up to 50%. Building-up a resource-efficient infrastructure is a central option for these countries to improve their resource productivity. High-income countries already have large parts of the infrastructure installed which only have to be maintained (which is less resource-intensive than new construction), the share of materials for public infrastructure is around 20-35%. This also raises the question, whether and how far urban mining from the existing large material stock could be an option on the way to dematerialization.

Thus, our preliminary conclusion is that there is a clear empiric relation between high per capita income and high material productivity. This is particularly important for high-income countries. But the indicator is not as appropriate and less evident for medium-income countries during the phase of building up infrastructure[43]. However, for wealthy countries, such as those within the EU, it is economically rational to consider forced material productivity strategies, to understand the drivers, potentials and costs behind it, and to design appropriate policy instruments accordingly (Dittrich & Dierk, forthcoming).

7.2 Resource Productivity in EU and Germany

The EU, as well as many countries within the EU—including Germany—launched programs around 2012 aimed at increasing resource productivity[44]. The following chart shows the development of resource productivity for the EU[45]. It can be observed that between 2000 and 2012 resource productivity increased by 25 index points, particularly during periods of rising or fluctuating prices following the financial crisis. Since 2012, resource productivity has risen again by another 25 index points, with a notable increase during the period of rising prices following the invasion of Ukraine.

43 Currently, the indicator and the data do not allow a calculation without public infrastructure. In our point of view it would be a good approach

44 EU launched, amongst other, the 'Roadmap to a Resource Efficient Europe' [COM(2011) 571], Germany adopted the German Resource Efficiency Program (ProgRess) which was updated two times, see e.g. https://www.bundesumweltministerium.de/themen/ressourcen/deutsches-ressourceneffizienzprogramm

45 EU uses the indicator GDP/DMC which is a bit different from GDP/RMC as it does not consider the material footprints of imports and exports. However, we tested the message of the graph with the international data set and conclude that both messages are comparable.

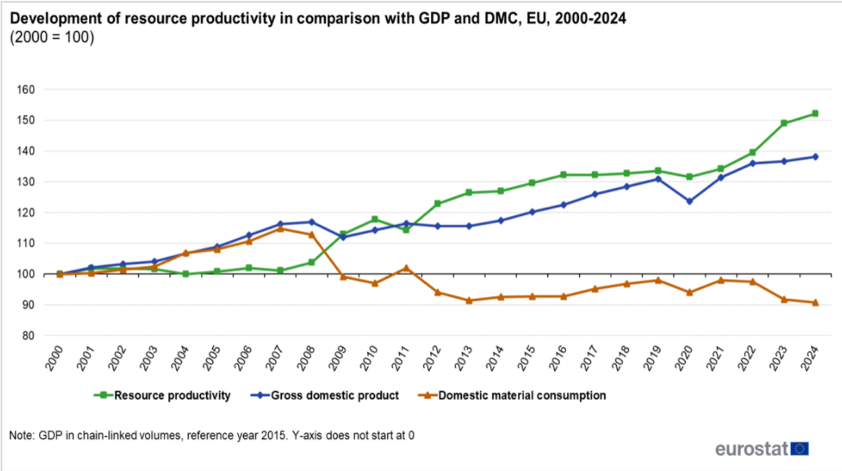

Figure 4: Development of resource Productivity compared to GDP and DMC. Source: (Eurostat (2025))

What are the factors influencing the increase of material productivity and material demand? The graph points to an important role of external shocks (including its impact on prices) compared to continuous policy intervention to foster resource productivity. The shocks lead to a decrease of material demand which remained stable (on the lower level) after the shocks. By contrast, the slight increases of productivity beyond the shocks seem to be mainly driven by increase of GDP in the EU while material demand remained rather stable. According to the precautionary principle it would be advisable to anticipate further external shocks by material saving activities today instead of being "driven by desaster" in the future.

Examining the development in Germany as an example, it becomes evident that Germany has experienced a significant increase in resource productivity. According to official German statistics, resource productivity increased by nearly 1.5% per annum between 2010 and 2021[46].

Fortunately, Destatis also calculates productivity increases comparable to international indicator and by raw material groups, which is very illuminating. An analysis of the developments that contributed to this result shows that productivity increase is primarily attributable to the energy transition. The amount of fossil raw materials declined as a result of the energy transition, and this magnitude is significant in the reduction of RMC. The additional metals and other raw materials used for wind turbines, PV systems, power lines, etc. are *quantitatively* less significant in comparison. But if they are part of the increasing share of *critical* raw materials driven by the global energy transition, the new supply dependencies and possible resource conflicts or price shocks are increasingly relevant.

The productive use of biomass and non-metallic minerals increased while it decreased slightly for metals. The findings concerning metals are interesting and at the first glance counter-intuitive. But this can be partly explained by the priorities on energy substitution and less concerns on metals at the starting phase of the global

[46] The German indicator is again different compared to international indicators and European indicators. In Germany, material productivity is measured as LV/RMI. Again, we compared the main trends with the international data sets as far as possible and the main message is comparable.

energy transition. It can be expected that in the future the focus on the productivity of metal ores will be much stronger.

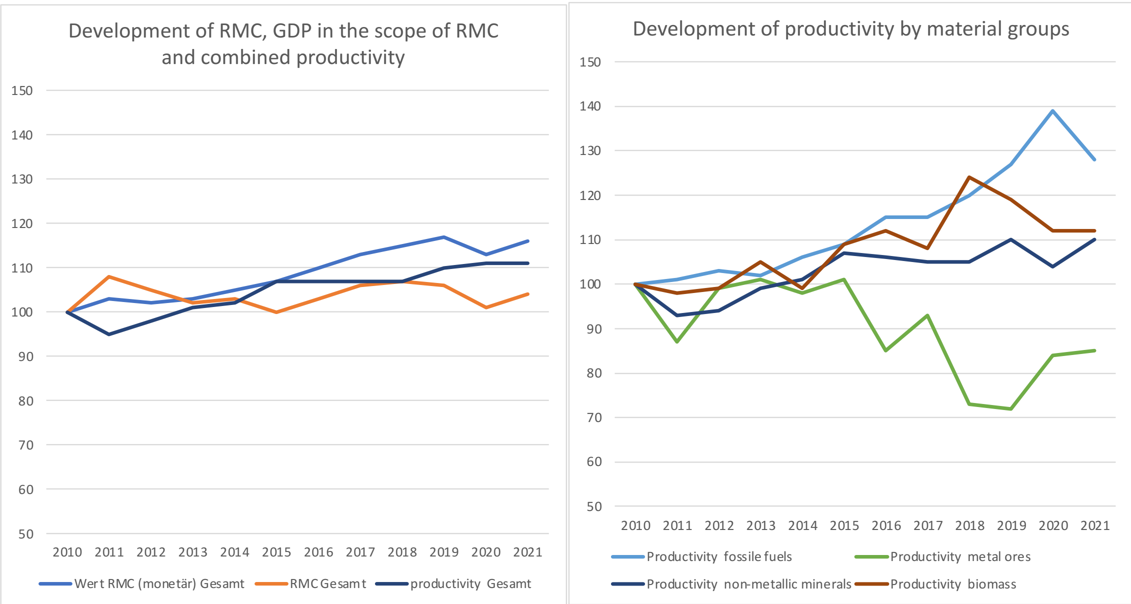

Figure 5: Resource Productivity in Germany by Material Categories. Source: Own graph based on Destatis (2025): Umweltökonomische Gesamtrechnung. Available at: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Umwelt/UGR/ueberblick/Publikationen/Download/statistischer-bericht-ugr-ueberblick-5850026259005.html

To date, we are not aware of detailed ex-post analysis that examines which factors have actually promoted the efficient use of raw materials in Germany and other EU countries or the EU as a whole, and which have not. Given the considerable amount of money that has been and continues to be invested in promoting resource efficiency, this should be addressed in future research.

7.3 The role of Resource Productivity with respect to Material Demand

We go back to the finding that fostering resource productivity is an important approach for all countries and resource productivity is an appropriate indicator particularly for high-income countries. However, rebound-effects remain a challenge, which should be anticipated and cushioned as far as possible. The underlying logic is in short: increases in productivity save money and thus stimulate investment in innovation and/or increased production. Innovation and alternative spending of saved energy or material costs are driving forces for growth and thus increasing demand – the classical macro-economic rebound effect. On a national or international level, the increase of resource productivity can thus be an important driver for growth (and competitiveness)[47]. But it is important to underline that the induced growth pattern by alternative spending of saved energy or material cost is important: the ecological and social *quality* of the induced branches and the

47 Enquete-Kommission "Wachstum, Wohlstand, Lebensqualität" des Deutschen Bundestages (2011): Herausforderungen für eine technisch-ökonomische Entkopplung von Naturverbrauch und Wirtschaftswachstum unter besonderer Berücksichtigung der Systematisierung von Rebound-Effekten und Problemverschiebungen. Available at: https://webarchiv.bundestag.de/archive/2013/0510/bundestag/gremien/enquete/wachstum/gutachten/m17-26-13.pdf

direction of the structural economic change behind cumulated quantitative growth figures do matter a lot.

From our empirical findings the following observations can be derived:

- On a global level considering all countries over twenty years simultaneous growth effects are observable: growing resource productivity is correlated with increasing material demand (per capita).
- But: this has been changing for high-income countries. The correlation between both, material productivity and material demand (per capita) has decreased from slight correlation in 2000 to no correlation at all. This might mean, that there is a trend where material productivity increased but material demand doesn't increase similarly.
- Going deeper into some country examples, it can be even observed that several high-income countries show an overall increase in material productivity and no increase or even a decrease in material demand (per capita). Examples are Germany as well as the USA.

We explain these optimistic preliminary findings, which possibly indicate a relative decline of rebound-effects, with three factors: 1. It reflects the impact of the energy transition, as fossil fuels are increasingly substituted by renewable energy sources, which are less material intensive. 2. It mirrors the decreasing relevance of new infrastructure or even (as in the case of Germany) the neglect of maintenance of the existing infrastructure. 3. There is an influence of increased overall efficient use of materials, including further efforts towards a circular economy.

To reach more ambitious material reduction goals and to adapt to climate change in the future it might be necessary to substitute existing material intensive infrastructures (e.g. streets, parking places, industrial sites, paved city areals, etc.) by less material intensive regenerative structures (e.g. parcs, trees, recreation zones etc.).

7.4 The role of Circular Economy towards ambitious Material goals

As has been demonstrated above, the concept of circular economy goes by far beyond the concept of resource productivity and recycling. In Europe, it comprises in theory the ten R-Strategies (see above, p.5, footnote 13) including conventional circular economy strategies such as recycling, repair and efficiency but it includes furthermore sufficiency-oriented strategies such as sharing or refusing as well[48]. One can say: the R-strategies of a Circular Economy tremendously enlarged the potential policy mix – if we understand Circular Economy in the broad sense including sufficiency strategies, it is a much wider concept compared to fostering only technology driven resource productivity. Thus, measured ex post by the indicator of resource productivity, CE-strategies could cause a giant leap of productivity increase due to much more material-light provisioning systems, processes and products.

48 European Commission (2020): A new Circular Economy Action Plan - For a cleaner and more competitive Europe. Available at: https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0017.02/DOC_1&format=PDF

The political goal in the EU is doubling the share of circular use of materials in overall demand of materials until 2030. Currently (in 2023), only 11.8 % of overall material demand is secondary (no virgin) material. Since 2010, the share increased very slowly (starting with 10.7 %)[49]. Thus, the goal can only be achieved with a significant increase in transformation speed[50].

A high number of studies have proved that circular economy in the broad sense has a high impact on material demand and at the same time it is a necessary political approach for climate mitigation[51]. It is logical that secondary or circular materials couldn't replace all virgin materials as we

- need food and feed stuff,
- do not have renewable substitutes for all non-renewable materials,
- do not yet have economically and technically feasible processes for used materials and
- we are far away from closing all loops which could be closed technically due to insufficient collection, processing and replacing.

A question therefore is: How much "circularity" could be achieved if we include as much R-strategies as feasible and promising? Estimates for a long-term outlook range between 27% and 38% calculated in the RESCUE project[52] up to a very optimistic estimation of 50% of overall material demand, which could be replaced by secondary materials[53]. Goals like this are only achievable with a significant increase of circularity and furthermore, a decrease of virgin material demand is necessary as well. Therefore, a wide approach is relevant: secondary materials are supposed to replace virgin materials, productivity and further circularity approaches have to be fostered and sufficiency approaches should be implemented to limit and decrease the overall demand for virgin materials.

It should be emphasized that sufficiency approaches are highly relevant for the decrease of the demand of virgin materials. This can be explained using energy demand as an example. The change of technology from fossil fuels to renewable sources requires materials as well such as metals and minerals for the plants. If the focus is only on the efficiency improvements, the impacts of uncushioned rebound effects may partly counteract the saving of energy. There is strong evidence, that the combination of efficiency improvements and sufficiency approaches amplifies the

49 Eurostat (2025): Circular material use rate. Available at: https://ec.europa.eu/eurostat/databrowser/view/cei_srm030/default/table?lang=en

50 E.g. Christis et al. (2023): ETC/CE Report 2023/6 Analysis of the circular material use rate and the doubling target. Available at: https://www.eionet.europa.eu/etcs/etc-ce/products/etc-ce-report-2023-6-analysis-of-the-circular-material-use-rate-and-the-doubling-target

51E.g. the already mentioned RESCUE Study for Germany as one of the first comprehensive studies or recent studies such as EEA (2025): Capturing Capturing the climate change mitigation benefits of circular economy and waste sector policies and measures. Available at: https://www.eea.europa.eu/publications/capturing-the-climate-change-mitigation

52 Dittrich et al. (2020): Transformationsprozess zum treibhausgasneutralen und ressourcenschonenden Deutschland – Vergleich der Szenarien. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2020_12_28_cc_06-2020_endbericht_vergleich_szenarien.pdf

53 Dittrich et al. (2021): Sekundärrohstoffe in Deutschland. Available at: https://www.nabu.de/imperia/md/content/nabude/konsumressourcenmuell/2104-22-ifeu-studie-sekundaerrohstoffe_in_deutschland.pdf

demand reduction for energy, so that the supply systems of renewable energies could be met with the currently known reserves of the required metals[54].

As long as we are striving for sustainability within planetary boundaries a goal for decreased material demand as indicated in the Austrian and German Circular Economy Strategies is very relevant as an orientation. Strategies of a Circular Economy combined with ambitious GHG-reduction policies reinforce each other and their synergies can contribute to reaching net zero and halving material use per capita easier, quicker and in a more cost-efficient way.[55]

54 Immler, H. (1990): Vom Wert der Natur; and Daly, H. (1999): Ecological Economics and the Ecology of Economics; and Bleischwitz, R. (2001): Rethinking productivity: why has productivity focused on labor instead of natural resources?

55 E.g. IRP (2020). Resource Efficiency and Climate Change: Material Efficiency Strategies for a Low-Carbon Future. Hertwich, E., Lifset, R., Pauliuk, S., Heeren, N. A report of the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya. https://www.resourcepanel.org/reports/resource-efficiency-and-climate-change ; Dittrich et al. (2020): Transformationsprozess zum treibhausgasneutralen und ressourcenschonenden Deutschland - Vergleich der Szenarien. UBA-Texte 06/2020. https://www.umweltbundesamt.de/publikationen/transformationsprozess-treibhausgasneutrales-ressourcenschonendes-deutschland-vergleich-der-szenarien;

8 GreenTech and structural Change of the Economy

In this chapter we change the perspective, looking at competitiveness from the supply side of technology development, innovation and the impact on economic structural change[56]. With regard to the transformative and dynamic concept of competition outlined in this paper—competitive in terms of defossilization and dematerialization of the economy—the development of GreenTech markets plays a crucial role. By GreenTech, we mean technologies, processes, and services that aim to reduce environmental pollution, promote more sustainable economic activity, and advance the decoupling of the economy from the consumption of natural resources. Particularly in terms of use, but also in terms of production, GreenTech should contribute to reducing emissions, conserving resources, and protecting the climate.

The Federal Environment Agency has continued the tradition of various German governments in compiling environmental technology atlases for Germany and has published a very informative study entitled "GreenTech made in Germany. GreenTech Atlas for Germany.[57]" The study, according to the Federal Environment Agency, demonstrated "... that the German GreenTech sector has long established itself as a key industry within the national economy. Many green technologies and services are already competitive and are poised to gain further relevance. The sector provides stable employment and contributes significantly to value creation. In 2023, GreenTech accounted for 9.0% of Germany's total gross value added (GVA), growing at an average annual rate of 4.7% since 2010—substantially outpacing other major industries. The sector employed 3.4 million persons in 2023, an increase of 800,000 compared to 2010. For comparison, the automotive industry—traditionally a core pillar of the German economy—employed around 1.1 million persons directly in 2023"(ibid., p.7). The seven "Lead Markets of the GreenTech Sector" that are examined in detail in the Atlas are shown below.

Figure 6: Lead Markets of the GreenTech Sector in Germany. Source: Prognos (2025): Greentech made in Germany 2025. Avaiable at: https://www.prognos.com/sites/default/files/2026-01/uba_greentech_atlas_2025_deutsch_barrierefrei.pdf

"Circular economy" is identified here for the first time as a special GreenTech sector. However, other GreenTech sectors can also contribute to the circular economy, and

56 You might call it „the quality" of growth if the combined effect of „Degrowth" (reducing the share of „brown" sectors based on fossil fuels) and „Green growth" (increasing the share of GreenTech, see above) is summarized and measured. See e.g how the rising share of the renewable energy sectors is contributing to China`s GDP growth; compare Carbon Brief (2026)

57 Umweltbundesamt (2025): GreenTech made in Germany. Available at: https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/uba_greentech_atlas_2025_englisch_barrierefrei.pdf

in the specific lead market CE, the potential associated with the ten R strategies is far from being fully exploited.

What is particularly interesting about the study is that, although it focuses on GreenTech made in Germany, it examines the national development of the seven lead markets in relation to global development, thereby also establishing a link to the average economic growth, competitiveness and positive employment effects of GreenTech.

The following Fig. 7 shows that the growth in employment in the German GreenTech sectors over a 13-year period was significantly greater than in comparable industrial sectors. This also explains why, in absolute terms, the number of employees rose by 800,000 (2.2 % per year) to 3,400,000 between 2010 and 2023. The share of the total workforce rose from 6.7% (2010) to 7,4% (2023).

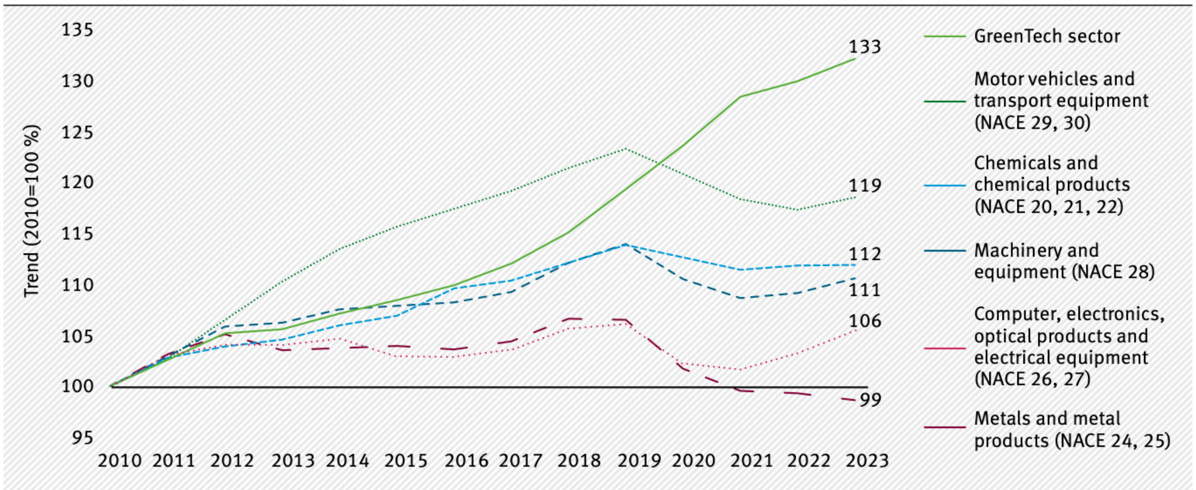

Figure 7: Trend in Persons Employed in Germany`s Greentech Sector and Comparison Sectors (Indexed 2010=100%). Source: Prognos (2025): Greentech made in Germany 2025. Avaiable at: https://www.prognos.com/sites/default/files/2026-01/uba_greentech_atlas_2025_deutsch_barrierefrei.pdf

The following Fig. 8 provides an overview of the overall status and distribution of the seven GreenTech sectors for 2023, as well as the average annual growth from 2010 to 2023 (price-adjusted). Compared to the average annual economic growth of 1.3% during this period, growth in all leading GreenTech sectors was significantly higher. If this trend continues, the share of GreenTech contributing to overall GDP growth will increase. Although the GreenTech sector Circular Economy was the largest in 2023 with a share of around 28% (€87.9 billion), its average growth rate of 2.3% was the lowest of all GreenTech sectors. This is an indication that the economic, social, and environmental opportunities of CE are far from being utilized to their full potential.

China is an interesting case how e.g. clean energy sectors can contribute to a greener pattern of growth: "Solar power, electric vehicles (EVs) and other clean-energy technologies drove more than a third of the growth in China's economy in 2025 – and more than 90% of the rise in investment. Clean-energy sectors contributed a record 15.4tn yuan ($2.1tn) in 2025, some 11.4% of China's gross domestic product (GDP) – comparable to the economies of Brazil or Canada […]"[58]

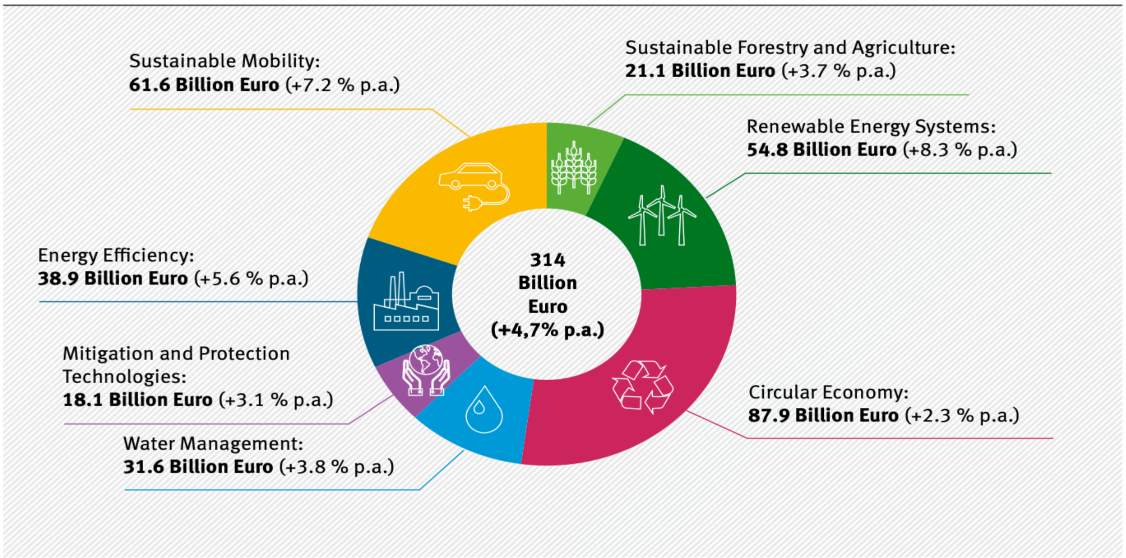

Figure 8: Gross Value Added of Germany`s GreenTech Sector in 2023 (Total and by Lead Markets) and Average Annual Growth from 2010 to 2023 (Price-adjusted). Source: Prognos (2025): Greentech made in Germany 2025. Avaiable at: https://www.prognos.com/sites/default/files/2026-01/uba_greentech_atlas_2025_deutsch_barrierefrei.pdf

For the future, the study expects an increase in gross value added to €622 billion by 2045 in the proactive scenario 2 (Climate-Neutral and Circular Germany), i.e., with an average annual growth rate of 3.1%, this represents almost a doubling compared to 2023. As the following figure 9 shows, the global GreenTech market has already reached a market volume of €1.02 trillion in 2023.

58 Carbon Brief (2026): Analysis: Clean energy drove more than a third of China's GDP growth in 2025. Available at: https://www.carbonbrief.org/analysis-clean-energy-drove-more-than-a-third-of-chinas-gdp-growth-in-2025/

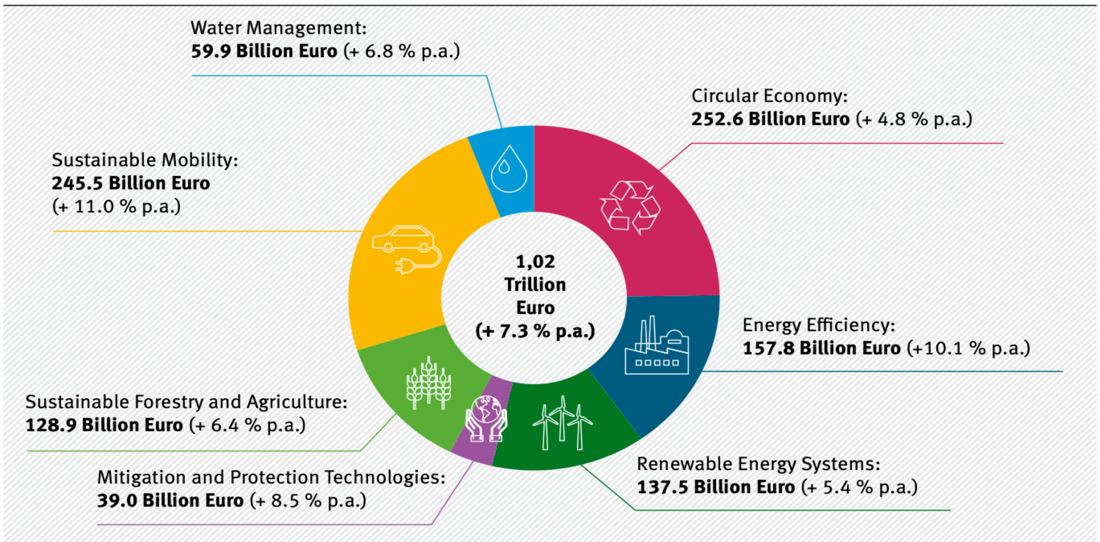

Figure 9: Global Market Demand in Lead Markets in 2022 in Billion Euros, with Growth from 2010-2022 in % p.a., nominal. Source: Prognos (2025): Greentech made in Germany 2025. Available at: https://www.prognos.com/sites/de-fault/files/2026-01/uba_greentech_atlas_2025_-deutsch_barrierefrei.pdf

Interestingly, both the total and all seven GreenTech sectors worldwide are showing significantly higher growth than the corresponding sectors of the German economy. Germany's export economy can benefit from this accelerated global growth in the GreenTech sectors. For a strongly export-oriented economy such as Germany's, it is particularly important. Whether this trend continues depends, according to the study, not on a lack of global demand, which, on the contrary, is likely to accelerate, but primarily on the availability of skilled workers (ibid., p.21).

Patents are an indicator of innovative strength and, in an international comparison, of medium- and long-term competitiveness. The following figure 10 emerges for the top 6 countries worldwide.

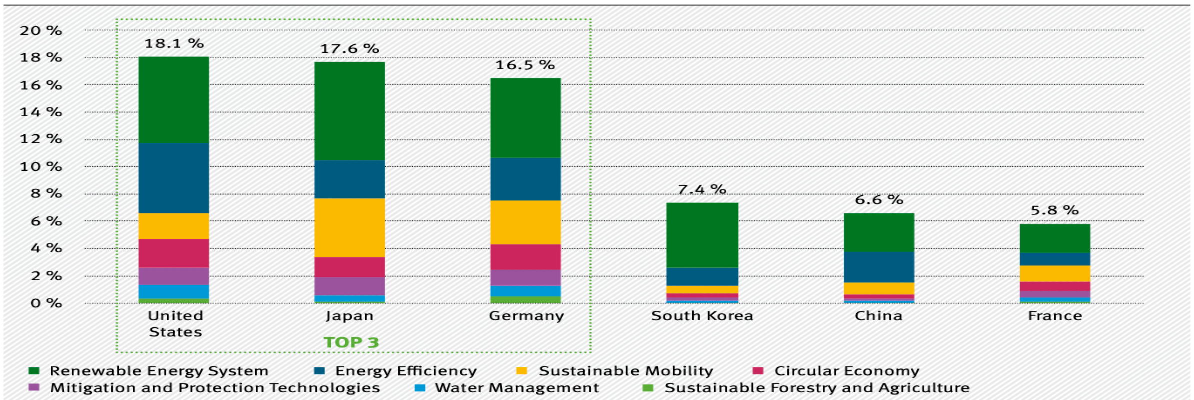

Figure 10: Shares of the Top 6 Countries in Total Greentech Patents Between 2010 and 2023, in %, with Distribution Across Greentech Leading Markets. Source: Prognos (2025): Greentech made in Germany 2025. Available at: https://www.prognos.com/sites/de-fault/files/2026-01/uba_greentech_atlas_2025_-deutsch_barrierefrei.pdf

It is evident that the top three countries, US, Japan, and Germany, have contributed comparable shares to patent development between 2010 and 2023, with Germany accounting for a relatively high proportion of patents in the circular economy sector.

The GreenTech study summarizes a number of recommendations that, although focused on Germany, can essentially be generalized to all EU member states: “Advancing the transformation towards climate neutrality and a circular economy: Germany must continue along its current path, thereby strengthening the domestic GreenTech market. As with other strategic industries, robust domestic demand serves as a foundation for global competitiveness. Reliable regulatory frameworks aligned with climate and circular economy targets are essential to reinforce market incentives…To keep pace with global competitors—particularly in light of China’s assertive innovation policy—Germany needs effective research funding, supportive conditions for startups, and strong public-private collaboration, that enable the development of innovative yet capital-intensive technologies“ (ibid., p. 7).

9 Financing the Energy Transition

Macroeconomic cost-benefit analyses provide important decision-making bases for more ambitious CE strategies and climate protection policy. However, this does not sufficiently answer questions of public and private financing. The advantages of integrating CE strategies and climate protection policy are also related to this, because the investment requirements tend to be estimated higher when viewed in isolation and when synergies are not used.

Studies[59] show that the *joint implementation of defossilization and dematerialization strategies* (increasing material efficiency; CE strategies) facilitates the achievement of ambitious climate protection goals. A study titled CE-Roadmap for Germany goes one step further: "The resource perspective on a Circular Economy …makes it clear that the vision of a climate-neutral and simultaneously resource-productive Germany can only be achieved by a comprehensively transformational approach: climate neutrality cannot be achieved solely through the transition to a Circular Economy but at the same time, the Circular Economy is a key prerequisite for doing so." (S.40)[60] This statement thus emphasizes that the transition to a Circular Economy is regarded as a *crucial precondition* for achieving climate neutrality.

The CE-Roadmap for Germany is based on the following positive guiding vision: "A systemically conceived and sustainable Circular Economy will make a comprehensive contribution to the EU target of net zero greenhouse gas emissions by 2050, allowing economic growth to be absolutely decoupled from resource consumption. It will ensure planetary limits are respected and sustainability goals achieved and help to enhance quality of life and ensure equitable prosperity through collaborative, intercompany value creation and innovation." (Acatech 2021, S. 35). This positive vision contains normative statements that have not yet been substantiated by existing integrated macroeconomic studies of a combined energy and resource transition, and who's empirical and scenario-based evidence therefore requires further investigation.[61] Since no integrated macroeconomic studies on this topic are available, detailed macroeconomic studies on the energy transition and climate neutrality in Germany are summarized below as a proxy.

Some key findings from German energy and climate protection scenarios up to 2030 and 2045 are briefly summarized below. The crucial question is whether, and if so

59 On a global scale for residential buildings and cars e.g. Pauliuk, Stefan et al (2021): Global scenarios of resource and emission savings from material efficiency in residential buildings and cars. Available at: F". „Lifting material efficiency (ME) to similar prominence as energy efficiency increases the feasibility of attaining the Paris goal of limiting global warming to well below 2 °C and may reduce the dependency on negative emission technologies….ME shows strong co-benefits in savings of raw materials, energy, and GHG emissions, and its technical and scaling feasibility is high. These advantages over negative emission technologies represent a compelling reason to give ME a higher priority in climate policy " (ibid,p.6)

60 Acatech (2021): Circular Economy Initiative Deutschland. Available at: https://www.acatech.de/projekt/circular-economy-initiative-deutschland/

61 The study Modell Deutschland Circular Economy (2023), conducted on behalf of WWF by Öko-Institut, FU Berlin, and Fraunhofer ISI, defines CE in a similarly normative way: A sustainable Circular Economy creates positive environmental and society-wide benefits and functions within planetary boundaries, supported by an alternative growth and consumption narrative". One target vision ("positive environmental and society-wide benefits") is well substantiated in this study by comprehensive model analyses. However, the further target reference "functions within planetary boundaries, supported by an alternative growth and consumption narrative" is insufficiently substantiated as a normative postulate.

how, the initially exorbitant additional demand for public and private investments in defossilization can be mobilized—and whether this can generate macroeconomic benefits and self-financing effects of the public budget compared to a wait-and-see strategy.

A recent comparison[62] of various studies on the investment needs to achieve climate neutrality in Germany indicates a range for annual public financing requirements between approximately €30 billion and €90 billion (2024 prices). Experts assume that this public financing demand must be met—despite reductions in environmentally harmful subsidies (estimated at €65 billion per year, see UBA 2021, ibid)—through modifications of the debt brake (ibid) and/or additional tax revenues (such as progressive taxation of the ultra-wealthy)[63]; the decision on a special fund approved for 12 years amounting to €500 billion is a step in the right direction but still insufficient for this purpose. These investments refer to additional expenditures also for climate mitigation ("Sondervermögen"); special fund for infrastructure and climate neutrality (SVIK)) and include public seed financing for infrastructure such as roads and rail networks, as well as leverage incentives to stimulate private investments. Total investments up to 2045, based on four studies, range between approximately €215 billion and €550 billion per year (2024 prices). The wide range results from different assumptions regarding the sectors included in the transformation, with business-as-usual investments accounting for between 11% and 28% of total investments.

The study concludes: "Investments in climate protection should not be viewed as costs but as economically sensible measures that lead to long-term savings and growth potentials. They can bring direct cost reductions, for example in fuel expenses, and generate long-term economic and fiscal gains, whereas inaction will cause higher public costs over time, such as those resulting from climate damages" (own translation; ibid., p. 5). Cost savings and national growth potentials arise, for example, from the reduction of energy import costs, which can be substituted by domestic value creation. German energy import costs[64] for oil and natural gas ranged between approximately €43 billion (2020) and €128 billion (2022) during the years 2008–2024.

62 FÖS (2025): Was braucht es für Klimaneutralität und die Modernisierung des Landes? Ein Vergleich der Investitionsbedarfe verschiedener Studien. Available at: https://foes.de/publikationen/2025/2025_06_20_FOES_DNR_Investitionsbedarf.pdf

63 For context, the draft federal budget for 2025 foresees core budget expenditures of approximately €503 billion for the current year. Net borrowing is projected at around €82 billion, significantly exceeding the previous year's level of €39 billion. (cf. https://www.bundestag.de/presse/hib/kurzmeldungen-1097400)

64 Cf. Statista (2025): Wert der Importe von Erdgas und Rohöl in Deutschland in den Jahren 2008 bis 2024. Available at: https://de.statista.com/statistik/daten/studie/151081/umfrage/importe-von-erdgas-und-rohoel-nach-deutschland/

10 Are ambitious Climate and Resource Strategies too costly?

We would like to conclude our plea for “green” competitiveness through ambitious climate and resource strategies by examining the relationship between the costs and benefits of climate protection, competitiveness, and (macro)economic rationality, referring to a comprehensive study by KfW/Deloitte (2025). This study refutes the myth that ambitious climate protection hinders competitiveness and (qualitative) economic growth. This myth is mostly based on inadequate methodology in economic cost-benefit analyses: Often, the (damage) costs of insufficient climate protection are ignored or the opportunities of a climate-friendly economic transformation are underestimated or the investments that would be made anyway under reference conditions (“Business as usual”/BAU) are not distinguished from the additional costs of ambitious climate protection or the additional costs of a climate protection investment program are not offset against avoided fossil fuel energy costs. Or all of these shortcomings occur cumulatively. Instead, the study demonstrates what its title promises: “The economic benefits of climate action. How decarbonization can enhance competitiveness and growth.” [65] We summarize the results of this study and compare it with a recent study of OECD/UNDP[66].

First: The comparison of four current studies (see Fig 11) illustrates that relatively ambitious climate protection (2°C target) generates significant growth gains compared to the currently emerging 3°C scenario by the turn of the century – understandably within a wide benefits range.

Study	Projected relative GDP gains by 2100 under a 2° C szenario compared with a szenario based on current policy/3° C warming
Bilal and Känzig (2024)[7]	up to 12% of global GDP
WEF and BCG (2024)[8]	10–15% of global GDP
Benayad et al. (2025)[9]	11–24% of global GDP
OECD/UNDP (2025)[10]	1–13% of global GDP

Source: Own representation based on the cited studies.

Figure 11: GDP gains through more ambitious climate mitigation policy. Source: KfW/Deloitte (2025)

Second: The KfW/Deloitte study states, that “[...]over the past five years only, climate related damages sum up to more than $ 1 trillion [...] The social cost of carbon in the latter half of the century would exceed $ 1,000 per ton of carbon dioxide emissions [...] The study argues that competitiveness can be strengthened by offering

65 It should be acknowledged, however, that global and long-term costs and benefits of climate and resource protection are not directly reflected at national and sectoral levels in the short term. For example, decarbonizing a country with a high dependence on fossil fuels (such as China, India, the USA, Russia, or Japan) remains a challenge for national competitiveness, regardless of the fact that ambitious decarbonization strategies of these countries would dramatically reduce global climate costs and increases global benefits.

66 Cf. OECD (2025): Investing in Climate for Growth and Development. Available at: https://www.oecd.org/en/publications/investing-in-climate-for-growth-and-development_16b7cbc7-en/full-report/investing-in-climate-for-growth-and-development-policy-highlights_867ee4f8.html

innovative products in growing markets, as well as through cost reductions—whether by increasing resilience, improving efficiency, or securing better financing options.“ (p.4)

Third: Completely in line with our above arguments concerning the rapid growth of GreenTech markets the study argues: ”The global market for green technologies has already been growing rapidly in the past. Both the demand for green technologies and capital inflows into the sector have recently increased at a dynamic pace, averaging around 7,3% and 9,6% per year, respectively. If these observed trends continue, the overall market volume could double in less than ten years. Looking further ahead, growth prospects for the green tech sector also remain strong: With the continued pursuit of ambitious climate policy plans, the global market for green technologies could triple or even quadruple by the middle of the century. However, political decisions will be crucial in shaping this growth potential“ (p.4). Based on the comparison of three scenarios with somehow different mixes of green technology development patterns and analyzing possible drawbacks the study summarizes: ”These figures highlight the interconnection of green tech growth opportunities and transformation paths: There are significant opportunities that strong global transformation policy can offer for the green tech industry. Yet the size of opportunities hinges on the strength and speed of global transformation activities. The drawback of the US as a major economic player from climate policy may thus be expected to have an impact. In fact, recent survey evidence suggests that current US policy has negative spillover effects on climate action in other countries—but the global growth prospects remain positive“ (p.12)

Fourth: Last but not least a study by the OECD/UNDP[67] relates this cost/benefit approach of the KfW/ Deloitte-study to indicators of sustainable economic development and recent NDC decisions. The study concludes that in an ambitious “Enhanced NDC Scenario,” global GHG emissions can be reduced by 34% by 2040, representing “…a pathway consistent with limiting global warming to 1.7 ^{o}C by the end of the century. The Enhanced NDCs scenario has a small but positive effect on global GDP growth in the next 15 years: global GDP in 2040 would be 0.2% higher than under the Current Policies Scenario…. Investing in clean energy and energy efficiency increases productivity and innovation, balancing the economic impact of policy constraints on prices and consumption. Reinvesting carbon revenues can further boost GDP while ensuring a just transition and securing public support for climate policies“ (ibid, p.8). Regarding the achievement of the SDGs, the report highlights that employment would slightly increase by 2040 compared to a “Current Policies Scenario” (net, despite job losses in fossil fuel sectors) and that there is especially significant potential for reducing poverty: “The findings demonstrate how coordinated investments in governance, social protection, green transitions and digital infrastructure can drive both energy equity and climate progress. By aligning energy transition efforts with development strategies, up to 90% of low- human development countries (where the Human Development Index (HDI) is below 0.55)

67 Cf. OECD (2025): Investing in Climate for Growth and Development. Available at: https://www.oecd.org/en/publications/investing-in-climate-for-growth-and-development_16b7cbc7-en/full-report/investing-in-climate-for-growth-and-development-policy-highlights_867ee4f8.html

could achieve substantial development improvements, potentially lifting an additional 175 million people out of extreme poverty by 2050 "(ibid., p.13).

11 Systemic Outlook and Summary

Shortly before the completion of this paper, a publication appeared that summarizes some of our perspectives and analyses of competitiveness for the first time in a systemic and monetized form.[68] This publication underlines our thesis and results from a very comprehensive and systemic point of view which should be shortly summarized as an outlook.

The publication builds on the physical basis of the regularly published Circularity Gap Report[69], but for the first time assesses monetarily and on a global scale the annual value losses per year that result from today's linear economy compared to measurable avoidance potentials achieved through progress in implementing circular economy strategies. The research question is as follows: ”What is the extent of avoidable economic value lost due to inefficient linear practices globally within a given accounting year?“[70] And the answer is striking: ”Initial estimate of the Value Gap suggests it amounts to €25.4 trillion (± €4.7 trillion) in avoidable annual economic value lost to linear material use, equivalent to almost 31% of global GDP.“ This impressive global range of avoidable losses does not only have encouraging implications for the economics of transformation to net zero and dematerialization. Disaggregating and focusing it to the national level it also allows a more systemic view on questions of competitiveness concerning front runners towards a circular economy.

The following ranges are estimated for the five pathways where the huge global value loss occur [71]:

- Processing losses: €904.2 billion (± €112.5 billion). Value lost during the transformation of raw materials into semi-finished or final products.
- Energy losses: €8.7 trillion (± €1.6 trillion). Inefficiencies across all stages of the energy system.
- Food losses and waste: €650.7 billion (± €28 billion) during the supply chain, e.g., storage, transport, and final consumption.
- End-of-life waste: €10.0 trillion (± €1.2 trillion). Products and materials where residual material and product value is not recovered.
- Consumption of fixed capital: €5.2 trillion (± €1.7 trillion). Premature obsolescence of long-lived assets when infrastructure, machinery, or buildings are outsourced faster than necessary.

Note that missed opportunities of harvesting the benefits of energy efficiency increase at all stages of energy transformation and of recovering value from end-of life waste should be targeted with priority due to their highest amount of avoidable value loss.

68 Circle Economy/Deloitte (2026); available at: https://dashboard.circularity-gap.world/report/2026/cgr-2026-overview

69 Compare for example for the year 2025 :Circle Economy (2025); available at: https://www.circularity-gap.world/2025

70 Circle Economy (2025), The Circularity Gap Report 2026. The Value Gap, Version 1.0, 22/12/202

71 Compare Circle Economy/Deloitte 2026, available at: https://dashboard.circularity-gap.world/report/2026/cgr-2026-overview, p. 25

The provision of ranges and the methodological explanations signal that these calculations represent a first bold attempt to monetize the losses in value of energy and materials in today's linear economic systems. For example, the prices for valuing negative externalization are determined by shadow prices, which are always based on estimates, and whose internalization in microeconomic cost calculations raises many practical questions in regard to competitiveness. However, the astonishing magnitude of avoidable value losses appears robust and fully confirms the basic thesis of this article: More ambitious steps by the EU and its member states towards a circular economy and climate neutrality can lead to substantial first-mover advantages and creates a significant competitive edge.

A brand-new study by the Boston Consulting Group[72] commissioned by the BDI—likewise confirms the ”opportunities of the circular economy“ for the German industry. In addition to the cumulative energy cost savings of approximately €38 billion enabled by this approach through 2045, as well as the additional reduction of 11 million tons of CO_{2e}, the study notes: ”The gross value added of the circular economy could more than double—rising from its current level of €60 billion to as much as €125 billion in 2045; thus, particularly in light of the economic stagnation of recent years, it represents a significant opportunity for growth (own translation).“[73]

We have attempted to clarify the meaning and societal desirability of ”competitiveness“ from various systems perspectives. It became clear that ”competitiveness“ is *not an end in itself*, but rather *a means* to achieve the medium- and long-term goals of a circular, decarbonized economy and a well-being society.

Our findings underline the importance of *systemic thinking and policy integrating* of CE- and decarbonization strategies particularly for high-income countries. The concept of circular economy in a broad sense is a decisive step forward towards a sustainable well-being society and for “green” competitiveness, particularly if it is linked to an overall reduction goal of resource demand and integrated with climate mitigation policies.

Our findings raise *questions to be investigated further*: 1) the particular contribution of the current political approaches to encourage resource productivity, CE-strategies and decarbonization should be evaluated to improve the systemic understanding, the interlinkages and the societal, distributional and environmental impacts. 2) the role of public infrastructures as a precondition for competitiveness in the classical meaning (e.g. to compete in international markets) should be reexamined. As currently highly material-consuming parts of material demand (with all associated environmental impacts) it should be analyzed how provisioning systems (e.g. nutrition, built environment, mobility, energy) can secure human needs in less material intensive and more climate and society friendly ways.

Ambitious climate mitigation, circular economy and dematerialization strategies foster the *rapid growth* of GreenTech and at the same time the *ambitious degrowth*

72 Boston Consulting Group/Bundesverband der Deutscher Industrie e.V.(2026), Wachstum, Wettbewerbsfähigkeit und Resilienz

73 Cf., Boston Consulting Group/Bundesverband der Deutscher Industrie e.V.(2026), S. 4

of fossil, resource intensive or risky sectors. Whether and how far this politically forced economic structural change to net zero and towards a circular economy adds up to an aggregated positive GDP-growth and an absolute decoupling from resource use not only in scenarios but in reality, remains an open question. One often neglected answer to this question is: Integrating *sufficiency policies as a third pillar* to the technical strategies like *consistency (renewables) und efficiency* can make it easier to reach net zero and risk-minimization.

Economic and technological global basic trends like the impressive innovations and cost reductions concerning e.g. renewable energy, batteries, electric vehicles, energy efficiency improvements, heat pumps, smart grids, AI, new materials etc. will not be stopped by the current refossilization backlash of the US. There might be short run competitive advantages by exploiting and offering profitable low cost gas or oil prices, but the opportunity costs of not using and driving the above mentioned Green Tech basic trends are high and might reduce the overall competitiveness of the US economy. We don`t expect that the global market introduction and the dynamics of scaling up GreenTech innovations can be destroyed by recent US energy and climate policy priorities. The backward-looking US-MAGA-policies may trigger a short term slowdown in the growth rates of GreenTech markets, but the global economic and ecological MEGA trends against natural scarcities will continue.

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