EYE OF EUROPE

Geopolitics of Industrial Decarbonisation

Workshop Report on Global Scenarios and R&I Opportunities for Europe

Calle Orense, 34, Madrid, Spain

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insight foresight institute

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Eye of Europe

The workshop is part of the research project **Eye of Europe**[1], funded by the European Union's Horizon Europe research and innovation programme and coordinated by UEFISCDI, the Romanian Research & Innovation funding agency. Eye of Europe aims to enhance the integration of foresight practices into Research and Innovation (R&I) policymaking across Europe. Ultimately, the project envisions a more cohesive and influential R&I foresight community that contributes significantly, as a collective intelligence, to shaping and guiding policy decisions.

Insight Foresight Institute

The workshop was organised by the Insight Foresight Institute[2], a Madrid-based Spanish limited liability company, founded by Dr. Totti Könnölä and Dr. José Manuel Leceta in 2015. The institute delivers pioneering insights and foresight in collaboration with businesses, public administrations, and other key actors in innovation ecosystems, orienting society towards sustainability in Spain, Europe, and internationally. Its management team, experts, and international advisory board entail versatile experience to lead transformation by conducting strategic guidance, foresight, horizon scanning, and strategic studies, as well as evaluation and impact assessment. Its innovation and transition studies deal with, for instance, multi-level governance of system innovations and innovation ecosystems, and management of open, radical, and disruptive innovations. The institute is active in various thematic areas, for instance, digital and green transition and industrial decarbonisation.

[1] More Information on the project and how to sign in the community: eye-of-europe-the-research-and-innovation-foresight-community (futures4europe.eu)

More information about the workshop, presentations and other materials are available here: https://www.futures4europe.eu/post/geopolitical-industrial-decarbonisation-scenarios-to-identify-ri-opportunities-for-the-eu-f4575

[2] For more information: www.if-institute.org

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Abstract

This report presents the outcomes of the *Geopolitical Industrial Decarbonisation Scenarios* workshop, convened on behalf of the Eye of Europe Horizon Europe project by the Insight Foresight Institute. Bringing together 30 participants from across the European Union—including policymakers at EU, national, and regional levels, industry leaders, energy and climate specialists, and foresight and forecasting experts—the workshop explored how the EU can navigate mounting geopolitical uncertainty while accelerating industrial decarbonization on a 2050 horizon.

The discussion was structured around two core aims. First, participants examined a suite of forward-looking geopolitical scenarios, assessing how divergent power dynamics, energy trade patterns, and technological trajectories could either hinder or catalyse the transition to a net-zero industrial base in the EU countries. Particular attention was paid to supply-chain resilience, strategic autonomy in critical materials, and the interplay between carbon border adjustments and global climate diplomacy. Second, the workshop sought to surface emergent research and innovation (R&I) needs and opportunities that would equip EU actors to thrive across the scenarios. Priorities highlighted include advanced electrification processes for hard-to-abate sectors, low-carbon hydrogen and synthetic-fuel value chains, circular-economy business models, and data-driven tools for real-time decarbonisation monitoring.

Outputs from the session feed directly into the Eye of Europe project's multi-workshop learning cycle. Immediate products comprise this extended report for attendees; aggregated insights captured in the public *Pilot Logbook Part I – What we did* and *Part II – What we learned*; and distilled policy recommendations to be released in the *Eye of Europe Policy Brief: Foresight Perspectives on Key R&I Topics.* Beyond documentation, the Insight Foresight Institute will leverage the findings to stimulate agenda-setting dialogues with EU bodies and industrial stakeholders, ensuring that identified R&I pathways inform Horizon Europe programming and other EU-level funding instruments. Workshop materials and presentations are retrievable via the futures4europe.eu knowledge-sharing portal, reinforcing the project's commitment to an open foresight community.

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1 Introduction

As the European Union intensifies its efforts to achieve net-zero emissions by 2050, several industries face transformative challenges and opportunities. Anchored in the European Union's broader climate and energy targets, the *New Clean Industrial Deal for Europe* seeks to accelerate decarbonisation across key sectors, such as energy, manufacturing, and transportation, while bolstering economic competitiveness and energy security. It is central to fostering innovation in clean technologies, including renewable energy systems, hydrogen and advanced materials sciences, alongside creating circular economy frameworks to reduce dependency on imported energy and critical raw materials. Also, strategic autonomy is prioritised by diversifying supply chains, investing in local production capacities, and strengthening partnerships with like-minded nations. By integrating robust policies, financing mechanisms, and public-private partnerships, the Deal could contribute to a just transition, revitalise regional economies, and ensure global leadership in the fight against climate change. This comprehensive framework could redefine the EU's industrial landscape, making it more resilient, sustainable, and globally influential and competitive.

The workshop contributed to this discussion by taking a long-term view and by focusing on the strategic question: How can the EU navigate amidst global uncertainties to foster a more resilient and effective path toward industrial decarbonisation? Addressing this requires a nuanced understanding of geopolitical dynamics, dependencies, and innovative solutions across various themes and scenarios.

2 Methods

The workshop began with a general explanation of the methodology to be applied—scenarios on day 1 or roadmapping on day 2—providing a framework for the day's activities. This was followed by presentations from experts with diverse backgrounds, including representatives from the European Commission and the Spanish Ministry of Industry. These contributions offered participants a broader perspective on the progress of decarbonisation through various initiatives.

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Following the presentations, participants were divided into three small groups based on their areas of interest. Each group focused on separate themes and worked under the guidance of dedicated moderators. Within these groups, participants exchanged ideas and engaged in in-depth discussions on their specific themes, using the methodological lens of scenarios or roadmapping. The outcomes of these group discussions were later shared with all participants, contributing to a collective reflection and synthesis of insights. See Annex 1 for more details on the presentations and the structure of the workshop. Following the workshops, the session recordings and post-it notes were transcribed and converted into scenario and roadmap narratives, as detailed in Sections 3, 4 and 5. This task was assisted by ChatGPT. Scenario approach: combining geopolitical contexts and decarbonisation themes.

What types of EU R&I policies on industrial decarbonisation would be effective in the years to come? To answer the question, we need to explore developments both at the global level and within the European Union. Several recent developments strongly suggest that a new world

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order will be a multipolar one, but we cannot know yet how these 'poles' would behave. Thus, it is imperative to consider several options. To do so, we explored different types of multipolar worlds (based on Havas & Weber, 2023). In the workshop, we excluded the possible scenarios of a fragile, non-competitive and non-sustainable EU and focused on exploring *in each scenario what ways a strong EU could decarbonise its industry and become ever more competitive, dynamic, and resilient*. In the workshop, we presented three context scenarios at the global and EU levels (Table 1):

A) genuine collaboration: 'poles' genuinely collaborate when tackling global challenges,
B) limited co-operation: antagonistic groups of countries are nevertheless willing to engage in limited co-operation, and
C) open hostility: at least one 'pole' is openly hostile towards others.

Table 1: Multi-level context scenarios for the EU R&I policies for industrial decarbonisation

Global Context 2050	Genuine Collaboration	Limited Cooperation	Open Hostility
Governance	Effective global governance Strong UN	Poles around leading powers willing to co-operate to tackle selected global issues Fragmented UN and IPCC	At least one hostile pole Collapsed UN, no IPCC
Production and innovation systems	Global networks and diffusion of climate solutions SGDs, CSR, ESG	Strategic autonomy Some co-operation to develop solutions Diffusion of climate solutions within regions between poles	Autonomy (close to autarchy) Diffusion of climate solutions among 'friendly' nations
Trade	Strong, effective WTO, climate integrated	Weakened WTO, bilateral agreements (among poles and nations)	Protectionism Trade wars
Security and defence	Expanded and redefined NATO, also for addressing climate crisis No major wars	Geographically confined NATO Proxy wars Defence budgets consume partly climate budgets	Shrunk and consolidated NATO Beyond proxy wars (Taiwan, Ukraine, etc.)

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			Defence budgets consume excessively climate budgets
Dynamic, Resilient and decarbonised EU	**A "Europe Thriving in Collaboration"**	**B "Europe, Respected Partner"**	**C "Fortress Europe"**
Governance	Expanded EU, Sustainable, smart and inclusive Global leader	Stable EU, Competitive, clean and secure	Expansive EU, competitive and secure
Production and innovation systems	Global inter-dependent networks	Strategic autonomy	Autonomy (close to autarchy)
Trade	EU leadership in global trade (excluding terrorist etc countries)	EU-driven strategic partnerships with third countries	Functional Single Market Trade wars
Security and defence	EU with expanded NATO	EU with smaller but united NATO	European defence alliance Direct conflict with a hostile pole

In the workshop plenary session explored how the EU could thrive in industrial decarbonisation in each of the three scenarios. Considering several types of a multipolar world offers an opportunity to think about different types of political and policy stances for example vis-à-vis Russia, China, and the US, which is important to derive future-proof implications and devise a future-proof EU R&I policy strategy. For example, the EU can make cognisant, well-considered preparations for a hostile, as well as a limited or genuinely collaborative relationship with Russia in the coming decades. While the latter may seem difficult to imagine, the option should not be discarded in the longer term. Further, this structure makes it easier to recognise that we need to put more emphasis on the security of the EU, and thus its cohesion. It also implies the need to take a more pronounced ethical stance by the EU when considering various options, actual and potential internal tensions, as well as external threats and challenges. Given how global relations might evolve in the three different world orders, the EU needs to take a position that is both robust about these three possible future worlds, and at the same time compatible with the basic values that the EU aspires to defend. These choices are likely to have crucial repercussions on its R&I policies as well.

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Major common features of the three multipolar worlds and general observations

The world is running on multiple separate tracks in all three multipolar worlds, while the level of cooperation and conflict between the poles varies in the different scenarios. Attitudes towards key determinants of well-being (inequality, freedom of expression, surveillance, ...) are highly divergent between the groups of countries, of which the various poles are composed. Thus, social tensions and inequalities might be high in one 'pole', while in another one a socially balanced development is of high priority. Planetary boundaries – including climate change – might be either neglected or respected in the different 'poles'. These major issues are tackled in markedly different ways in the three types of multipolar worlds, just as access to critical resources.

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State actors, businesses, NGOs, and newly emerging actors might behave in different ways in the same scenario. Competition and collaboration might occur in parallel (both among and inside the 'poles', as well as among the different types of actors). Co-operation in research, technological development and innovation activities (attitudes towards collaboration, as well as its domains, channels and forms, the types of actors engaged) are likely to vary across the scenario sketches. Finally, the actual ways, in which the EU tackles the major challenges and disruptions could vary in the three scenarios, depending on to what extent the various major actors (the EP, the Council, the Commission, big businesses, NGOs, …) can shape the agenda and control the actions needed to implement the decisions. Subsequently, we elaborate further on the three context scenarios.

2.1.1 Context Scenario A) Genuinely collaborative multipolar world in 2050

Given the emerging global challenges, there are strong and successful efforts to set up global governance mechanisms to tackle critical issues (climate, biodiversity, migration, access to energy and other natural resources, regional conflicts, ...). Sustainable development goals (SDGs) are at the top of the agenda. Planetary boundaries are major concerns for all major stakeholders in all poles. Businesses are active partners in global trade, investment, and innovation activities across the poles.

The global system is characterised by genuine collaboration among major powers, supported by a revitalised and effective United Nations. Major global actors—especially the WTO and an expanded, redefined NATO—play crucial roles in facilitating co-operation and mitigating conflict.

The European Union seizes the opportunity to emerge as a dynamic and resilient actor that promotes sustainability, inclusivity, and shared prosperity. The EU is politically and financially strong enough to tackle the major societal and environmental challenges in its own territory with innovative solutions, supported by effective R&I policies, orchestrated between the EU and member states' levels, as well as across the relevant policy domains. These strengths and successes make the EU a leading partner – able to co-shape the agenda – in global collaborations, which, in turn, also creates favourable conditions to these efforts. The EU stands at the forefront of a truly co-operative international system. By harmonising domestic integration with global engagement, the EU helps build a world in which collective progress is both an ambition and a lived reality.

Governance

- The EU expands and reinforces its internal integration, enlarging its membership based on shared democratic values and sustainable development goals.

- Within a robust global governance structure, the EU shapes international norms on climate action, human rights, and responsible technology use.
- Strong partnerships between the EU and international bodies facilitate quick, coordinated responses to crises, whether health-related, environmental, or humanitarian.

Production and Innovation Systems

- Multinational production and innovation systems are seamless and highly innovative, and thus efficient, driven by common sustainability standards. EU firms are recognised leaders in clean tech, renewable energy, and responsible AI.
- Corporate Social Responsibility (CSR) guidelines, largely shaped by EU leadership, are widely adopted around the world.
- Innovation activities flourish, especially in green industries, reflecting public-private partnerships that prioritise job creation, social wellbeing, and environmental stewardship.

Trade

- The World Trade Organization enjoys renewed credibility; disputes are resolved by genuine discussions, reaching consensus.
- The EU champions open markets and invests in new trade alliances, signing comprehensive agreements that include labour and environmental protections.
- Global interdependence in trade thrives, with the EU setting high standards that entice partners to meet stringent requirements for market access.

Security and Defence

- NATO is enlarged and redefined to address modern threats, including cyber attacks, climate-induced crises, and terrorism. A strong EU pillar within NATO helps unify security priorities.
- Joint military-industrial projects and intelligence-sharing agreements foster unprecedented interoperability among allies.
- Although threats exist, conflict is largely contained through collaborative crisis management and widespread diplomatic engagement.

2.1.2 Context Scenario B) Multipolar world with limited cooperation in 2050

Different systems and standards in different parts of the world have solidified, creating several parallel groups of states, which, however, 'talk to each other'. Leading powers of the poles gradually recognise the need for international cooperation (e.g., given major disasters) in tackling the most urgent (and possibly less demanding) issues. Limited multilateral (global) governance mechanisms are in place to tackle these carefully selected critical issues. Success is achieved in tackling jointly some of these issues, lowering the probability of major conflicts. Global trade, investment, and innovation activities across the poles occur, but to a rather limited

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extent. The international context is marked by limited cooperation rather than outright hostility or full-scale collaboration. Global governance is fragmented, with power resting in loosely formed blocs around major nations. The United Nations still exists but operates with diminished authority; bilateral and regional agreements often replace universal solutions.

Within this world, the European Union maintains a stable position, commanding respect on key issues—particularly climate, digital standards, and rule of law—yet not achieving the fully transformative leadership seen in more cohesive times. The EU is politically and financially strong enough to tackle the major societal and environmental challenges in its territory with innovative solutions, supported by effective R&I policies, orchestrated between the EU and member states' levels across policy domains. The outcomes of these efforts, however, are severely constrained by the limited nature of global collaboration. Given its strengths and successes, the EU is a respected partner in global cooperation. Yet, its global cooperations are limited only to selected poles and some issues. The EU retains enough coherence and economic heft to remain a respected partner on the global stage. However, with uneven collaboration worldwide and a focus on regional interests, its influence grows only selectively, pivoting between partnership and guarded autonomy.

Governance

- The EU endures as a unified actor but prioritises internal stability and strategic autonomy. New member states join cautiously, mindful of sovereignty and economic impact.
- The EU remains an indispensable hub for common standards in finance, data governance, and environmental policy, for instance.
- At the global level, major poles (e.g., the US, China, and regional coalitions) negotiate to solve immediate challenges, but deeper collaboration on long-term issues is limited.

Production and Innovation Systems

- The EU strives for strategic autonomy, especially in critical sectors, such as semiconductors, pharmaceuticals, and energy and transport technologies.
- Production and innovation networks become increasingly regional rather than global. While trade continues, key sectors are protected via targeted subsidies and "Buy European" preferences.
- Corporate Social Responsibility norms linger but vary widely across regions; the EU sets relatively high standards internally while coping with less stringent practices elsewhere.

Trade

- The WTO is weakened, with countries turning to bilateral and regional pacts for dispute resolution and market access.

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- The EU signs selective partnership agreements with third countries to secure access to essential resources and advanced technologies, negotiating from a position of moderate strength.
- Trade tensions flare periodically. While not at the level of full-blown "trade wars", smaller disputes over subsidies, digital services taxes, and market access are common.

Security and Defence

- The NATO persists, albeit smaller, focusing on collective defence close to allied territories. European NATO members, including non-EU countries, carry more responsibility for funding and operations.
- Proxy conflicts emerge around strategic hotspots (e.g., cyber domains, resource competition, or regional flashpoints). The EU's role in mediating or participating depends on each member state's stance.
- Though major wars are absent, simmering disputes require constant diplomatic attention, and EU military cooperation is practical but limited by national priorities.

2.1.3 Context Scenario C) Open hostility in 2050 - Fortress Europe

In this scenario, open hostility dominates world affairs. International organisations like the UN and WTO have largely collapsed or lost legitimacy. A few major powers engage in overt or near-direct conflict, while alliances splinter. The EU, under pressure from external threats and global chaos, retrenches into a "Fortress Europe" mindset—prioritising security, self-sufficiency, and inward cohesion above all else.

At least one strong pole wants to impose its values (ideologies), political, and socio-economic structures on others. The expansionist pole/s encourage/s their favoured firms to encroach into other poles to undermine them. Antagonistic ideologies (political systems) cripple global cooperation altogether, making it impossible to tackle global critical issues. That triggers ever more severe major conflicts, leading to open hostility (cold and hybrid regional wars; the fatality of an all-out [nuclear] war is understood, though).

The EU is forced to focus on defence and security issues, at the expense of tackling major societal challenges in its territory. Given its economic strengths, the resources required for significantly improving its defence capabilities might be sufficient, especially if it can form alliances with other poles.

The EU turns inward and militarises to shield itself from a fractious, aggressive global system. Although it protects core European interests and citizens from immediate threats, "Fortress Europe" struggles with diminished global influence, challenging economic trade-offs, and the moral dilemmas that arise when security concerns trump broader humanitarian aspirations.

Governance

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- Membership in the EU is locked or carefully controlled, emphasising internal stability and shared defence. Democratic values remain important, but emergency measures are common, restricting civil liberties in the name of security.
- The EU's governance structures become more centralised, enabling swift action but raising questions about transparency and accountability. Survival needs/ objectives overshadow many idealistic goals.
- Global leadership is minimal, with the EU focusing primarily on its own resilience and crisis management.

Production and Innovation Systems

- Self-reliance is paramount. Strategic industries—especially energy and defence—, as well as developing critical technologies are heavily protected and subsidised. Security and defence considerations rule innovation and production strategies and activities.
- The EU invests massively in domestic manufacturing, reinforcing supply chains behind its borders to mitigate external vulnerabilities.
- Sustainability goals remain on the table but often sidelined by immediate security and economic concerns. Environmental policy can become a casualty of conflict-driven priorities.

Trade

- Many global trade routes are disrupted by conflicts and aggressive protectionism. The EU imposes strict controls at its borders to prevent destabilising imports or outflows of sensitive goods.
- Multilateral trade structures have collapsed, replaced by ad hoc deals with the few remaining neutral or allied regions.
- Global trade wars escalate; sanctions and counter-sanctions are the norm. The EU invests in alternative markets, but overall trade volumes fall sharply.

Security and Defence

- NATO shrinks and consolidates; European countries form a tightly knit defence bloc under an EU-led command structure.
- Armed conflicts break out in various hotspots (e.g., direct clashes with Russia or other hostile powers). Defence spending surges across the EU, at the expense of social and environmental programmes.
- Cyber warfare and other forms of hybrid conflict are widespread. Civil preparedness, from border control to infrastructure resilience, becomes a top priority.

2.1.4 Scenario work under the themes of industrial decarbonisation for sustainable and competitive European Union

The geopolitical issues reflect the complex global and regional challenges the EU must tackle to decarbonise towards sustainable and competitive industrial sectors. Addressing these

requires strategic alliances, resilient supply chains, and proactive engagement in global trade and diplomacy, positioning the EU as a leader – or at least a strong, respected partner in the coalition of the willing – in the green industrial transition. For the group work in the workshop, the issues were clustered into three themes:

- Energy Security and Supply (moderated by Attila Havas, HUN-REN Centre for Economic and Regional Studies)
- Critical Raw Materials for Renewables and Electric Vehicles (EVs) (moderated by Totti Könnölä, Insight Foresight Institute)
- Decarbonisation of Hard-to-Abate Manufacturing Sectors (moderated by Karl-Heinz Leitner, Austrian Institute of Technology)

We related three scenarios to the above-mentioned themes of geopolitics in industrial decarbonisation (Table 2). We worked in small groups on each of the themes, analysing their possible future developments under the scenarios. After the scenario discussion, each group reflected on the implications of today´s decision-making on the EU research and innovation needs and opportunities to attain the EU's industrial decarbonisation by 2050. See below Sections 3–5 for the outcomes of the group work further elaborated to scenario narratives with the help of ChatGPT. Thus, they go well beyond and sometimes even deviate from the discussions in the workshop. These narratives have not been discussed and reflected with the participants; hence they should be treated rather as work in progress that would merit further participatory expert work to reflect their coherence and implications to decision-makers today. Nevertheless, we believe they provide a set of internally coherent scenarios to spark further reflection on future developments.

Table 2: Context scenarios and themes

	Genuine Collaboration	**Limited Co-operation**	**Open Hostility**
Dynamic, resilient and decarbonised EU	*A "EU Thriving in Collaboration"*	*B "EU, Respected Partner"*	*C "Fortress Europe"*
Energy Security and Supply			
Critical Raw Materials for Renewables and EVs			
Manufacturing in Hard-to-Abate Sectors			

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2.2 Roadmapping Approach: Projecting R&I Needs and Opportunities

Roadmapping built on the findings of the scenario work of the specific themes. Based on the findings, participants discussed the identified R&I needs (demand) and emerging R&I opportunities (offer). Emerging R&I areas are further projected towards the future, contributing to the EU's industrial decarbonisation and competitiveness. Drivers and barriers were identified, including policy measures and stakeholders' actions.

In each group, the findings were grouped in related R&I areas contributing to the attainment of the EU's industrial decarbonisation by 2050, within the 'Limited cooperation scenario': The potential of each area to contribute to the EU's industrial decarbonisation and competitiveness was reflected and actions needed were defined. Societal drivers and barriers were identified, S&T advances and their implications to markets were considered. Finally, needed policy measures were elaborated. The outcomes of the group work are presented in sections 3–5 and further elaborated with the support of ChatGPT.

Table 3: Structure for Roadmapping of related R&I Areas in the "Limited Cooperation" Scenario

	Present	**2030**	**2040 and beyond**
Societal drivers and barriers			
Policy and governance			
Market deployment of industry applications			
Science and technology			

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3 Energy Security and Supply – Scenarios and Roadmap

The workshop discussions on scenarios and roadmapping are summarised in Annex 4. These findings were used to elaborate scenario and roadmap narratives with the support of ChatGPT.[3]

Scenario A ("Shared Currents") imagines a highly collaborative Europe, where governance is agile and transparent, innovation thrives through open knowledge-sharing, and trade in green energy feels borderless.

[3] Thus, they go well beyond and sometimes even deviate from the discussions in the workshop. These narratives have not been discussed and reflected with the participants; hence they should be treated rather as work in progress that would merit further participatory expert work to reflect their coherence and implications to decision-makers today. Nevertheless, we believe they provide a set of internally coherent scenarios to spark further reflection on future developments.

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Offshore wind, solar, hydro, and modular nuclear blend seamlessly, supported by hydrogen infrastructure and real-time balancing markets. Security rests on collective deterrence, with NATO cyber brigades and joint patrols protecting energy flows. Scenario B ("Guarded Flows") is more cautious: the EU pursues strategic autonomy with strong but flexible governance, significant renewable and nuclear deployment, and heavy reliance on subsidies to fill technological gaps. Trade is managed through bilateral deals rather than global frameworks, making energy markets prone to volatility. NATO's role narrows to regional defence, while reserves and cyber defences bolster resilience. Scenario C ("Iron Grid") depicts a defensive, inward-looking Europe under emergency governance. The state commands energy supply, citizens endure rationing, and industry adapts to restrictive operating schedules. Trade shrinks to monitored corridors with close allies, and energy security is militarised, with drones, frigates, and compulsory household storage forming the backbone of a sovereignty-first system.

Subsequently, the roadmap shows how Europe might evolve from today's turbulence to long-term resilience: the 2020s are marked by innovation and populist tensions, the 2030s by deep integration of infrastructure and policy as decarbonisation aligns with security, and the 2040s by net-zero energy as the unquestioned baseline. By then, Europe's energy system is resilient, market-driven yet politically anchored, and science continues to push the technological frontier.

3.1 Scenario A: Shared Currents – Europe's Collaborative Energy Shield

Governance

A nimble European Energy Council steers policy in lock-step with the UN's revitalised climate governance. Regulations land as concise "green orders" agreed in hours by video vote across capitals. Citizens follow every step on open dashboards, keeping ministers honest.

Production and innovation systems

Pan-European offshore wind rings the North and Baltic Seas and blends seamlessly with Spanish sun, Norwegian hydro and Ukrainian small-modular reactors. Electrolysers hum along the Atlantic coast, turning surplus power into green hydrogen that slides through the 12-nation "HydroLoop" pipeline. R&D thrives on

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open patents; Catalan start-ups license Danish turbine software overnight, while Hungarian labs trial next-gen sodium batteries with Portuguese cork insulators.

Trade

Energy flows feel borderless. Under the WTO-brokered "Zero-Carbon Commons", green electrons, hydrogen, and renewable-based e-fuels cross customs with a single QR code. Africa and Europe co-own solar parks in the Sahel; in return, EU storage firms ship second-life batteries to Lagos tram lines. Short-cycle spot markets balance weather blips in minutes, shaving pricing shocks to trivia.

Security and defence

NATO's climate taskforce guards cables, pipelines, and orbital solar farms with joint cyber brigades and uncrewed patrol cutters. Because every partner shares transparent stock data, sabotage earns no windfall, and deterrence is mostly digital. Defence budgets hold steady as resilience spending soaks up the heavy lifting.

3.2 Scenario B: Guarded Flows – Strategic Autonomy in the Continental Power Matrix

Governance

Brussels prizes strategic autonomy yet keeps one eye on allies. An Energy Resilience Board sets minimum storage levels and crisis protocols, while member states retain leeway to cut bespoke deals. Emergency powers exist, but parliaments still debate them under the glare of public streaming.

Production and innovation systems

Europe covers two-thirds of its demand with continental renewables and advanced modular nuclear, but critical gaps persist. Poland leans on domestic lignite-to-hydrogen pilots; Italy runs giant gravity-storage towers in Alpine quarries. Subsidies swing behind "dual-chemistry" battery lines that swap scarce cobalt for manganese in a fortnight.

Trade

With the WTO weakened, energy links hinge on rolling five-year pacts. The EU exchanges turbine tech for Chilean green ammonia and barters Spanish desalination IP for Moroccan solar baseload. Border carbon checks bite hard, yet trusted partners gain "fast-lane" status. Prices spike after each renegotiation.

Security and defence

A leaner NATO focuses on the near abroad. EU corvettes escort LNG shuttles through the Arctic summer route, and cyber units shadow refinery-control systems against ransom gangs. Sixty-day strategic reserves of gas, hydrogen, and critical minerals sit in granite caverns in Sweden, rotated by algorithm to curb spoilage.

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3.3 Scenario C: Iron Grid – Fortress Europe's Self-Sufficient Supply Doctrine

Governance

Permanent emergency statutes give a central Energy Commissariat sweeping command over supply. Public briefings are terse and compulsory: grid status, ration tiers, blackout maps. Civil liberties bend under the weight of survival, though elections still draw a grudging turnout.

Production and innovation systems

Autarchy rules. State-owned consortia blanket the North Sea with colossal wind arrays feeding hydrogen cracker-plants on the Dutch coast. Urban roofs bristle with mandatory solar panels. Heavy industry shifts to night-shift only, swallowing curtailed power when it is cheap. Direct-air-capture units outside Ruhr steelworks funnel captured CO_2 into synthetic diesel for the strategic fleet of military vehicles.

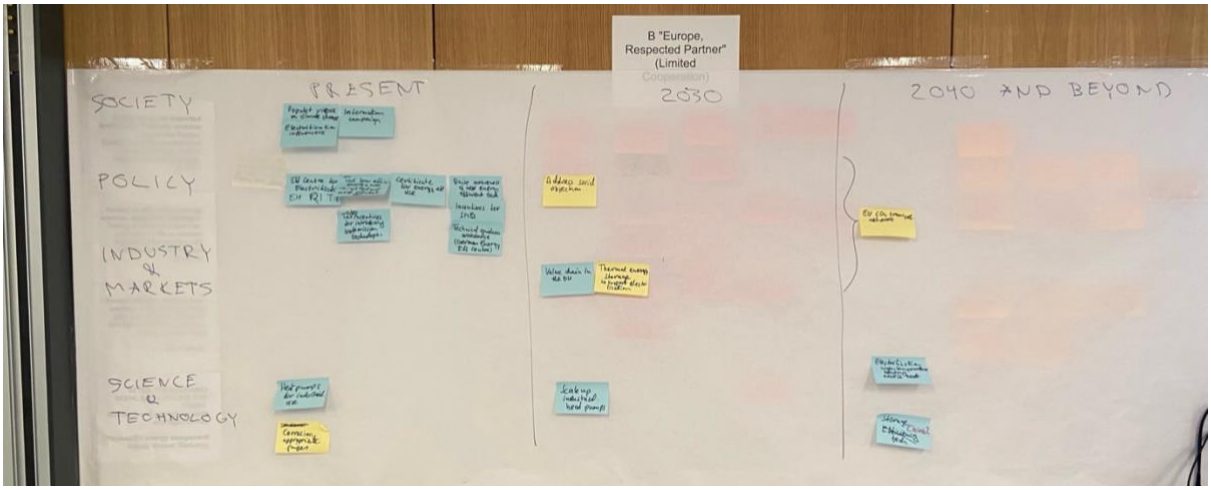
Trade

Most borders bristle with sensors. Limited corridors stay open to friendly neighbours for bartered uranium and rare earths, each convoy tracked by armed drones.

Security and defence

European Defence Forces fuse army engineers with grid operators. Drone swarms guard pylons; naval frigates shadow every ammonia tanker crossing the Med. Compulsory household "black-box" batteries try to keep lights on during outages, when military sites take precedence. The public mood is austere yet stubbornly united: energy equals sovereignty, and sovereignty is non-negotiable.

3.4 Roadmap: Energy Security & Supply



Present – the turbulent 2020s

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Rising bills feed a populist backlash against green policy, yet a new tribe of "electrification influencers" keeps climate ambition on the front pages. Brussels responds with a lean *Centre for Industrial Electrification* and brisk taxes on waste heat, sweetened by SME vouchers and hands-on advice modelled on German efficiency centres. Early movers in industry fit 10 MW high-temperature heat-pumps and bolt thermal-storage blocks onto ageing steam loops, turning price spikes into market advantage. In the lab, engineers harden hydrogen pipes against corrosion and trial carbon-capture solvents on refinery flue-gas.

2030 – the integration decade

By the decade's end most citizens accept that security and decarbonisation are two sides of the same coin; resistance narrows to nimby rows over new pylons. An EU-wide CO_2 pipeline and storage grid reaches its first hubs, while a digital permit portal cuts the time needed to complete cross-border energy projects from years to weeks. Power-price rebates now hinge on plant-level efficiency certificates, creating a clear, bankable signal for retrofit finance. In the marketplace, gigawatt electrolyser parks spring up beside offshore wind and modular SMRs fill inland gaps. Industrial heat-pumps breach 400 °C; solid-oxide electrolysers slice hydrogen costs, and AI-driven demand response shaves double-digit peaks. Policy has become the great orchestrator: social licence unlocks bold rules, rules de-risk investment, and scaled deployment showers data back onto scientists.

2040 and beyond – resilience as standard

Net-zero energy is no longer a goal but the default. Households swap power with the grid on dynamic tariffs and accept occasional "dark-sky hours" while storage re-charges. A fully meshed *EuroGrid*, laced with seasonal hydrogen caverns, is now treated as critical defence infrastructure. Real-time carbon quotas trade alongside electrons, and strategic stockpiles guard rare catalysts. Markets mature: green ammonia sails to Asia, surplus wind is stored as long-duration heat bricks, and local symbiosis exchanges waste heat and captured CO_2 between neighbouring plants. Science keeps the edge – super-conducting cables slash losses, plasma furnaces deliver zero-carbon metals, and gigaton-scale direct-air capture feeds synthetic-fuel clusters. Public trust cements political will, policy guarantees demand, thriving markets fund ever-bolder research – and Europe's lights stay on, come what may.

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4 Critical Raw Materials – Scenarios and Roadmap

The workshop discussions on scenarios and roadmapping are summarised in Annex 5. These findings were used to elaborate scenario and roadmap narratives with the support of ChatGPT. [4]

Three scenarios provide alternative views on Europe in 2050 standing at a crossroads defined by the metals and minerals that power its batteries, turbines and data centres. “Circular Abundance” imagines a continent that turns critical raw materials into a shared commons, trading scrap as smoothly as streaming data. “Strategic Flexibility” shows an agile, deal-making Europe that juggles substitution, bilateral swaps and rapid chemistry pivots to keep the lights on in a choppy multipolar world. “Siege of Scarcity” warns of a fortress mindset where every shipment is armed-guarded, innovation strains under state control. Together, the three scenarios sketch the spectrum of possible futures—co-operation, calculated pragmatism and defensive autarky—against which today’s policy choices can be related to.

The roadmap of Europe’s journey from “Patchwork Pioneers” (2025) to “Circular Abundance” (2040+) charts a transition from fragmented, contested raw material policies to a mature, self-reinforcing circular economy. Initial resistance to mining pushes innovation in urban-mining, material passports and design-for-disassembly, while by 2030 shared platforms, unified secondary-materials markets and supportive

[4] Thus, they go well beyond and sometimes even deviate from the discussions in the workshop. These narratives have not been discussed and reflected with the participants; hence they should be treated rather as work in progress that would merit further participatory expert work to reflect their coherence and implications to decision-makers today. Nevertheless, we believe they provide a set of internally coherent scenarios to spark further reflection on future developments.

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procurement rules foster trust, scale and investment. By 2040, nearly half of critical metals come from recycling or substitution, governed by streamlined digital frameworks, as doughnut economics, advanced clean-tech and radical science drive resilience, prosperity and Europe's strategic autonomy.

4.1 Scenario A: Circular Abundance – Europe's Collaborative Critical-Raw-Materials Commons

Governance

The Union is slim yet lively: a lean Brussels secretariat manages pan-European rules while a "Materials Council" elected by member-state parliaments steers strategy. Africa, Latin America and Australia sit as equal observers, given they co-own the Global Secondary Materials Register. Regulation is light-touch but ruthless on transparency. Every policy is published as a two-page brief, debated in public livestreams and amended by real-time citizen polls. The result is trust: voters see how cobalt quotas, carbon caps and recycling targets fit together, and lobby in minutes when tweaks are needed.

Production and innovation systems

Critical metals are treated like water once was: essential infrastructure. Urban-mining plants cluster round old steelworks; micro-smelters convert scrap magnets to neodymium ingots in hours; biorefineries crack black-mass sludge into battery-grade nickel without solvents. Subsidies are passé— instead, open-source patents and "first-loss" insurance lure private cash into early-stage trials. Universities share kit on a cloud-booked rota, so a start-up in Vilnius can prototype an iron-nitride motor one week and a sodium-ion anode the next. Failure is quick, cheap and logged for all to learn.

Trade

Containers move on the same blockchain that tracks product warranties. Customs mainly check radiation levels; everything else is settled by smart contracts before the ship docks. Tariffs are near-zero for anything provably circular, higher for virgin ore with unpriced externalities. The few disputes that arise go to a fast,

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AI-assisted tribunal hosted in Reykjavík—cases average three days. Critical-mineral prices swing within tight bands, damped by real-time inventory data that spot shortages weeks ahead.

Security and defence

Because supply is diversified and transparent, raw materials are no longer a flashpoint. Europe's defence posture focuses on cyber-shielding the register and patrolling sea lanes for piracy, performed by uncrewed trimarans under joint EU-AU command. Armed conflict over mines has fallen sharply; intelligence shows militants cannot profit when every shipment is tagged, tracked and insured only if untainted by coercion. Defence budgets shrink, yet Europe's deterrent credibility rises: sabotage yields no windfall, so the temptation fades.

4.2 Scenario B: Strategic Flexibility – Europe's Critical-Raw-Materials Balancing Act

Governance

Power is layered and pragmatic. Brussels sets ceilings on strategic-metal stockpiles, but individual states strike their own bilateral deals. A rotating "Resource Quartet" of Germany, Spain, Poland and Sweden brokers common positions before big moments—think OPEC meetings with a Brussels accent. Consultation is swift but messy; WhatsApp diplomacy sets the tone, and formal communiqués follow later. Citizens accept the hustle, valuing agility over elegance.

Production and innovation systems

Industrial strategy is a bar-bell: heavyweight subsidies for lighthouse projects—Finland's rare-earth refinery, Portugal's lithium brine fields—paired with agile grants for substitution tech. Gigafactories carry modular tool-heads so they can flip from cobalt-rich to nickel-rich chemistries inside a fortnight. Recycling capacity exists but lags demand, forcing periodic "magnet holidays" when auto plants idle for upgrades. Engineers treat volatility as sport, swapping alloys and dopants the way chefs change menus.

Trade

Europe signs rolling five-year exchange pacts: lithium for wind-turbine blades, gallium for biotech IP. Nothing lasts forever, everything is renegotiated early. A digital "materials passport" tracks each gram from mine or waste-bin to end-of-life, and Brussels slaps steep re-entry fees on scrap that leaves the Single Market but returns unprocessed. Ocean freight sails in lightly armed convoys; insurers demand it after last decade's Strait of Malacca hijacks. Prices spike twice a year on average, and CFOs budget storm funds accordingly.

Security and defence

Supply disruption tops the threat matrix. EU-flagged corvettes escort ore carriers, while satellite constellations watch rail lines from the Congo to the Baltic. Defence ministries stock a ninety-day buffer of dysprosium and niobium, rotated through military-grade battery plants. Cyber units guard refinery process controls— ransomware once shut a Swedish separator for four days and cost €3 billion in spot-market panic. Diplomats do heavy lifting: every minerals deal bundles clauses on joint patrols and intelligence swaps, binding partners into co-dependence rather than loyalty.

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4.3 Scenario C: Siege of Scarcity – Fortress Europe and the Militarised Critical-Raw-Materials State

Governance

Emergency rule, renewed annually, grants Brussels sweeping powers over extraction and allocation. A central "Materials Commissariat" sets production quotas, issues compulsory licences and can requisition private stock with 24-hour notice. National governments comply under threat of sanction funds being frozen. Parliamentary oversight survives only on paper; most debates occur in closed committees citing national-security privilege.

Production and innovation systems

State-owned consortia run every critical-metal asset from Lapland iron to Balkan borates. Autonomous drills cut ore in glacial pits, guarded by armed drones. Fab lines in Toulouse and Chemnitz have been retro-fitted to accept lower-purity feedstock—performance drops, but anything that keeps the lights on is good enough. R&D tilts to radical substitution: ceramic superconductors, aluminium-graphite batteries, ferrite motors. Progress is slow; engineers burn out under relentless pressure, and brain-drain to freer markets is steady despite exit controls.

Trade

External commerce is rationed and escorted. Ore rarely crosses EU borders unless under swap-deals for grain or antibiotics. Sanction lists change monthly; one week Chile is friendly, the next it's blacklisted for withholding molybdenum. Smuggling thrives in the Adriatic, but the volumes are small. A punitive export ban on refined germanium has back-fired, prompting Asian buyers to copy-cat blockades on hafnium. World Trade Organisation rules are dead; arbitration happens at gunpoint or not at all.

Security and defence

Supply chains are militarised. The EU Navy's "Blue Shield" escorts every high-value convoy; loss of a single rare-earth carrier counts as a hostile act. Special Forces secure Arctic and deep-sea operations, fending off both pirates and eco-saboteurs. Civil protection plans treat material shortages like natural disasters— rolling blackouts, priority lanes for hospital drones, compulsory metal-return schemes. Defence industries enjoy first call on dysprosium, gallium and titanium; civilian quotas take what remains. European society endures, but every headline reminds citizens that sovereignty now hangs on grams of hidden metal.

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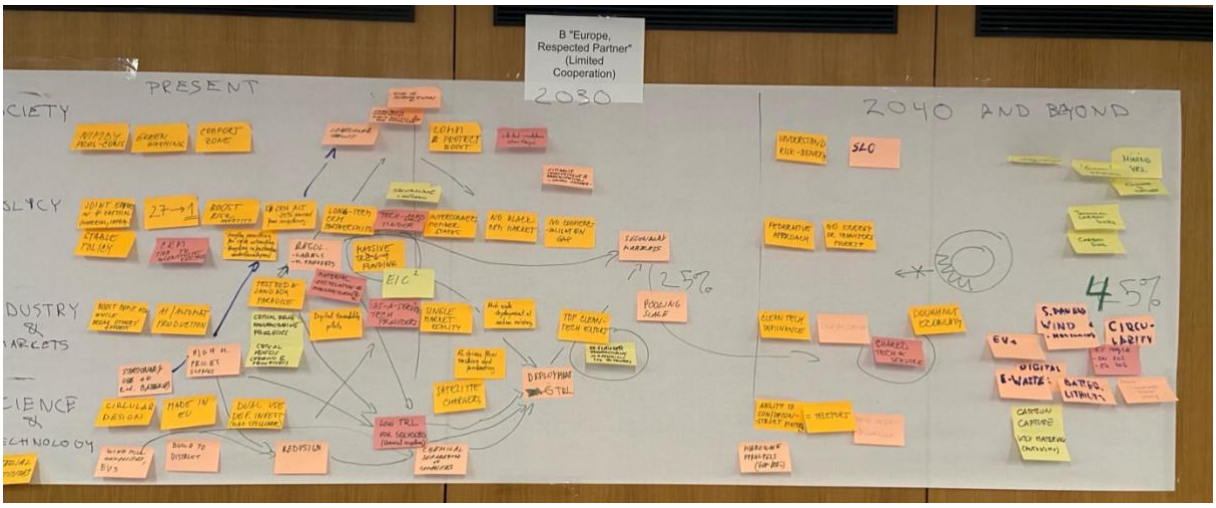
4.4 From Patchwork Pioneers to Circular Abundance: Europe's Critical Raw Materials Roadmap



Present (2025) — "Patchwork Pioneers". Europe is still wrestling with nimbyism: citizens demand green goods yet bristle at new mines, so policymakers rush out the EU Critical Raw Materials Act and toy with a mild CRM tax to tip the maths towards circular use. Tight supply keeps prices high, encouraging first-of-a-kind "urban-mining" plants, digital material passports and AI-guided disassembly lines, while labs tinker with nickel-light batteries, low-temperature solvolysis and "build-to-deconstruct" product design. Social scepticism slows bricks-and-mortar projects, yet that very resistance forces clearer rules, and the promise of dependable policy gives innovators just enough confidence to scale their pilots.

2030 — "Connected Commons". By now discarded phones, e-bikes and heat pumps flow through citizen-share platforms that trade waste for credits, boosting trust in recycled metal and softening local opposition. EU capitals stitch a single secondary-materials market, shrinking black-market trading and trimming permitting from years to months; public procurement rules snap up recycled feedstock, closing the commercialisation gap. Mid-scale hubs cluster around ports, gigafactories swap tool-kits to jump from cobalt-rich to manganese-rich chemistries in a fortnight, and AI forecasts steer material streams in real time. Widespread consumer faith legitimises tougher rules, those rules de-risk private investment, and bigger plants feed data back to scientists, accelerating the next wave of process tweaks.

2040 and beyond — "Circular Abundance". The public conversation shifts from *why* to *how far*: social-licence frameworks balance mining risk and benefit, and carbon-sink initiatives become a point of pride. Policy ambition leaps to sourcing almost half of critical metals from European recycling and substitution, enforced by universal material passports and smart contracts overseen by a lean, livestreamed "Materials Council". Markets run on doughnut economics—leasing trumps ownership, high-entropy alloy printers and autonomous sorters wring fresh value from what used to be slag—and clean-tech exports dominate. Science stretches the frontier with gigaton-scale carbon capture feeding syn-fuel reactors, ceramic superconductors that bypass rare earths, and drones patrolling e-waste mountains. Confidence breeds bolder

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standards, predictable rules anchor global investment, and booming circular markets bankroll still more radical science, locking Europe into a self-reinforcing loop of resilience, prosperity and strategic autonomy.

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5 Manufacturing in Hard-to-Abate Sectors – Scenarios and Roadmap

The workshop discussions on scenarios and roadmapping are summarised in Annex 6. These findings were used to elaborate scenario and roadmap narratives with the support of ChatGPT. [5]

Three scenarios – albeit extreme ideal types – were developed for the European heavy industry corridor:: in "Hydrogen-Driven Heavy Industry" the continent glides on a transparent, treaty-bound hydrogen grid that knits yards and kilns from Bergen to Bari; in "The Modular Fabrication Model" ultrasmart, plug-and-play plants swap feedstocks as easily as smartphone apps, smoothing shocks but demanding constant diplomatic choreography; while in "Steel-Curtain Sovereignty" Europe retreats behind data-walled borders, running fortress foundries on captured carbon and rationed power, sacrificing openness for absolute security. Together these scenarios trace the outer limits of how governance, technology and geopolitics could remake manufacturing in today's hard-to-abate sectors—revealing trade-offs.

The roadmap on Europe's heavy industry shows how the sector could undergo a profound transformation: citizens' climate demands and EU policy clarity are driving early adoption of electrified kilns, high-temperature heat pumps and carbon-removal pilots, with grassroots pressure unlocking capital for low-carbon steel, cement and plastics. By 2030, hydrogen hubs, circular-steel clusters and modular automation make clean production mainstream, supported by strong public finance, trade pacts and trusted data that build social acceptance. By 2040, Europe's "Industrial Commons" exports ultra-low-carbon materials globally, powered

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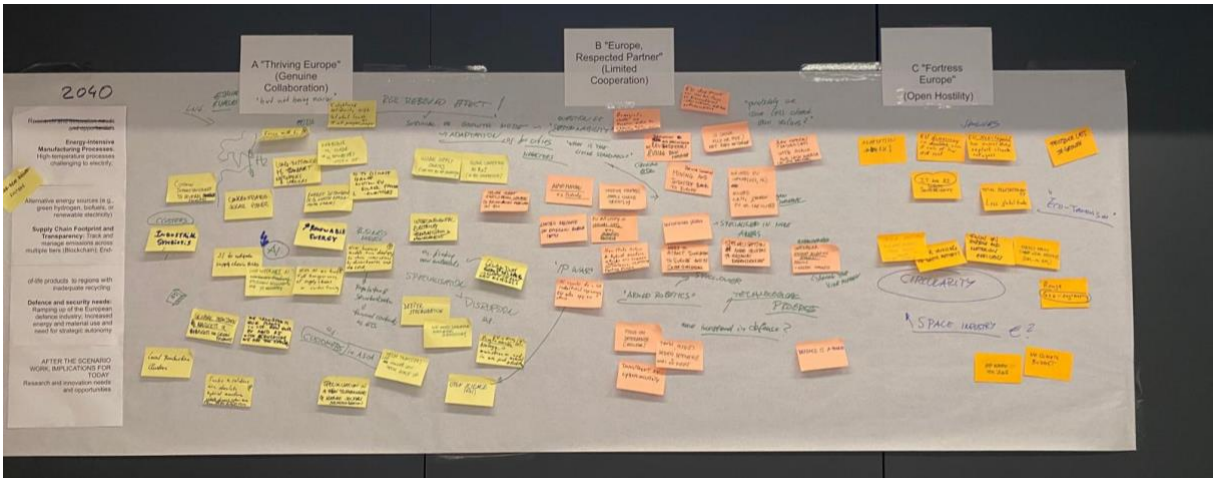
by abundant renewables, orbital data and fully integrated carbon removal, proving that climate ambition and industrial competitiveness can thrive together.



5.1 Scenario A: Hydrogen-Driven Heavy Industry

Governance
Brussels now chairs the "Net-Zero Council", where ministers log in daily to approve single-page edicts. The UN's revived Industry Compact backs every rule, so permits, subsidies and carbon caps look identical on the global level. Citizens monitor the lot on public ledgers; lateness shames a minister faster than a vote of no confidence.

Production and innovation systems
Steel, cement and chemicals flow through a continent-wide "Electric Arc Spine". Scandinavian surplus wind propels Spanish green-hydrogen furnaces before lunch, while Iberian solar tops up Polish plasma kilns after tea. Pilot plants are born in hackathons: a Czech micro-reactor for lime today, a Portuguese algae-based binder tomorrow. Intellectual property is pooled; firms earn points for sharing blueprints and spend them on royalty-free patents from the same vault.

Trade
Every product carries a live carbon passport. Container cranes flash green when the ledger shows "below-benchmark" emissions and slap a levy on the rest. Europe swaps lightweight composite rebar for Australian nickel and sells AI-tuned pyrolysis tech into Africa's booming circular-cement belt. The WTO's Zero-Carbon Fast Track clears paperwork in thirty seconds—enough time to sip an espresso.

Security and Defence
NATO's Climate Task Force patrols pipelines, data cables and offshore electrolysers with uncrewed corvettes. The alliance drills for "cyber-blast" scenarios: a hack, not a bomb, could still freeze a hydrogen grid. But deterrence works; would-be saboteurs know sabotage gains them nothing—stockpiles and repair drones close most gaps within hours.

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5.2 Scenario B: The Modular Fabrication Model

Governance
The EU keeps cohesion by practising "strategic elasticity". A light Brussels framework sets emission ceilings; member states pick the route—bio-char in Finland, geothermal kilns in Italy, CCS in Germany. Emergency powers exist but require sunset clauses, debated live on encrypted parliamentary feeds.

Production and innovation systems
Gigafactories sit behind bar-bell policy: megagrants for flagship hydrogen steel in Sweden and nimble vouchers for every start-up that can shave a kilowatt-hour off clinker. Plants are modular; when cobalt prices jump, robots swap cathode lines before the weekend shift. Supply-chain AI gives a week's warning of any shortage, but firms still budget for one "carbon storm" quarter a year.

Trade
The WTO creaks, so Europe relies on rolling five-year covenants. It trades Spanish low-carbon ammonia for Chilean lithium, Hungarian heat-pump patents for Moroccan green phosphates. Carbon-adjustment at the border is strict but negotiable—trusted partners earn fast-lane status, others queue behind. Prices lurch after each renegotiation; CFOs keep storm chests full.

Security and Defence
A slimmed NATO hugs Europe's perimeter. EU corvettes escort ammonia tankers through the Med while cyber brigades shield refinery control rooms from ransom gangs. Ninety-day strategic stores of nickel, molybdenum and basalt fibre sit in alpine caverns, rotated by algorithm to curb spoilage.

5.3 Scenario C: Steel-Curtain Sovereignty

Governance
Permanent emergency statutes empower a new "Industrial Commissariat" to requisition energy, labour and data within hours. Elections still happen, but civil liberty bends to the twin mantras of survival and self-sufficiency. Transparency is rationed: the public sees grid status, little else.

Production and innovation systems
State-owned trusts run every strategic furnace from the Ruhr to the Rhônes. Night-shift steel soaks up curtailed offshore wind; daylight is reserved for civilian grids. Cement plants inject captured CO_2 straight into on-site mineralisation pits. R&D is relentless but closed—engineers work under oath, swapping titanium for basalt, cobalt for iron-nitride, however long it takes.

Trade
Borders bristle with sensors. Only two corridors stay open: one for uranium from friendly Canada, another for rare-earth scrap from the Balkans. Every convoy travels under drone escort; a lost trailer is treated as a hostile act. Export bans on fuel-cell stacks hurt the treasury but keep propulsion secrets at home.

Security and Defence
The EU Defence Force fuses army engineers with grid operators. Drone swarms guard pylons; submarine cables wear armoured jackets. Civil defence drills treat material shortages like natural disasters—rolling

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brown-outs, compulsory battery returns, priority lanes for hospital drones. Society is austere yet unflinching: industry equals sovereignty, and sovereignty is non-negotiable.

5.4 Roadmap on Electrifying the Heavyweights: Europe's Path to Net-Zero Manufacturing

Present: foundations laid, sparks of change
Climate-savvy citizens, restless for action, push firms to publish real-time footprints and turn recycling into a social badge of honour. Brussels is meeting expectations with predictable carbon prices, fast permits and open-access R&D that rewards risk-takers. Early movers secure public contracts for low-carbon steel, cement and plastics, while carbon-removal pilots book their first revenues thanks to AI-verified storage. In the labs, electrified kilns, high-temperature heat pumps and retrofitted crackers sprint to demonstration scale, buoyed by a new wave of talent drawn to Europe's open science culture. Grass-roots pressure legitimises bold regulation; that clarity de-risks private capital, which drags fresh hardware out of the lab and proves that heavy industry can thrive on electrons, not fossils.

2030: the integration decade
Public support stays solid as hydrogen hubs and circular-steel clusters deliver visible jobs and pride. The EU finances SME retrofits with a post-COVID-style bond; border carbon rules and converging international prices end leakage, while renewable-heat targets and resource diplomacy lock in secure supplies. Circularity becomes mainstream: scrap quotas in cement, mandates for reusable fuels and a flourishing offsets market for scaled carbon removal. Five-year trade pacts exchange green ammonia for lithium and phosphate rights. On the ground, hydrogen replaces coke and gas in prime furnaces; modular automation lets plants switch feedstocks within a weekend; AI-directed industrial symbiosis dovetails waste heat and CO_2 streams into neighbouring processes. Trusted data smooths social acceptance, emboldening policymakers to tighten ceilings, which guarantee demand, attract scale finance and pour operational insights back into the next tech iteration.

2040 and beyond: resilient, zero-carbon heavy industry

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Buying negative-emission products is now second nature, and GDP growth has ceded the spotlight to well-being and climate security. Europe's "Industrial Commons" rests on a world-class science base and a manufacturing core that exports ultra-low-carbon alloys and biotech binders worldwide. Carbon removal is fully embedded in law, geo-engineering research is regulated but allowed, and space-based factories begin feeding ultra-pure feedstocks back to Earth. Cheap, abundant renewables drive plasma furnaces and high-entropy alloy printers, while direct-air capture loops seamlessly into synthetic-fuel production. Electricity is too plentiful to meter. Societal demand for restorative industry anchors political will; long-term carbon value is bankable policy; assured markets bankroll mega-scale innovation; and science, supercharged by planetary and orbital data, finally closes the emissions loop. Heavy industry—once "hard-to-abate"—now stands as Europe's loudest proof that climate ambition and competitiveness can march in lock-step.

6 Conclusions

The workshop structured *"what-if"* geopolitical context scenarios in plenary, and co-constructed in break-out sessions thematic scenarios before switching to a back-casting/ road-mapping sprint, where teams mapped priority research and innovation levers, time-sequenced milestones, and critical policy enablers. This integrated *context and thematic scenario work plus road-mapping* workflow proved efficient at converting long-range uncertainty into actionable R&I agendas. Its low-tech, dialogue-centred design makes it readily transferable to other domains (e.g., circular-economy transitions, digital sovereignty, climate-adaptation finance). Embedding this type of work as a standing module in EU and national programme formulation would help institutionalise anticipatory thinking, ensure that R&I investments remain robust across multiple futures, and continually refresh cross-sector stakeholder networks.

The workshop leaves no doubt: the EU's race to net-zero will be played in a hard-edged geopolitical arena. Whether the world turns truly collaborative, reluctant to cooperate, or openly hostile, energy, materials, and heavy industry sit on the top of the agenda. The discussions showed that resilience and decarbonisation are now aligned goals. The EU therefore, needs clean-tech supply chains that can flex with shocks, a grid designed as critical defence infrastructure, and industrial processes able to swap feedstocks overnight. In short, future competitiveness will depend less on today's cost curves and more on how fast our systems can pivot when the global weather changes.

Three levers stood out for research and innovation. First, scale green hydrogen, long-duration storage and AI-optimised electro-markets so electrons and molecules move across borders as simply as data. Second, close the raw-materials loop: mine the urban stock, build plants that treat scrap like ore, and bankroll chemistry that cuts out scarce metals altogether. Third, turn heavy industry into a modular "plug-and-play" platform—electrified kilns, hydrogen in direct reduced iron production, high-entropy alloy printers—so the EU can make steel, cement, and chemicals even if trade routes freeze. Each lever works best when knowledge is shared, regulation is quick and carbon footprints are tracked in real time.

For the EU's R&I policy this means a pivot from cautious projects to bold, scenario-tested portfolios. Horizon Europe's successor should twin every big grant with a stress-test against multiple geopolitical futures, back open-source patents that widen options for the EU, and fund pilot lines that can be repurposed at speed. Defence, trade, and climate teams must sit at the same table when calls are drafted, while public procurement and emissions trading system (ETS) revenues give innovators the early markets they need. Agile, mission-driven programmes, deep data transparency, and a sharper focus on circular substitution will place the Union where it needs to be: ahead of the curve, whatever the world throws at it.

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Annex 1: Workshop Agenda

Time: 10-11 April, 2025

Location: Calle Orense, 34, Madrid, Spain, https://maps.app.goo.gl/YZSLCk1ABLSsdS1x7

Workshop Agenda Day 1 – Scenarios

Timing	Activity	Purpose	Setting
12.00-13:00	Registration and tapas lunch	Registration and networking	Venue
13.00-13.15	Introduction to the workshop	Sharing information on background and approach of the workshop	Plenary
13:15-13:30	Keynote: Marcos Escudero, Ministry of Industry and Tourism of Spain, Head of Industrial Policy Division: Advances in Industrial Decarbonisation in Spain	Presentation providing the context Q&A	Plenary
13.30-13:45	Keynote: Ignacio Asenjo, DG ENER, European Commission: Geopolitics and Industrial Decarbonisation in the EU (TBD)	Presentation online providing the context Q&A	Plenary
14:00-14:15	Introduction to the scenario work	Introduction to the methods, themes and global context scenarios Q&A	Plenary
14:15-15:00	Common scenario work	Reflection on cross-cutting themes vis-a-vis EU plans for industrial decarbonisation in different scenarios	Plenary
15:00-15:30	**Coffee Break**		

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15:30-17:30	Scenario work on specific themes	Reflection of specific themes vis-a-vis EU plans for industrial decarbonisation in different scenarios	Small groups
20.00	**Informal Dinner** The cocktail in the restaurant La Reinosa, Av. General Perón 13 (Madrid)		

Workshop Agenda Day 2 – Roadmapping

Timing	Activity	Purpose	Setting
8:30-9:00	Registration	Registration	Venue
9:00-9:15	Welcome	Introduction to the workshop and day 2	Plenary
9:15-9:45	Keynote: Evgeni Evgeniev & Antonio Ferrandez Garcia, DG RTD, European Commission, R&I and Industrial Decarbonisation in the EU	Online presentations providing the context Q&A	Plenary
9:45-10:00	Key visions and messages from the scenario work on Day 1	Sharing the scenario findings of small group work	Plenary
10:00-10:15	Introduction to roadmapping on R&I needs and emerging areas	Roadmapping emerging R&I areas	Plenary
10:15-11:00	Roadmapping on specific themes	Roadmapping on specific themes for emerging R&I areas	Small groups
11:00-11:30	**Coffee Break**		
11:30-12:30	Roadmapping cont.	Roadmapping emerging R&I areas	Small groups
12:30-13:00	Presentations and feedback	Sharing the roadmapping findings and experiences from the small groups	Plenary

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13:00-13:30	Wrap up Futures4Europe platform, Radu Gheorghiu, Eye of Europe	Feedback, next steps and further EoE opportunities	Plenary
	End of Workshop		

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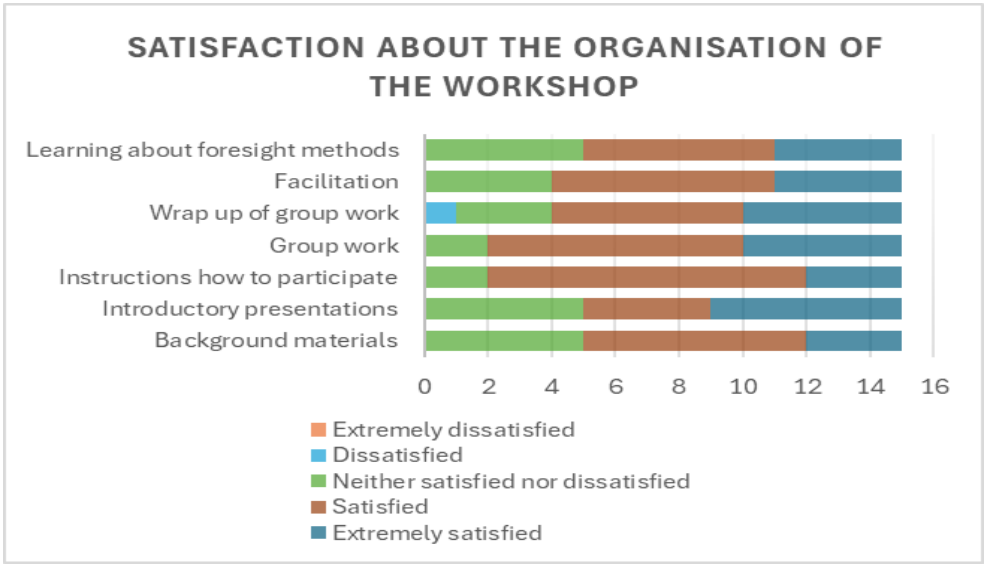
Annex 2: Participant Feedback

Post workshop survey

Participants answered a survey at the end of the workshop. Organisational aspects as well as outcome-related questions were included. 15 participants completed the survey. Not every question has 15 answers, given that many of them were not compulsory.

How satisfied are you with the following aspects of the organisation of the workshop? (1 extremely dissatisfied > 2 dissatisfied > 3 neither satisfied nor dissatisfied > 4 satisfied > 5 extremely satisfied)



How satisfied are you with following the following aspects related to the topic and outcomes of the workshop? (1 extremely dissatisfied > 2 dissatisfied > 3 neither satisfied nor dissatisfied > 4 satisfied > 5 extremely satisfied)

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Annex 3: List of participants

Surname	Name	Organisations
Álvarez	Rodrigo	ASPAPEL
Bañares	Susana	Redeia
Barrenetxea	Elena	Insight Foresight Institute
Belona	Silvia	DGAE
Blasko	Ronals	VAIA
Cuesta	David	NTT Data
Díaz López	Fernando	HEC Paris
Escudero	Marcos	MINTUR
Evgeniev	Evgeni	DG RTD
Ferrandez	Antonio	DG RTD
Friberg	Lars	VINNOVA
Gerber	Pedro	IMDEA
Gonzalez	Nieves	CDTI
Havas	Attila	HUN-REN CERS
Jariego	Francisco	IFI Council
Käär	Karin	Tallin Tech
Könnölä	Totti	Insight Foresight Institute
Leitner	Karl-Heinz	AIT
Linares	Pedro	ICAI Comillas University
Mortera	Alicia	IMDEA
Nieto	Oscar	Mondragon University
Polak	Martin	VAIA
Rimini	Michele	OECD
Suleau	Marie	SPW Wallonie
Tavares	Marilda	DGAE
Trifonova	Mariana	EPI Bulgaria
Tukianinen	Taina	University of Wasa
Woeffray	Oliver	ARUP

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Annex 4: Results Group 1: Energy

TABLE 7 OUTCOMES FROM SCENARIO WORK, GROUP 1.

	Genuine Collaboration	Limited Cooperation	Fortress Europe
Dependency on imported fossil fuels.	CCUs and DAC	STEEPV; 100% renewables in generation; incremental taxes on oil and gas; CCUs and DAC tech deployed/adapted in collaboration with strategic partners (Canada, Japan, UK, India, etc); re-start energy relations with Russia; breakthrough in internal collaboration on nuclear fusion commercialisation.	Re-colonisation vs equitable co-operation; value-based co-operation vs transactional co-operation; development of work on energy communities and energy hubs as much as possible.
Access to alternative energy sources, especially hydrogen.		Joint tech development (renewables, mining, etc); Africa as a partner to produce hydrogen; industry-specific onsite energy valorisation; EU-South Korea joint R&I on green hydrogen, specifically hydrogen-powered vehicles.	Increase decarbonisation ambition; increase efficiency (rewarding); taxing oil and gas; finding new partners (in mining etc); energy saving (tech, behavioural), incentives, business models; Africa as a partner to produce hydrogen should be accompanied by full access to electricity in countries involved; CCUs and DAC tech (made-in-EU) are deployed at scale in EU countries.
Energy infrastructure		Increase infrastructure interconnections; interconnection (extent, efficiency coverage); adapts transatlantic liquid fuel transport to hydrogen carriers; full integration of EU energy market grids, extend to EU candidate/potential candidate countries.	Efficiency of energy infrastructures (grids, storage); EU forced to develop specialised energy hubs and R&I hubs on a regional basis; maximise interconnectors and storage; restrict individual transport; fossil refineries adapted to renewables.

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TABLE 10: OUTCOMES FROM ROADMAP WORK GROUP 1.

	Present	2030	2040 and beyond
Society	Populist views on climate change; information campaign; and electrification influencers.	Address social objection.	
Policy	EU centre for electrification; tax low efficiency use, introduce more efficient use; certificate for energy use; tax incentives for introducing low emission technologies; raise awareness of the need for energy efficient tech; incentives for SMEs; technical guidance and assistance (German Energy Efficiency Centre)		EU CO2 transport network.
Industry & markets		Value is in the EU; Thermal energy storage to support electrification.	EU CO2 transport network.
Science & technology	Heat pumps for industrial use; corrosion-resistant pipe system.	Scale up industrial heat pumps.	Electrification; high-temperature heating; storage efficiency tech.

Annex 5: Results Group 2: Critical Raw Materials

TABLE 8: OUTCOMES FROM SCENARIO WORK, GROUP 2.

	Genuine Collaboration	Limited Cooperation	Fortress Europe
Diversification of supply chain partnerships.	WTO; free innovation competitive advantage; EV materials imported from partners; strategic partnership (ERMA);	CRM has political price; NIMBY; EV materials EU 30%.	Friendly nations; deep sea mining; rethink supply chains; hyperlocal productions; EV material EU 0%; OPEC for rare and critical materials.
Domestic production and processing.	One global VC; build up industry; CRM registry; EV production EU 50%;	Radical state aid; eco-design for circularity; VC competitors; tariffs; digital traceability; buying existing solutions; extend EU partners; competitors' development; EV production EU 30%;	Urban mining; open system, closed; space colonisation; hostile competition; EV production EU impossible.

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Circular economy and substitution.	More effort if the EU is in the lead; green design; carbon registries; compensations; open-loop systems; open market; EV recycling EU 70%.	EV recycling EU 70%	Research for own solutions; monopolies; carbon capture, high priority; EV recycle EU 100%; tactical circular economy; closed-loop systems.
R&I needs and opportunities.	Research and innovation universities the mission	Silicon-free solar cells; firepower boost and easy cost to finance; resource policy and horizontal prices; later specialisation more in geopolitics; competitive specialisation and partnerships; R&I matching platform; innovation is driven by markets;	Maximum efficiency from defence spillovers; R&I over social spending; R&I results over human lives.

TABLE **11:** OUTCOMES FROM ROADMAP WORK GROUP 2.

	Present	2030	2040 and beyond
Society	NIMBY pros-cons; green washing; comfort zone; consumer trust; strategic marketing; role of science fiction.	Communication and protection boost; citizens' involvement and participation (citizen markets).	Risk-benefit; SLO; mining.
Policy	Joint effort in critical materials/infrastructures, etc; 27→1; boost risk adversity; stable policy; CRM tax to incentivise recycling; EU CRM ACT 25% sourced from recycling; lengthy permitting for CRM extraction, recycling infrastructure underdeveloped; long-term CRM partnerships; tech-academia tinder; signalling partners; regulation with labels and m. passports; massive TRL 6-9 funding; EIC^2.	Interconnected states; no black CRM market; no commercialisation gap; secondary markets.	No energy or transport poverty; technical carbon sinks; carbon sink.
Industry & markets	Boost competitive advantage while breaking other efforts; AI automated production; test bed and sandbox paradise; material recycling € and manufacturing 2x€; critical review manufacturing processes; critical needs (product and processes); as-a-service to tech providers; digital	Single market reality; mid-scale deployment of urban mining; top clean tech export; pooling scale. 25%	Clean tech dominance; shared tech and service; doughnut economy. 45%

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	traceability pilots; high market prices support.		
Science & technology	Material substitutes; stationary use of 2nd batteries; circular design; made in EU; dual use def invest (max spillover); windmill composites EVs; build to destruct; redesign; low TRL for solvolysis (chemical recycling).	Re-engineer manufacturing materials (e.g. 3d printers); AI-driven flow tracking and forecasting; deployment 6 TRL; satellite chargers; chemical separation of composites.	Carbon capture; key materials (autonomy); e-waste; EVs; solar panels; wind; lithium; EV recycle (EU 70%); circularity.

Annex 6: Results Group 3: Manufacturing

TABLE 9: OUTCOMES FROM SCENARIO WORK, GROUP 3.

	Genuine Collaboration	Limited Cooperation	Fortress Europe
Energy-intensive Manufacturing Processes.	Enlightened solidarity with the Global South; long-distance H2 transport network; enabling H2 trade and H2 green derivatives; global supply chains; global competitions R&I; common infrastructures to several countries; concentrated solar power; energy dependency (e.g. north Africa solar farms); due to climate change southern EU solar panels; solar heat fuels from waste.	From transnational interactions, ad-hoc collaborations; is China an ally or foe? Not relying; raw materials partnership with Africa and LATAM; demographic shifts; innovation, and specialisation on renewable materials and using raw materials.	Adaptation R&I; EU democracy in decline, even if the rule of law still exists; produce less de growth; IT and AI Europe sovereignty; total self-sufficiency, less global trade.
Supply Chain Footprint and Transparency.	Industrial symbiosis; AI do mitigate supply chain risks; interoperate AI emission according to standards; with AI we have full transparency of supply chains and carbon tracing; renewable energy; new business models have	Automation e.g. robots; keeping strategic supply chains is costly; limited reliance on external energy supply; EU autonomy in GPT; mining and industry back to Europe; EU	Circular, renewable business models make more sense; focus on energy and materials efficiency; energy from cheap local resources; Circularity; rogue, geo-engineering; no climate budget.

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	developed to share innovations to decarbonize and do CDR; intercontinental electricity; transmission management; quantity computing, supply chain new materials.	infrastructure on CCS and H2, secured CRMs; deglobalized world, specialization in more areas; need to attract innovation to Europe and its commercialisation; specialisation in more sectors to reduce dependencies; interpolar emissions accounting standard, pricing green markets.	
Defence and security needs.	Deeper specialization; domestic innovation institutions; programmable biology; open science R&I; tech transfers and collaboration on tech scale up; specialisation in a few technologies and nature sectors decarbonisation; we transform our plants to use renewable energy and AI with regulations; global standards for markets and markets for green products; local production clusters; tanks and soldiers are obsolete, hybrid warfare like robots, drones etc.	AI agents do a lot of industrial espionage, the EU also spies on others; focus on deterrence (nuclear?); tanks, missiles, soldiers deteriorate, wars of the future; investment in cybersecurity; defence is a priority.	No money for R&I; European space industry?

TABLE **12:** OUTCOMES FROM ROADMAP WORK GROUP 3.

	Present	2030	2040 and beyond
Society	Storytelling, STEM, climate heroes; increase education, bio-literacy, etc; keep society involved; more science in compulsory education.	Society stays supportive.	Potential fragmented Europe; norms, companies, and public buy CDR; economic growth is given lower priority.
Policy	Better regulation and predictability; disruptive innovations institutions; carbon pricing (tax, emissions, trade, etc); public goods, open access innovation; the EU needs to	Invest in SMEs; European integration/EU bonds for climate change; UK back in the EU; mitigate fragmentation; EU will work together like in COVID;	Strong manufacturing base in the EU supported by strong EU science; CDR

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	promote programmable biology for process industry; EU regulation guarantees a growing market for recycled materials vs virgin materials.	climate/ resource diplomacy for the global south; renewable energy targets and incentives.	scaled up and accepted.
Industry & markets	Funding the transition; CDR pilot; carbon removal; AI-for-carbon tracing in value chains, public procurement; central bank level up, fund R&D; technology must be competitive and marketable.	CBAM and international carbon pricing; importance of circularity; CDR scale up; Circular Economy, reuse fuels.	Cutting-edge research is focused on geoengineering and carbon alternative use; geoclimatic engineering; manipulation technologies; markets are dominated by mega European companies.
Science & technology	Recruit disruptive scientists from the US; electrification of industrial heat; crackers; energy storage.	Hydrogen as feedstock and for high-temperature processes; automation technologies; defence technologies like armed robots; focus on strategic industries, AI, green technology, biology and agriculture; cybersecurity; solar heat; process integration, industrial symbiosis, waste heat; AI agents for espionage; biotech and nanotech; bioproducts, bio-economy.	Clean technology is widely available (electricity is cheap and abundant); space factories.

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