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Trends and Challenges of the Global Energy Transition:

Insights of the Freiburg Energy Talks 2025

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Preface

The Freiburger Energy Talks offer an exclusive platform for leading decision-makers and strategists from academia, industry, politics and finance across continents, with the aim of promoting coherent strategies for the global energy transition. The conference series started in 2021. In 2025, the Freiburger Energy Talks took place on the 18th and 19th of May, as usual in Freiburg/Breisgau, Germany, and were co-organised by the Fraunhofer Institute for Solar Energy Systems (Fraunhofer ISE) and the Academies' initiative 'Energy Systems of the Future' (ESYS). Fifty participants from 12 countries took part and shared their ideas on how to restart the energy transition after the recent setbacks in global climate policies. See the annex p. 21 for the full list of this year's participants.

1. Energy transition is gaining momentum amid uneven times

The transformation of the energy system has made significant progress: today, **two dollars are invested in clean energy for every dollar spent on fossil fuels globally** — whereas ten years ago, fossil fuels still dominated. [1] This shift is particularly evident in the power sector, where solar PV now attracts more investment than all other electricity sources combined. Installations of wind and solar continue to rise, with solar increasing by 29% and wind by 8% from 2023 to 2024. [2] Major economies such as the USA, China and the EU have managed to reduce their greenhouse gas emissions. [2; 3] Some countries—including Germany, the USA, Australia, and South Africa—have even succeeded in decoupling economic growth from emissions, as illustrated in Figure 1.

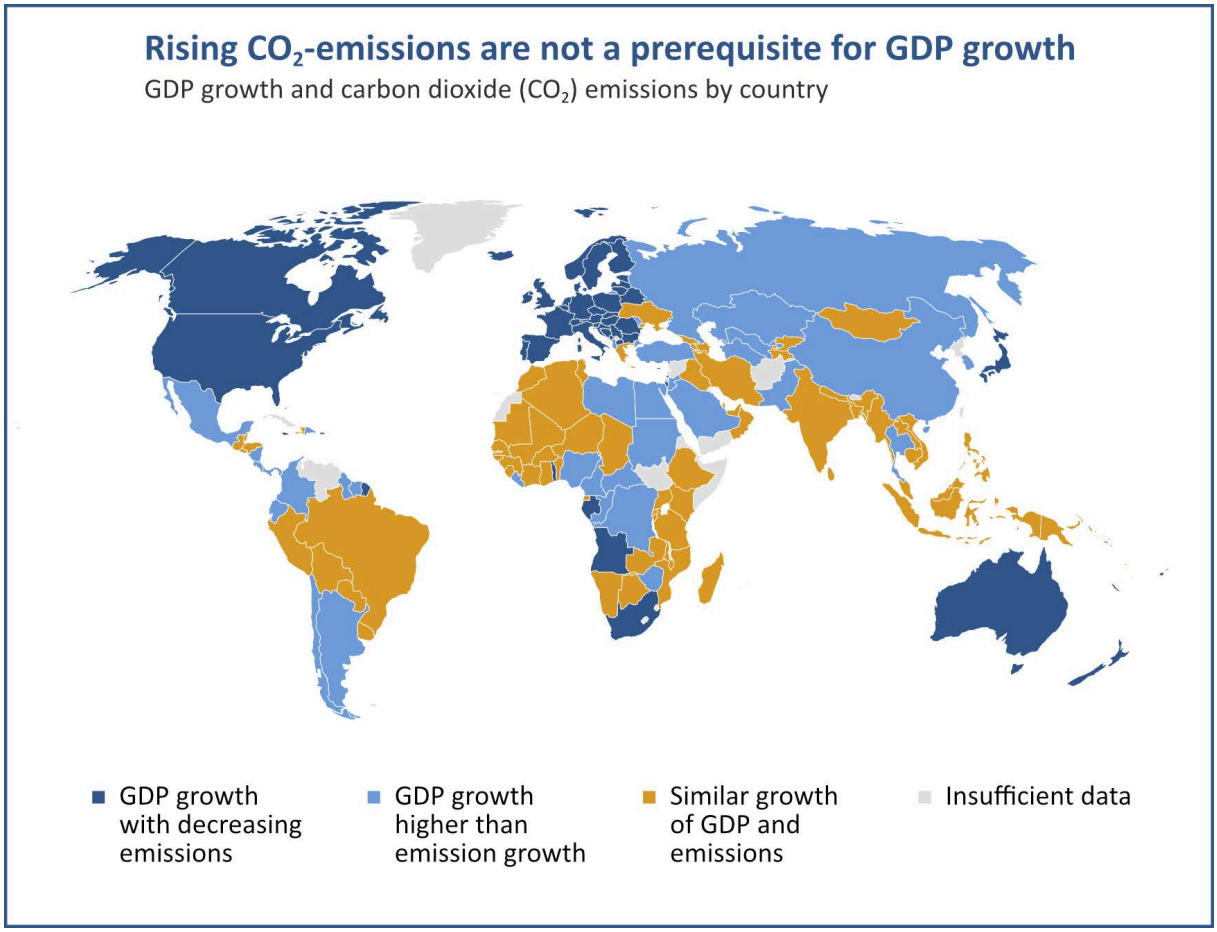


Figure 1: Decoupling growth and CO_2 emissions by country. Source: Illustration based on UTN/KAS 2024 [4] edited by ESYS.

Yet despite the strong growth in renewable energy capacity in recent years, fossil fuels remain the dominant energy source in the G20 energy mix. Globally, coal and gas consumption increased by 2 and 3 percent respectively [2], pushing **global fossil fuel use to an all-time high** (see Figure 2). Rather than replacing fossil fuels, renewables have largely been added to the existing energy mix. Reflecting on this dynamic, historian Jean-Baptiste Fressoz has described the current development as an 'energy addition rather than an energy transition'. [5] If this trend continues, the goal of limiting global warming to a maximum of 2 degrees Celsius is unlikely to be met.

Furthermore, **climate action is facing growing headwinds**: wars and geopolitical tensions, trade conflicts, a renewed focus on national interests over global cooperation, as well as concerns about economic decline and a resulting turn toward industrial policy, have led policymakers to deprioritise—or, in the case of the current U.S. government, even abandon—climate protection efforts.

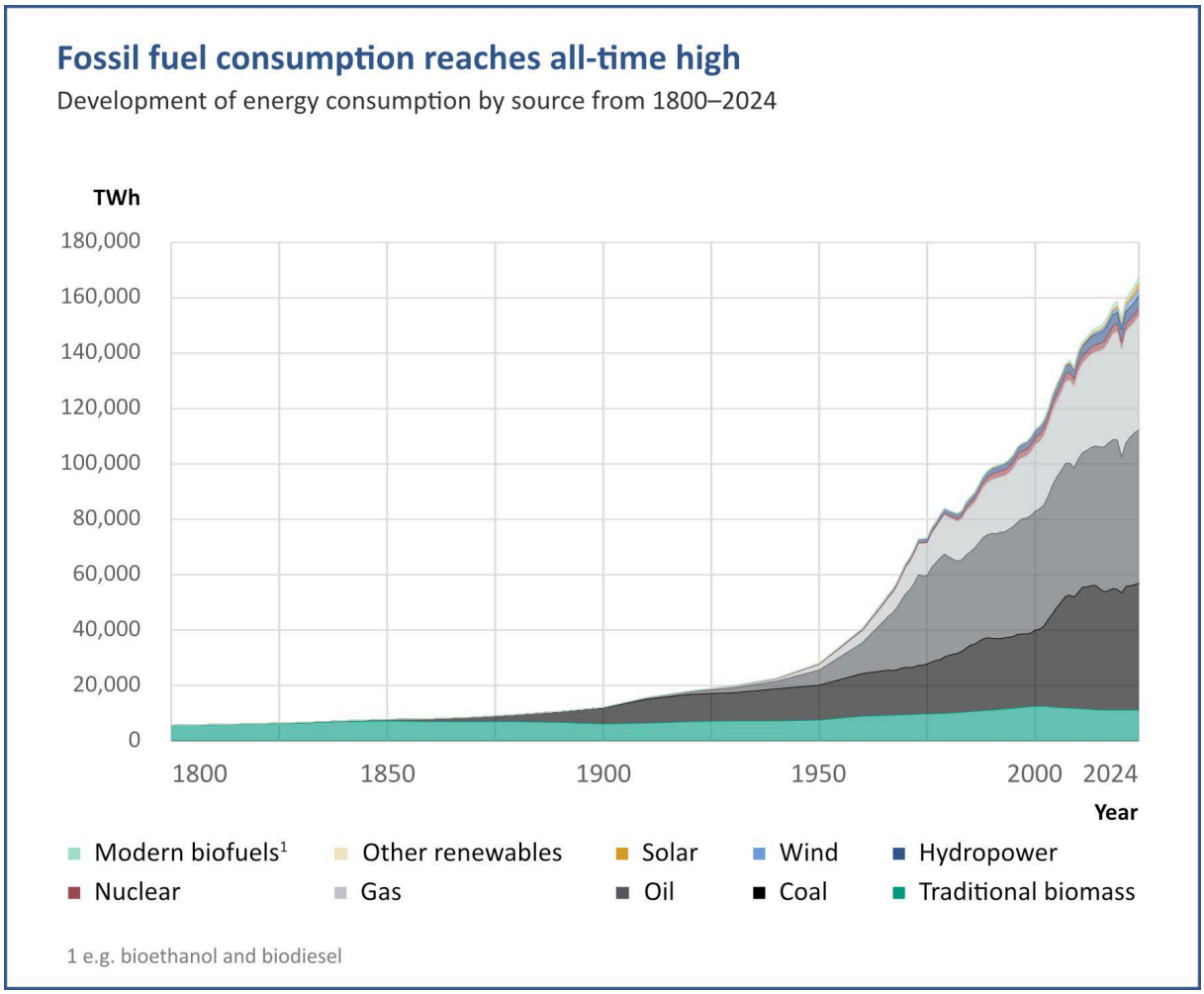


Figure 2: Development of global direct primary energy consumption since the 19th century. Source: Illustration based on Energy Institute 2025 [6] edited by ESYS.

Against this backdrop, the Freiburger Energy Talks 2025—co-organised by Fraunhofer ISE and the Academies' initiative 'Energy Systems of the Future' (ESYS)—explored how the energy transition's current momentum can be sustained; how the next phase, involving carbon management technologies, climate friendly hydrogen and synthetic fuels, can be enabled; and how global developments that threaten the phase-out of fossil fuels can be addressed. Therefore, this year's discussions focused on four topics that reflect key challenges for policymakers: energy security and resilience; value creation; financing; and a transparent and just transition.

The overall finding across all discussed topics was that the reduction of fossil fuels in absolute terms and not only as a share of the energy mix is crucial to foster the transition. Key strategies include:

- Expanding renewables
- Phasing out fossil fuel subsidies
- Developing circular supply chains
- Boosting energy efficiency
- Reducing overall energy demand

Targeted international exchange and cooperation can support these transformation approaches by facilitating the sharing of best practices and existing experiences.

2. Energy security and resilience

Resilience is 'the ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management'. [7] Therefore, resilience is not only the capacity to deal with change and recover: its presence also facilitates further development—inter alia geopolitically and regarding climate change. Resilience is insurance, a safeguard that systems, societies and communities can continue to afford a liveable future even after disruptions. That is why resilience must be strengthened in these turbulent times, in order to improve the ability of future generations to act and enable them to cope with significant ecological, technological and political changes.

Russia's warfare against the whole of Ukraine since 2022 has demonstrated that highly differentiated economies and energy systems can turn away from energy sources in short periods of time, if alternatives exist: Germany has rapidly shifted its gas imports away from Russia, in particular with the help of supplies from Norway. The global gas trade is undergoing significant regional changes—for Europe, this means turning away from Russia and increasing imports from the USA. The IEA has run scenarios estimating that this trend may continue in the next ten years (see Figure 3).

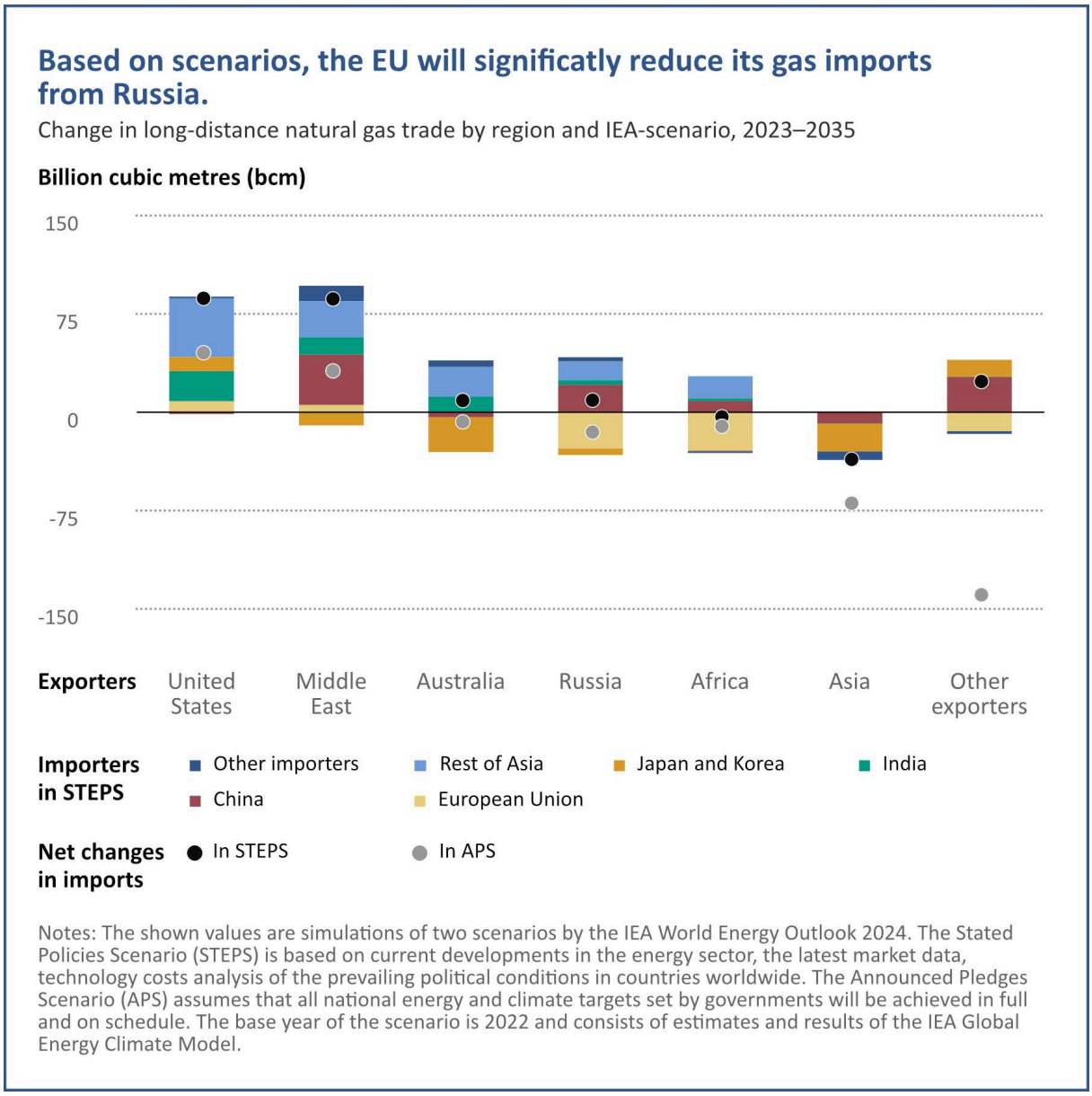


Figure 3: Changes in global gas trade 2023–2035. Source: Illustration based on IEA [8] edited by ESYS.

Dependencies on fossil energy sources and few providers are risk factors that can and should be responded to in different ways. Solutions include achieving higher energy efficiency, reducing the total amount of energy required or expanding domestic and European renewable energy capacities. Another option is diversifying the supply routes and increasing the number of suppliers. However, interdependencies do not necessarily lead to vulnerabilities. They can also lead to a higher level of resilience, if there are mutual and approached cooperatively, as the European energy system shows.

Scenarios indicate that Germany will continue to be dependent on imports of energy (carriers) in the future. For example, they show a positive import balance for electricity in 2045. But Germany's dependence on energy imports will decline by the middle of the century and the intensification of intra-European electricity trading will strengthen the security of the supply. [9; 10] Regardless of the exact import shares, it is clear that the restructuring of energy systems leads to different kinds of interdependencies, e.g., regarding raw materials, electricity imports, climate-friendly hydrogen (derivatives) or the supply of skilled workers. These

all have to be addressed during the energy system transformation. In this context, the restructuring of economic sectors that have strongly contributed to general value creation to date (e.g., steel, chemicals, automotive industry) will be essential. Value chains will change as a result of shifts in the interaction between the import of raw materials or intermediate products and domestic production. This can lead to a conflict of objectives between economic efficiency and independence (see Figure 4) and thus have a decisive impact on the resilience of societies and energy systems.

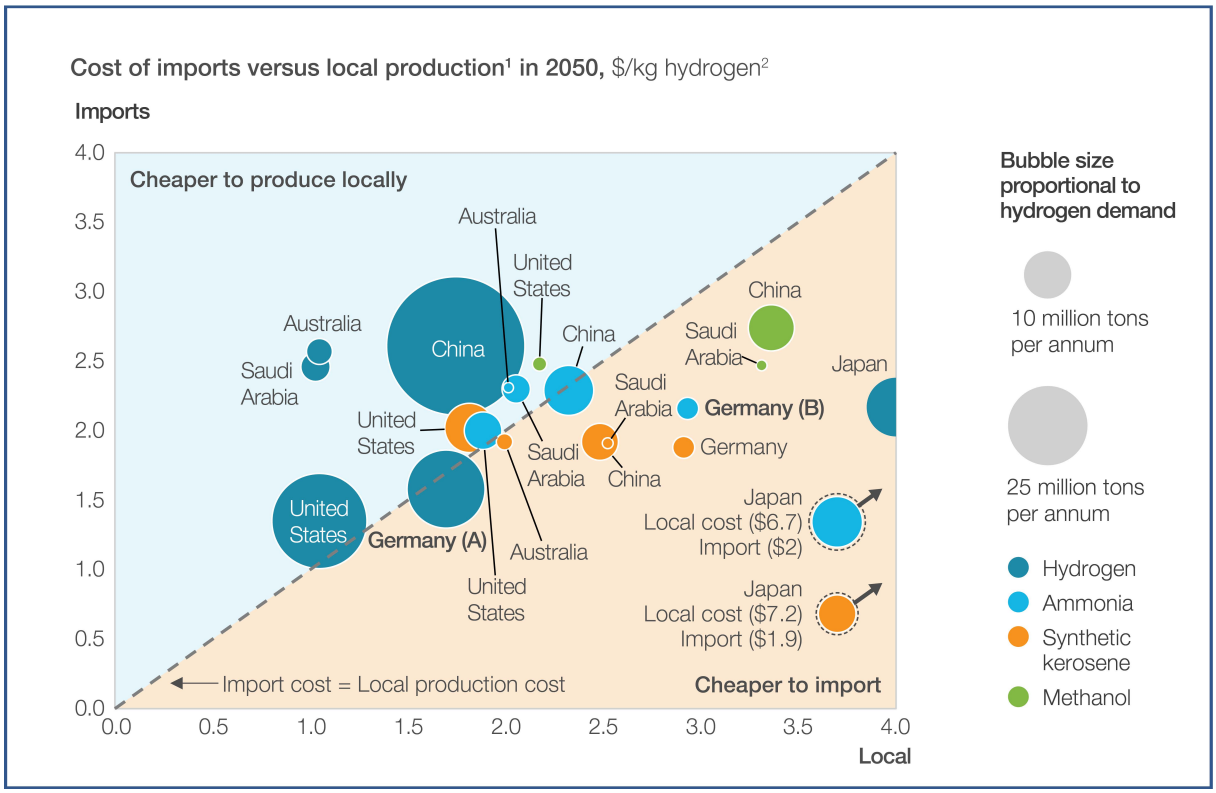


Figure 4: Cost of imports versus domestic production of hydrogen and derivatives for different countries in 2050. Source: Hydrogen Council [11].

In Workshop 1, 'Energy security and resilience: strategies for a stable energy system in times of crisis', participants discussed the following challenges and identified the respective solution approaches:

Challenge: Resilience is often seen as a burden instead of an advantage

Resilience is often seen as an extra effort with additional costs rather than a strategic necessity.

Possible solutions:

- A mindset shift is required: resilience should be treated as insurance against external shocks and as a foundation for adaptive and flexible systems.
- Resilience should not be politicised, as this undermines its effectiveness. It must be based on objective risk assessments, quantifiable data and long-term responsible political action.

Challenge: Strict regulation frameworks hinder important energy projects

Current regulatory frameworks often slow down the implementation of vital energy projects. EU-level regulation, while ambitious, frequently lacks flexibility for diverse national contexts. For example, some member states struggle to implement mechanisms such as Power Purchase Agreements due to local market design.

Possible solutions:

- Permitting procedures must be reassessed and streamlined where feasible.
- To ensure global scalability, lean regulatory environments are essential during the early stages of technology deployment. Tighter controls can follow once international markets and standards are established.
- The EU's leadership in regulatory design—notably with instruments like the ETS and CBAM—should be promoted as a model for international harmonisation in cooperation with like-minded countries.
- Reviving and strengthening the World Trade Organization (WTO) by aligning it with climate objectives could help reduce trade barriers and support a globally coordinated sustainable transition.

Challenge: Effective resilience strategies require comprehensive databases

A significant obstacle to risk mitigation and strategic planning is the lack of integrated data and comprehensive databases for full value and production chains.

Possible solutions:

- New concepts for comprehensive data collection and transparency must be developed. Emerging technologies such as artificial intelligence or satellite-based (real-time) monitoring can streamline data gathering, improve traceability and support the creation of circular supply chains.
- Enhanced international collaboration and cross-border infrastructure investment in climate-friendly technologies can strengthen strategic planning and lower project costs through enlarged datasets, shared innovation and deployment.

3. Value creation through the energy transformation

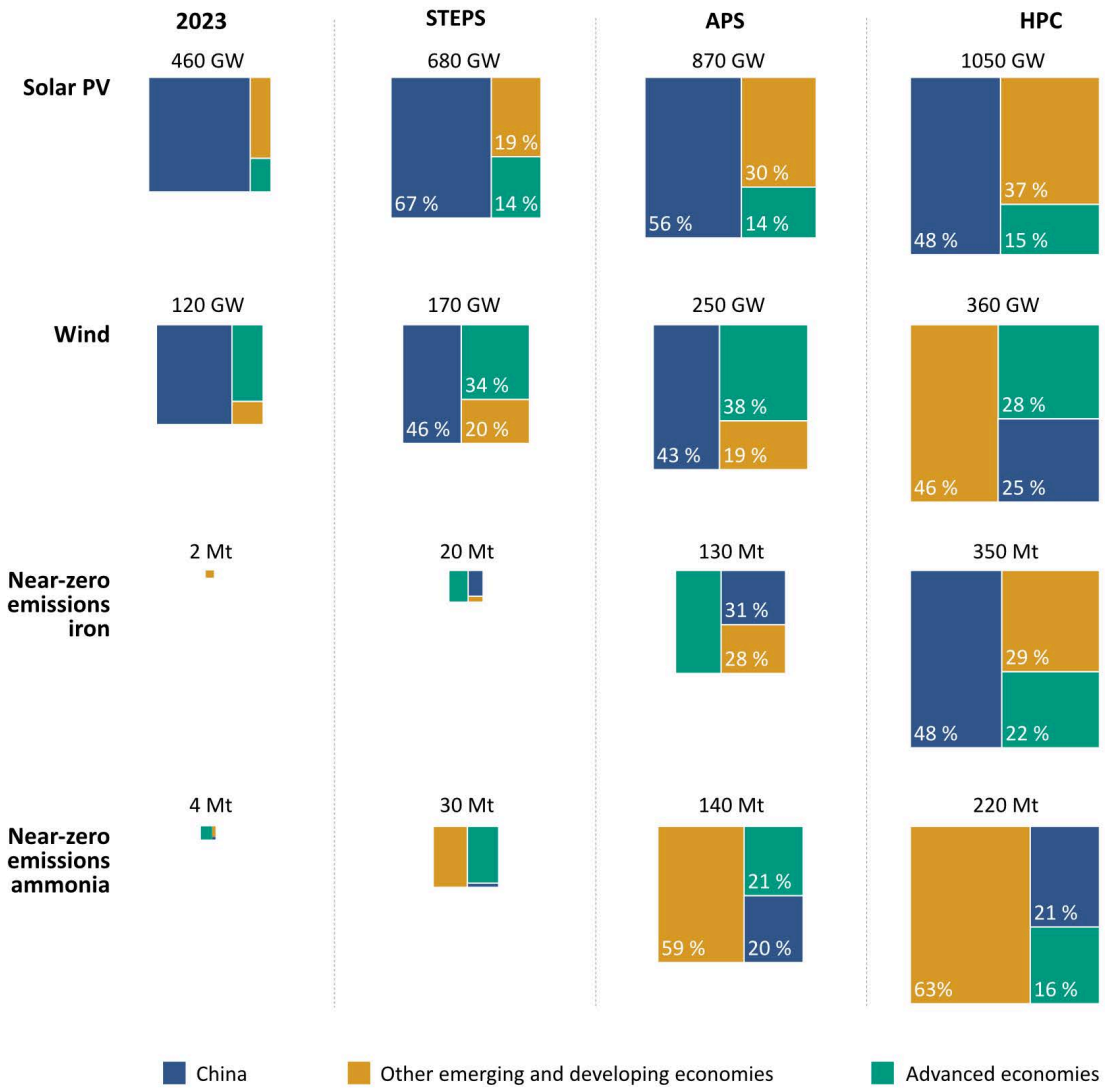
The clean energy technology industry bears an immense potential: the IEA estimates that it could be worth USD 650 billion in 2030 and provide up to 14 million manufacturing jobs. [12] The value creation takes place in the following value chains:

- Raw material extraction and processing
- Mechanical and plant engineering
- Component manufacturing
- EPC of plants and infrastructure
- Production of energy carriers without GHG emissions

Scenarios from the IEA suggest that while developed countries are attractive investment markets with growth prospects, China and other developing and emerging countries show the biggest potential for clean energy technologies (Figure 5).

China shows great potential for clean energy products overall, while other emerging and developing countries show potential in certain technologies

Country/country group shares in clean technology production for different IEA scenarios until 2050



Notes: The shown values were published in the Energy Technology Perspectives 2024 and are based on two scenarios by the IEA World Energy Outlook 2024 and an additional high potential case (HPC). The modelling horizon spans from 2023 (base year) to 2050 with annual time steps. The stated Policies Scenario (STEPS) is based on current developments in the energy sector, the latest market data, technology costs analysis of the prevailing political conditions in countries worldwide. The Announced Pledges Scenario (APS) assumes that all national energy and climate targets set by governments will be achieved in full and on schedule. Solar photovoltaics (PV) refers to module production, wind refers to nacelle production.

Figure 5: Regional/country shares in clean technology production for different IEA scenarios. Source: Illustration based on IEA 2024 [13] edited by ESYS.

Moreover, taking part in the energy transformation may require countries to shift their focus and industry strategies. This is the case for Germany, where downstream processes are adding more value than upstream processes (Figure 6).

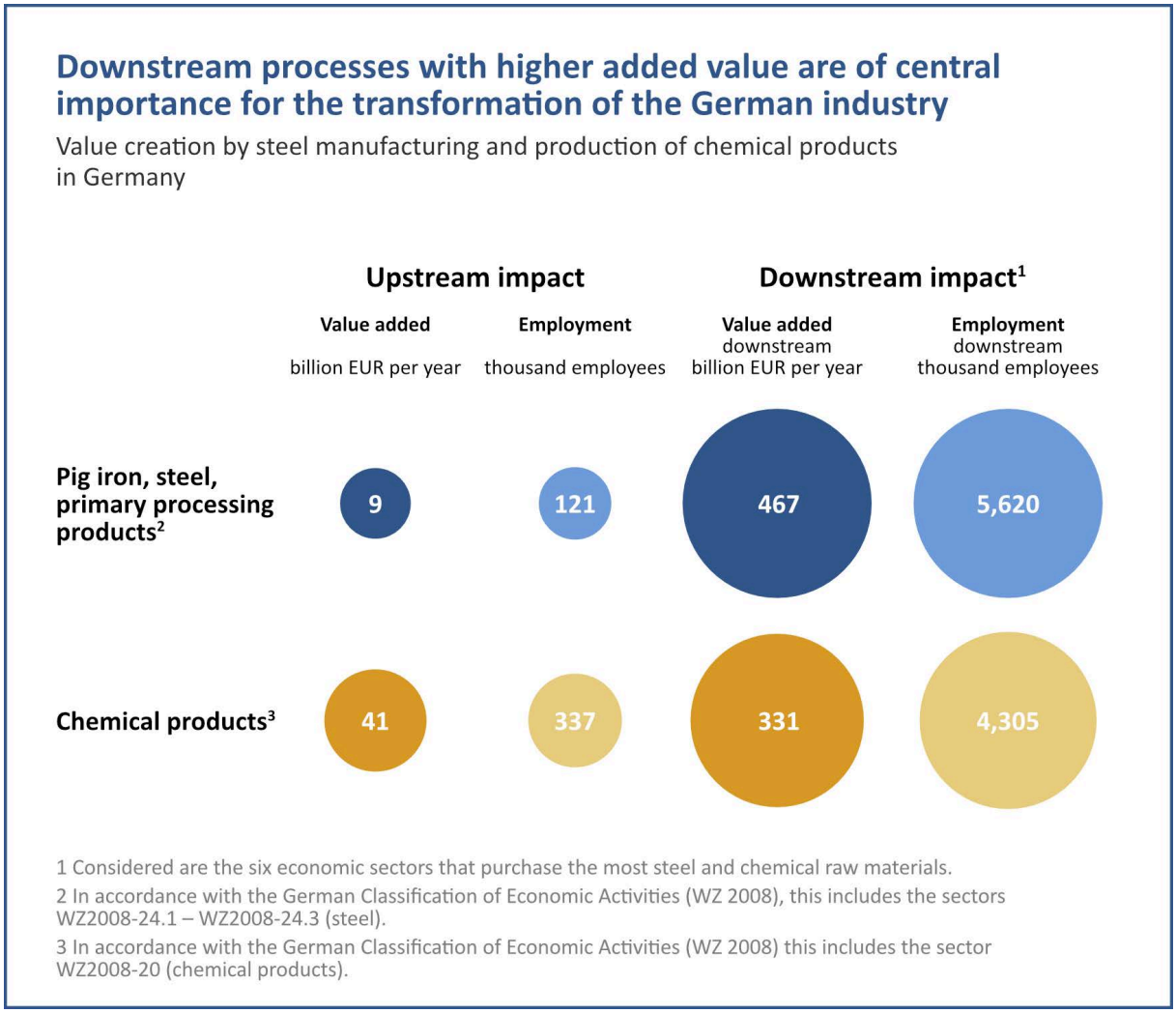


Figure 6: Shift in value creation due to new energy vectors—upstream vs. downstream impact for German industry
Source: Illustration based on Verpoort et al. 2024 [14] edited and translated by ESYS.

In Workshop 2, 'Challenges and solutions for the transformation of energy systems to net zero', participants discussed the following challenges:

Challenge: Changes in global value chains demand adaptation and transition

The global value chains are changing, causing losses in former key industries and economic downturn, but also sparking new business opportunities. The global energy transition is both driven by and a driver of significant shifts in value chains (and must be seen as such).

Possible solutions:

- This transformation demands urgent and coordinated adaptation across sectors, including industry, governance and international cooperation.
- Achieving a successful transition requires deep, cross-sectoral and cross-border collaboration—not limited to primary industries like energy and automotive but extending across national boundaries.
- Governments play a crucial role as enablers, fostering alignment among scientific, industrial and policy frameworks to ensure a synchronised and effective transformation.

Challenge: Protectionism diminishes the benefits of international energy cooperation

Countries move toward more sovereignty and control. The global trend toward protectionism is reshaping and weakening the landscape of international energy cooperation.

Possible solutions:

- Energy security in the future should be grounded less in avoiding dependence and more in exchanging dependencies, shifting away from fossil fuel reliance. Cooperation is not necessarily a loss of sovereignty and partnerships can strengthen energy systems and value creation processes.
- Demand-driven, country-tailored approaches: the focus must shift to demand-side strategies tailored to each partner country's needs and capacities. Effective cooperation starts with understanding local demand contexts—this builds sustainable partnerships.

Challenge: Turning theoretical concepts into real-world business cases

While a number of theoretical concepts and ideas to boost the energy transition have already been developed, the challenge is turning them into real-world business cases and products.

Possible solutions:

- Translating innovation into real-world impact requires a strong focus on pilots and proof-of-concept projects that validate ideas, build trust and attract investors. Governmental support through targeted subsidies and funding is vital to de-risk early-stage ventures and catalyse private sector involvement.
- To foster scalability, regular platforms for engagement can enhance international alignment and speed up the diffusion of knowledge. Furthermore, it is imperative to develop business models that align with climate goals while remaining commercially viable, ensuring long-term private sector commitment
- Timely action is crucial: this requires tight coordination between science, industry and governments to ensure that decisions can be made with both speed and credibility. Strategic communication plays a central role—high-level political and corporate commitment must be complemented by grassroots and local engagement.
- Building connected ecosystems—linking start-ups, investors, researchers and institutions—is key to accelerating progress. Collaboration must begin early in project lifecycles to scale efficiently and avoid bureaucratic bottlenecks that could delay implementation.

4. Financing: incentives and investment

The use of fossil fuels in global energy consumption has reached a record high (see Chapter 1). However, a look at investments in the energy sector, which are of crucial importance for future development, shows that the ratio of clean versus fossil energies in global energy investment has changed during the last ten years. Total global energy investment exceeds USD 3 trillion and only a third of it goes into the fossil fuels oil, natural gas and coal. Not only are two-thirds of investments in clean technologies—the increase in investments is also attributable to clean technologies and renewable energies. Furthermore, renewables have the largest single share of the total volume (see Figure 6). At USD 450 billion, solar technologies (utility scale and rooftop), in turn, amounted to the largest share of investments in renewables. [1]

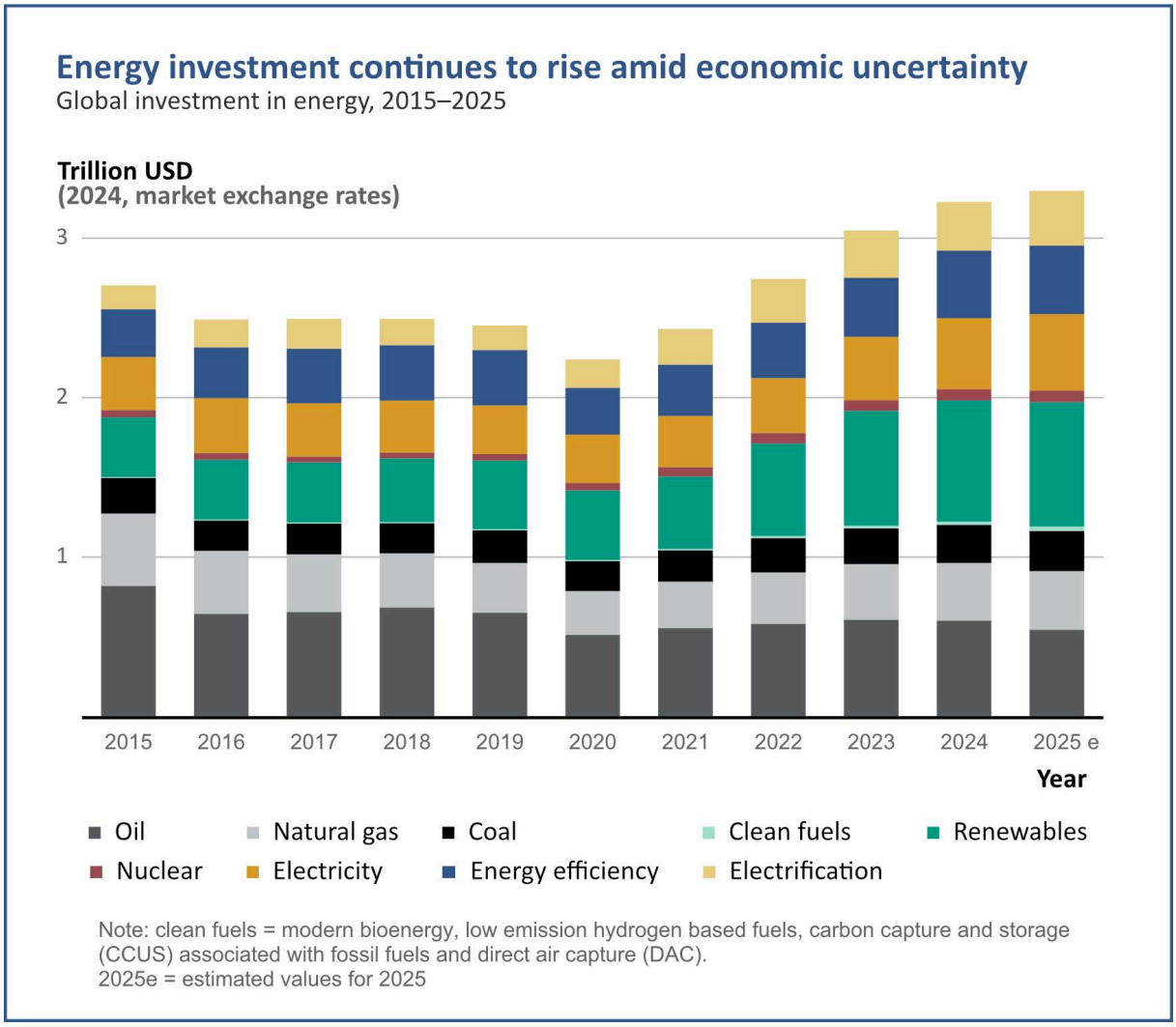


Figure 7: Global energy investments 2015-2025. Illustration based on IEA 2025 [1] edited by ESYS.

Private investment accounts for by far the largest share of global energy investment, both in fossil fuels and clean fuels. However, the share of public funding for clean technologies is lower than that for fossil fuels (see Figure 8). [1]

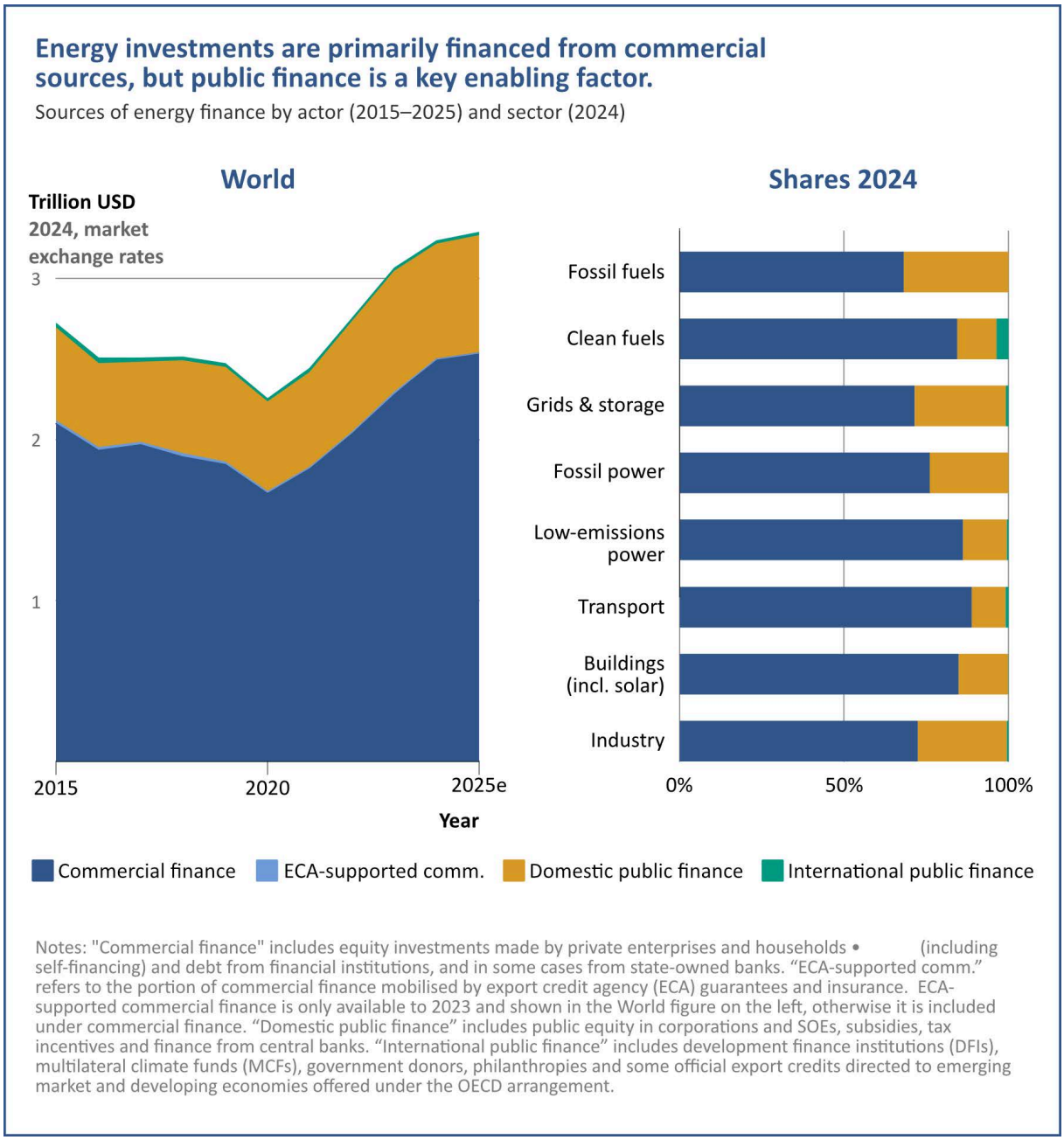


Figure 8: Public and commercial finance in global energy investments. Source: Illustration based on IEA 2025 [1] edited by ESYS.

These growth rates for clean technologies and especially renewables cannot be taken for granted, partly because the glowingly positive investment environment of recent years, with its extremely low interest rates [15] and strong policy support, is becoming increasingly gloomy. New trade policies, custom disputes, higher material prices or unsecured access to raw materials and anti-deglobalisation approaches could lead, amongst other things, to a more challenging capital market environment for renewables and clean technologies. [1] Attractive investment conditions are particularly in demand at present, however, because the current total annual expenditure for renewable power generation capacity, grids, flexibility, energy efficiency and energy conservation will have to be nearly doubled to achieve the 1.5 degree target path and the two energy objectives established at COP28 in Dubai for 2030: tripling global energy capacity and doubling energy efficiency. [16] USD 4,499 billion per year for investments in the areas mentioned above

will be needed between 2024–2030 (2023: USD 1,289 billion). [17] In order to achieve the envisaged global renewable power capacity 11,000 GW in 2030 (2024: 4,770 GW), 1,040 GW of new capacity will be required annually over the next five years. [18] An additional increase is therefore necessary, requiring greater efforts than the already significantly higher and unprecedented growth rates in renewable capacity seen in recent years (2022–2023: +560 GW; 2023-2024: +741 GW). [16; 18]

In Workshop 3, 'Financing the future: incentives and investments for the energy transition', participants discussed the following challenges and solution approaches:

Challenge: Providing stable and predictable conditions for long-term competitiveness

Increasing political uncertainty, the resurgence of fossil and nuclear agendas and the volatility of capital markets are undermining project bankability and long-term competitiveness. A stable and predictable political and financial environment is critical for the success of the global energy transition.

Possible solutions:

- Clear political support for climate protection, climate adaption and energy system transformation is essential. This includes binding commitments and paths for greenhouse gas neutrality, robust infrastructure planning and effective regulatory frameworks. A special focus must thus be placed on infrastructure for transmission, flexibility and storage.
- Narratives and communication efforts for energy transition and climate change have to be adapted in such a way that they can be applied in different political contexts. They should also counter mis- and disinformation to strengthen established paradigms regarding climate change and adaption; environmental protection; energy system transformation; and international cooperation—covering topics such as carbon pricing, CBAM and subsidy reforms.

Challenge: Developing fair competition rules competition in the global clean technology market

A fair and competitive global energy market requires changes in subsidy policies and needs to create a level playing field.

Possible solutions:

- It is urgently necessary to phase out fossil fuel subsidies and to implement market-based mechanisms that assist the implementation of low-carbon and carbon-free solutions such as carbon pricing or emissions trading systems. Market-based approaches must be framed by legal instruments like carbon border adjustment mechanisms (C-BAM) to minimise the relocation of production facilities (carbon leakage) and so ensure fair competition across regions on the path to net zero.
- It is important to address the social dimensions of energy transition. Policies must consider the broader impacts on communities and ensure that vulnerable populations are supported through inclusive and equitable transition strategies.

Challenge: Stimulating demand and willingness to pay for green products

There is currently a lack of demand for green products. Consumers are not yet willing to pay enough for clean tech solutions.

Possible solutions:

- To scale clean technologies effectively, it is crucial to boost financial market attractiveness and create demand-driven momentum in green sectors. This includes tools like enforceable quotas and taxonomies; power purchase agreements; contracts for difference; and incentives for emerging technologies such as hydrogen, sustainable aviation fuel, green steel and green cement.
- Building up lead markets will be essential for the implementation of climate-friendly technologies. A targeted procurement policy by governments can support this process. Its establishment should also be taken into account in initiatives for renewable energies, greater sustainability, regional development etc. (e.g., European Programme for Reconstruction and Development (EPRD) or International Finance Corporation (IFC)). Special attention should be given to SMEs and start-ups, who often lack access to finance and struggle with navigating complex regulatory environments. Creating an attractive and accessible support ecosystem for them can position governments as critical enablers of clean tech lead markets.
- A key point is mobilising enough private and institutional capital (e.g., pension and sovereign wealth funds). Their commitment is crucial, not least for the long-term financing of climate friendly solutions.

5. A transparent and just transformation: social challenges and opportunities

Transformation means a fundamental change from an actual state to a target state. From a social perspective, overcoming an existing dominant pattern—in this case restructuring an unsustainable energy system—leads to significant political, economic and technological change. The establishment of new system structures is also usually a long-term process that is characterised by uncertainty and the search for suitable solutions. [19; 20] Such far-reaching changes also cause resistance from political and social groups and raise conflicts of interest that need to be moderated and negotiated.

Different cultures, markets, industry sectors and stakeholders have different challenges and needs and, thus, react differently. Transformation processes are already inherent complex. In addition, the necessary transformation of energy systems is also encountering a phase of multiple critical situations—economical, societal, geopolitical and environmental—that is already overwhelming for various people. Behavioural changes and societal norms contribute more than technical efficiency to successful restructuring processes. So, the potential innovations, technologies and solutions must be solutions for daily life, too. Transparent communication of the transformation steps and social accompaniment of the associated processes are necessary to make people aware not only of the resulting advantages but also of the associated disadvantages. Only thus can individuals recognise where they can actively contribute or offer support. In short, social aspects are not an add-on: they are a central task that must be addressed in energy system transformation processes.

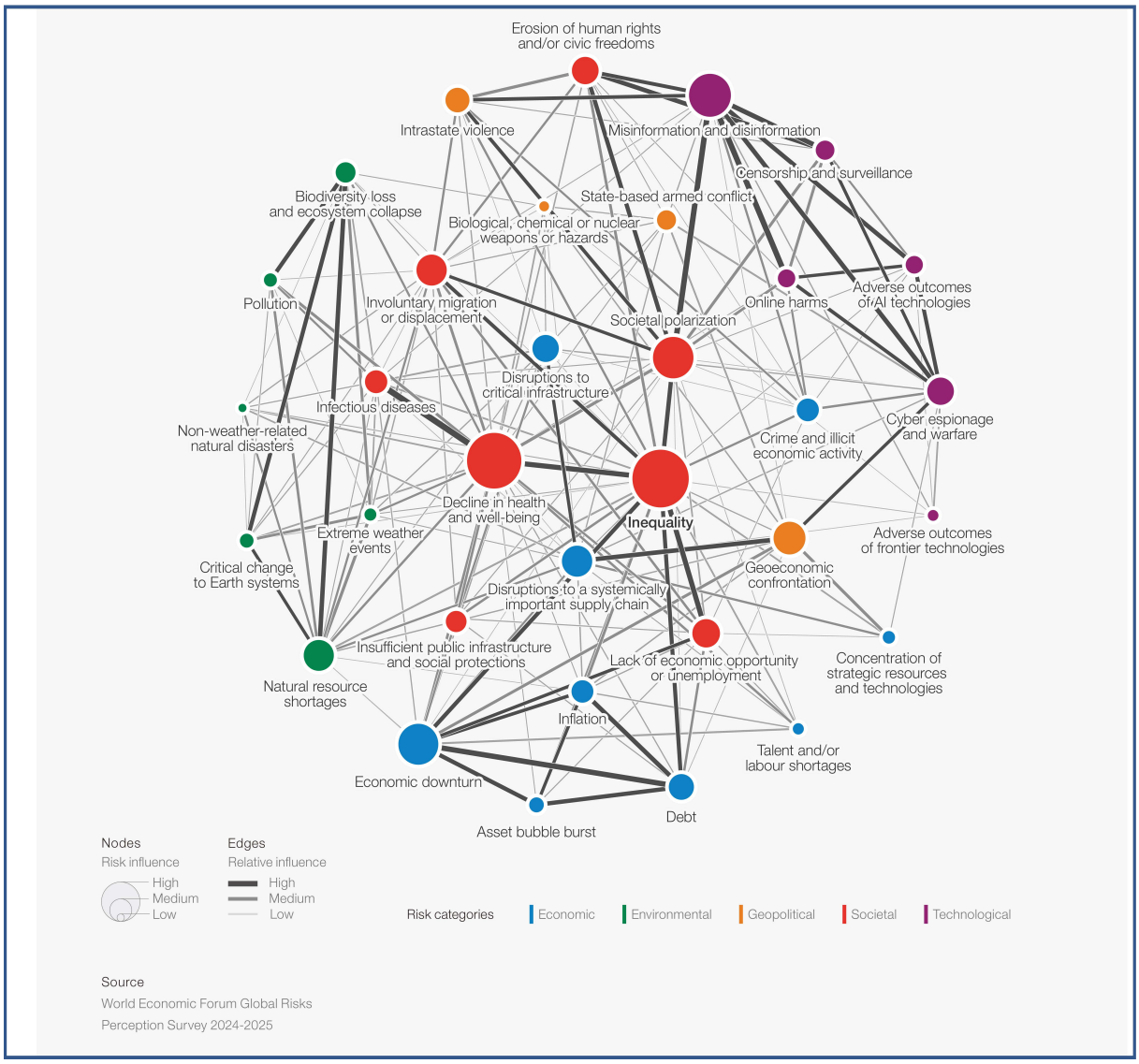


Figure 9: Global risk landscape. Source: World Economic Forum [21].

More and more, inequality (wealth and income) is one of the most central and highly interconnected risks. Societal polarisation, decline in health and wellbeing as well as mis- and disinformation are also highly ranked and interconnected factors (Figure 9). The challenge for the sustainable transformation of energy systems is therefore all the greater because social and economic risks factors are increasing and ecological aspects are losing importance in public awareness. [21] This contributes to weakening of trust in science and political/ democratic institutions; together with higher levels of mis- and disinformation through content platforms and new technologies like AI, this has the potential to diminish the collective sense of shared values.

Even though new clean energy technologies can create value and boost the economy, as seen in Chapter 3, not everyone is currently profiting from this value creation: investments in renewable energy exceeded those in fossil fuels, yet most investments in renewable energy installation take place in OECD countries and China. Only 2% of global renewable investments were in Africa. [22] From a political point of view, the unequal distribution of economic benefits from transitions may present obstacles to both national climate action and international climate cooperation. Several studies of OECD countries concluded that local and national support for transitions is linked to economic benefits and generation of local jobs. [23; 24; 25]

In Workshop 4 ‘A transparent and just transformation: social challenges and opportunities’, participants discussed the following challenges and identified these solution approaches:

Challenge: Establishing of stakeholder-oriented transformation processes

The energy transition must be transparent and sensitive to cultural differences, especially in diverse regional contexts. Communication styles, local perceptions of infrastructure and socio-economic priorities can vary widely; in some regions or poorer communities, immediate concerns like clean water, sanitation or corruption may take precedence over climate issues.

Possible solutions:

- One-size-fits-all approaches must be avoided, because infrastructures and associated risks of projects will be accepted differently depending on the region. Local relevance and cultural sensitivity must guide both policy and implementation.
- Implementing the transition is a mixture of gradual and parallel processes, often facilitated by individual, highly active participants or political decision-makers, who should be specifically supported and integrated into project planning and processes.
- In order to achieve behavioural changes and shifts in social norms, education on energy and environmental issues should begin at an early age and address topics related to daily life.

Challenge: Limiting national thinking patterns

National priorities are an obstacle to the successful global implementation of an energy system transformation.

Possible solutions:

- Regional and cross-border cooperation can promote earlier and more efficient energy system transitions. For example, if regions near borders have stable energy infrastructures or good energy production conditions for people on both sides of the border, joint infrastructure projects and shared access to energy resources across borders can accelerate problem solving, help stabilise regions and potentially reduce migration pressures.

Challenge: Reducing inequalities in global clean energy investments

Spending patterns in clean energy technologies show excessive inequalities, so disparities in global clean energy investment and usage are too strong. For example, Africa, with 20 percent of the world’s population, receives only 2 percent of investment. [1]

Possible solutions:

- In the past, decisions in the energy sector focused too much on costs. Criteria like resilience, social acceptance, risk transparency and equity must be integrated into energy planning, funding and decision-making.
- Developing countries should pursue alternative, sustainable industrial pathways, avoiding the missteps made by developed countries. They should industrialise in a different manner by implementing existing green technologies wherever possible, to mitigate their dependence on fossil solutions in a shorter period of time.
- Developed countries must step up their structural and financial support for less developed countries—especially for developing countries. The access to fund resources must be simplified, because its current complexity is a barrier for many developing countries. Fair access to climate mitigation and adoption funds; the optimisation of regional and local financial structures; and the streamlining of fund disbursement processes are therefore important steps toward the successful realisation of the global energy system transition.

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In the initiative "Energy Systems of the Future" (ESYS), acatech – National Academy of Science and Engineering, the German National Academy of Sciences Leopoldina and the Union of the German Academies of Sciences and Humanities provide input for the debate on the challenges and opportunities of the German energy transition. Within the Academies' Initiative, over 160 experts from the science and research communities come together in interdisciplinary working groups to develop policy options for the implementation of a secure, affordable and sustainable energy supply.

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