Study on R&I opportunities to strengthen EU clean energy security now and looking to 2050

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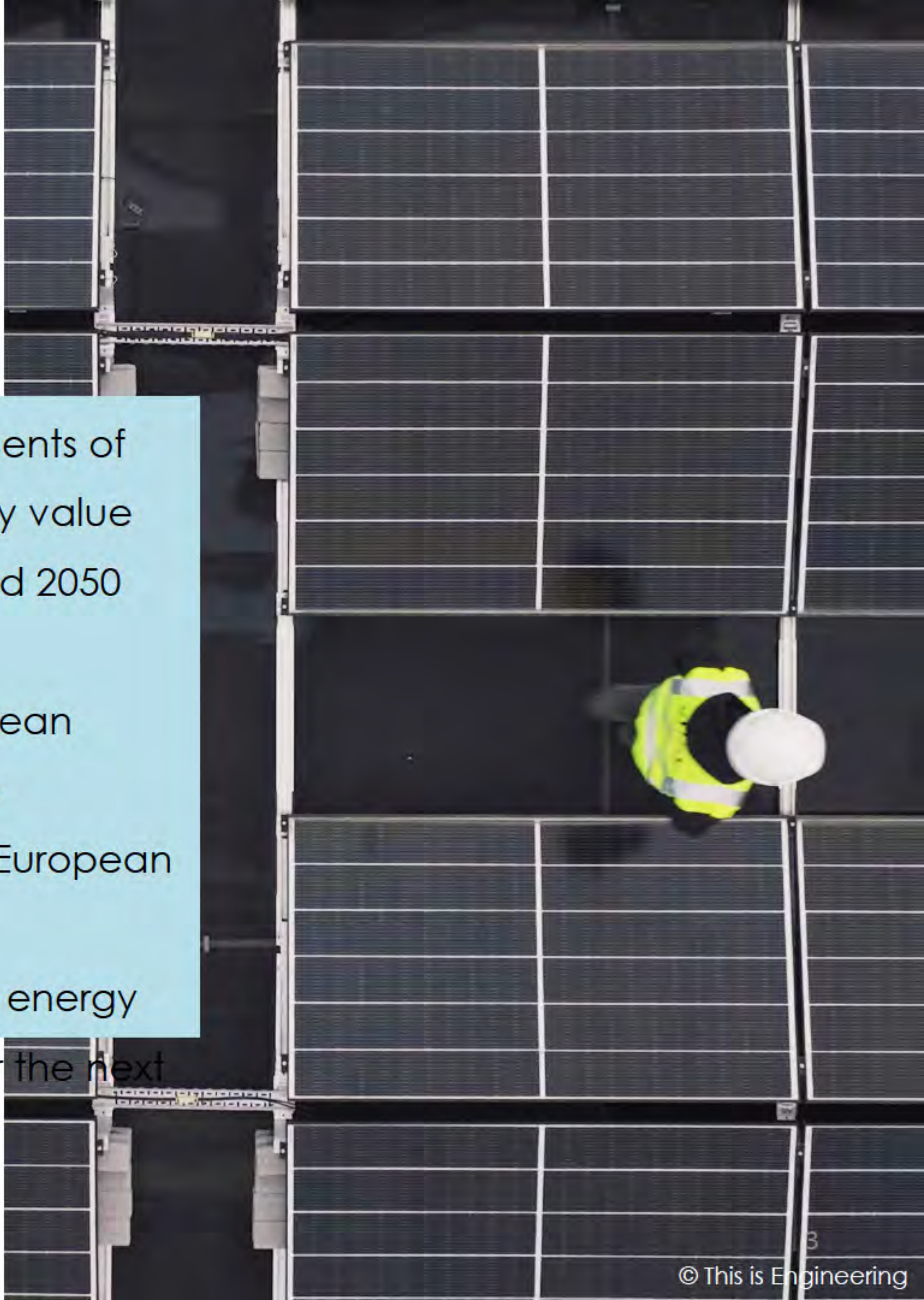
Overview of presentation

- Study objectives and approach
- Task 1: Scenario development
- Task 2: Energy security assessment of clean energy value chains
- Task 3: Developing and R&I action plan to strengthen energy security
- Task 4: Validation workshop
- Results: R&I action plan

Study objectives

- Assess the energy security components of European clean energy technology value chains now and looking to 2030 and 2050
- Identify research and innovation opportunities and challenges for clean energy technology value chains to maintain, boost or mitigate risks to European energy security
- Set out an action plan to enhance energy security of whole value chains over the next 10 years



Study scope

Energy security

"The uninterrupted availability of energy sources at an affordable price" (International Energy Agency) which for clean energy technologies includes more than the source of energy but the whole value chain.

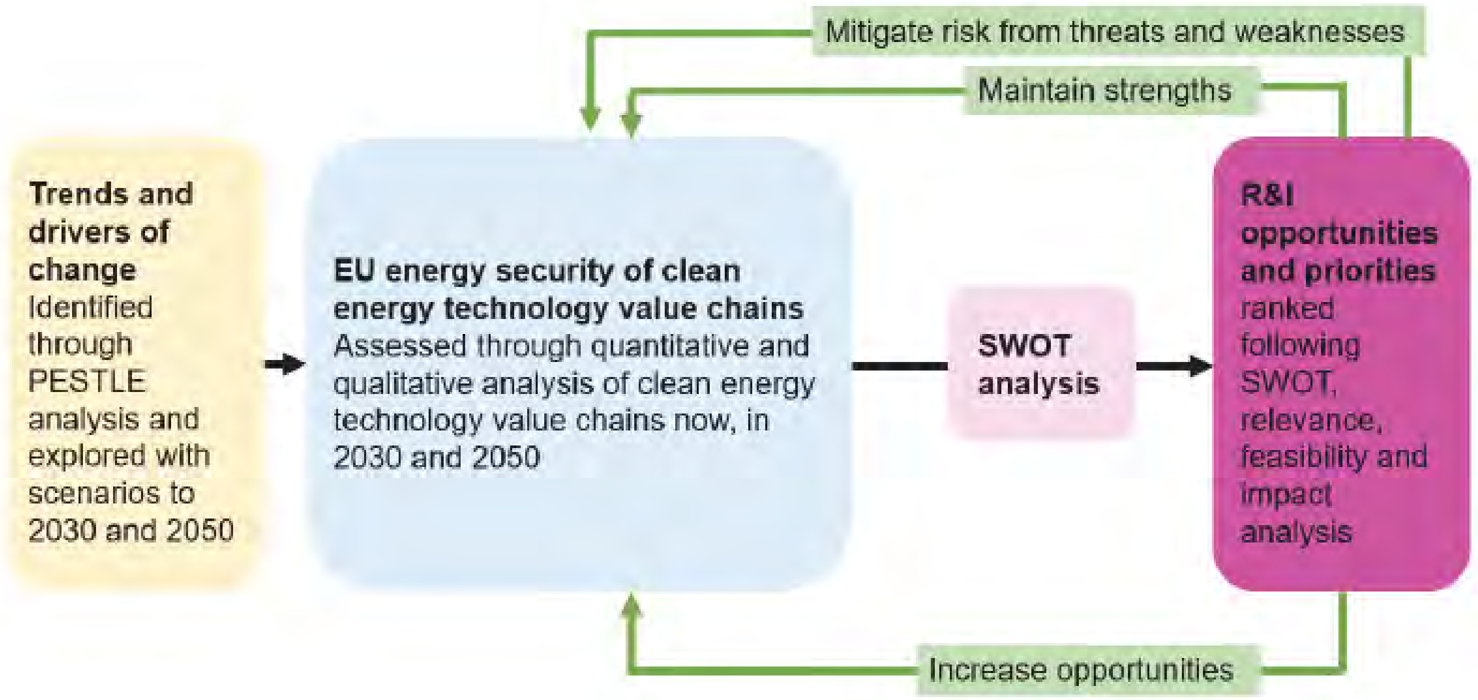
Clean energy technologies in scope:

Advanced Biofuels, Bioenergy, Concentrated Solar Energy, Geothermal Energy, Hydropower, Ocean Energy, Photovoltaics, Wind Energy, Renewable and Solar Fuels, Carbon capture Utilisation and Storage, Electricity and Heat Storage, including Batteries, Hydrogen and Intermediate Energy Carriers, Heat Pumps, Smart Energy Grid Technologies, Energy Building and District Technologies, Off-Grid Energy Systems, Energy Transmission and Distribution Technologies, Smart Cities.

Out of scope

- Physical impact/vulnerabilities of individual clean energy technology facilities to natural events and malicious threats (noting that climate adaptation and cybersecurity is in scope)
- Nuclear power
- R&I interventions outside of the influence of/implementation by the European Commission

Study conceptualisation and operationalisation



- **Task 1:** methodology development and scenarios
- **Task 2:** assessment of energy security of technology value chains
- **Task 3:** development of the R&I action plan
- **Task 4:** validation workshop

Study assumptions

- Value chains are considered more secure if they are located in the EU.
- EU policy trends and decarbonisation ambitions are maintained or increase.
- Energy needed to deploy clean energy technologies is also clean

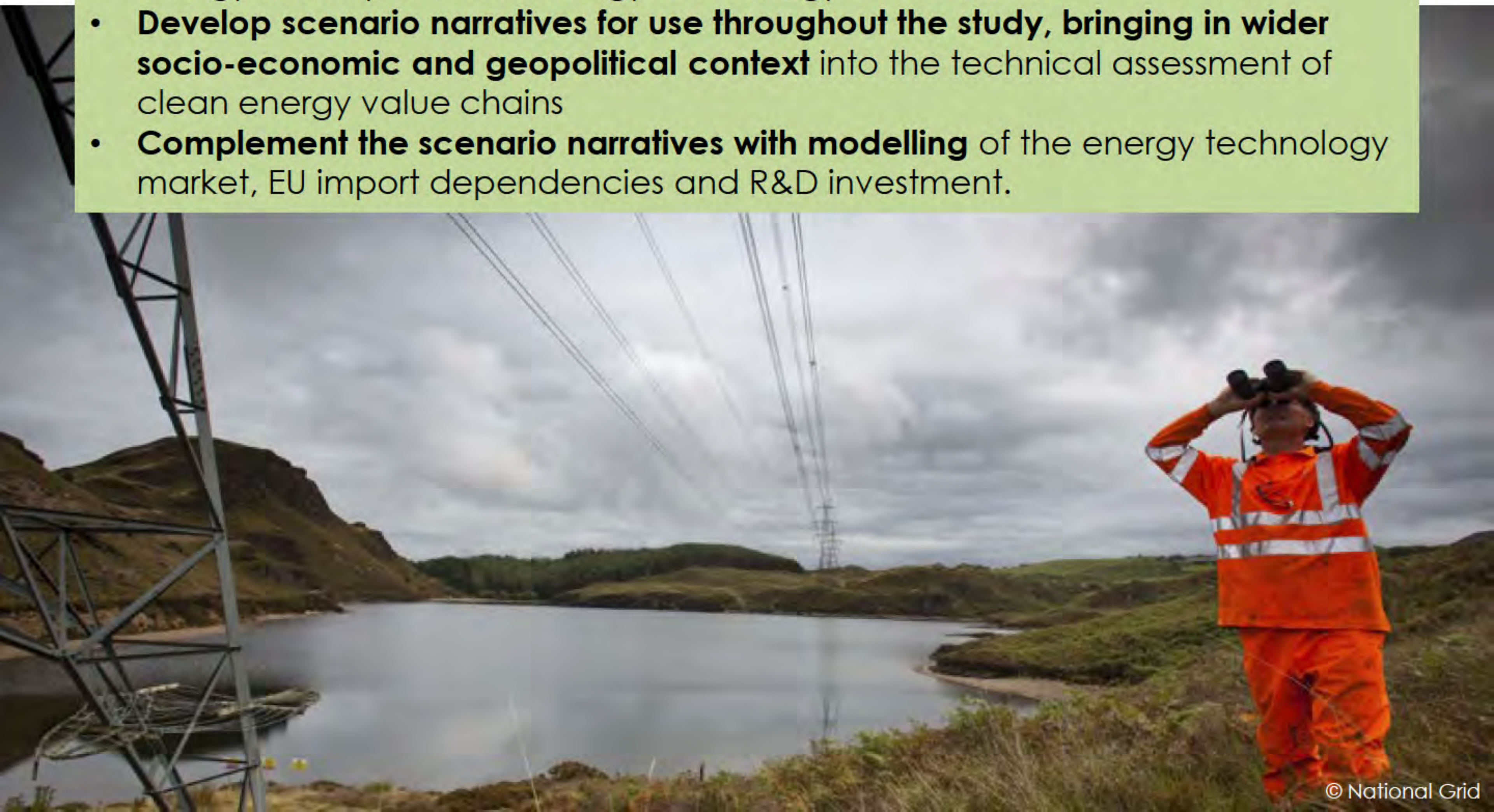
Study limitations

- Energy security is a system characteristic, however this study is focused at the value chain level.
- The technology categories are broad and analysis may not be applicable to all value chains in the technology category.
- The granularity of assessment is at the level of the main value chain elements (e.g. ‘advanced electronics’ and not the type of chip) and the main aspects of the energy security indicators (e.g. ‘biodiversity risks’ not particular species)
- The energy security assessment should be considered a mapping exercise of main risks, not a detailed technological assessment of value chains.

Task 1: Scenarios development

Aims

- **Identify key trends, drivers of change and uncertainty t**hat may affect EU energy security of clean energy technology value chains
- **Develop scenario narratives for use throughout the study, bringing in wider socio-economic and geopolitical context** into the technical assessment of clean energy value chains
- **Complement the scenario narratives with modelling** of the energy technology market, EU import dependencies and R&D investment.



Scenarios for future EU energy security

'A scenario is a generally intelligible description of a possible situation in the future, based on a complex network of influence factors. (Gausemeier et al, 1998)

Purpose of the scenarios

→ **Process** to explore how political, social, economic, environmental, technological and legislative trends may influence EU clean energy security.

→ Three plausible future scenarios that provide **challenge** to future EU clean energy security.

ScMI Scenarios Development Process

Identify your system

Identify important drivers

Identify projections

Develop narratives

→ complemented with corresponding macroeconomic and energy systems (GEM-E3) modelling

PESTLE findings and drivers of change

PESTLE analysis takes into account relevant political, economic, social, technological, legislative and environmental trends identified in the **literature and expert interviews**.

Political	Economic	Social	Technological	Legislative	Environmental
• Conflict and geopolitical uncertainty • EU member states' policies • Industrial policy and globalisation • International relations • Politics of the global clean energy transition	• Future economic environment • Global trade • Global energy market and investment • Cost of energy	• Public perceptions (energy security, clean energy technologies, climate change) • EU skills and workforce • Just transition • Demographic trends and mobility	• Circular economy • Emerging technologies • Increasing digitalisation • Clean energy technology innovation • Semiconductors • Low-carbon transport transition	• EU legislation • Critical Raw Materials Act • Circular Economy Action Plan • International legislation	• Critical materials • Climate change • Environmental impact of clean energy technologies

Scenarios for future EU energy security

Scenarios are not predictions.
The scenarios present a **plausible future with challenges to EU energy security** to provide a mechanism and future context for **stress-testing** of the energy security of clean energy technology value chains. The scenarios do not define the future energy mix.

Scenario 1
The EU decarbonises alone, amidst global challenges

- EU has met its Net Zero ambitions, pursuing the green transition **at any cost**. The rest of the world has not decarbonised, pursuing their policies of the 2020s.
- The world is **multipolar**, with protectionism and regional instability. Supply chains have regionalised, with some **short-lived disruption** in particular to critical raw materials.
- The **economy** is in recession, but the EU has continued to increase investment in energy R&I.
- The **cost of energy** is higher than the 2020s.
- **Public opinion** is polarised with regards to the energy transition.
- **Global temperature rises** are on track for 2.7C warming in 2100.

Scenario 2
A digital EU meets Net Zero with global collaboration

- Net Zero is achieved globally. The EU successfully pursued a Just Transition and public opinion supports the energy transition.
- The world is collaborative, with limited conflict.
- The EU relies on **global supply chains** and **digitalisation** to decarbonise. **Demand from supply chains and the workforce** were strained due to high demand in the **2030s**.
- The economy is growing, and the EU has continued to increase investment in energy R&I.
- The cost of energy is lower than the 2020s.
- **Global temperature rises** are on track to remain below 2C warming.

Scenario 3
Global conflict overshadows decabonisation priorities

- The EU has missed its decarbonisation target.
- **Conflict between major powers**, with **trade wars** and **cyberwarfare**, has led to **major supply chain disruption** and regionalisation.
- The economy is in **recession** and the **EU energy R&I investment** did not increase compared to the 2020s.
- **Global temperature rises** are on track to meet 3C warming by 2100.

Task 1 outcomes: Scenarios RAG rating overview

Energy security indicator	The EU's pursuit of Net Zero amidst global challenges		A digital EU meets Net Zero with global collaboration		Global conflict overshadows decabonisation priorities	
	2030	2050	2030	2050	2030	2050
Geopolitical availability (CRM)	Amber	Amber	Green	Green	Amber	Red
Abundance (CRM)	Amber	Amber	Red	Green	Red	Red
Circularity	Amber	Green	Green	Green	Amber	Green
Supply chain complexity	Green	Amber	Red	Amber	Amber	Green
Supply chain location	Amber	Amber	Amber	Amber	Red	Green
Digital vulnerability	Green	Amber	Amber	Red	Red	Red
Physical vulnerability	Green	Amber	Green	Amber	Red	Red
Broader sustainability	Green	Amber	Amber	Green	Red	Amber
Affordability	Amber	Amber	Amber	Green	Amber	Amber
Skills	Amber	Red	Amber	Green	Green	Green

GEM-E3 model

GEM-E3 is a recursive dynamic large scale applied CGE model that covers the whole world linked through endogenous bilateral trade transactions.

- Calibrated to base year production, bilateral trade and market shares
- **Demand** for technologies is driven by prices and policies.
- **Changes in market shares** depends on private R&D and learning by doing.
- Public R&D has uniform cost implications globally.

Photovoltaics
CCS
Wind turbines
Biofuels
Batteries
Hydrogen

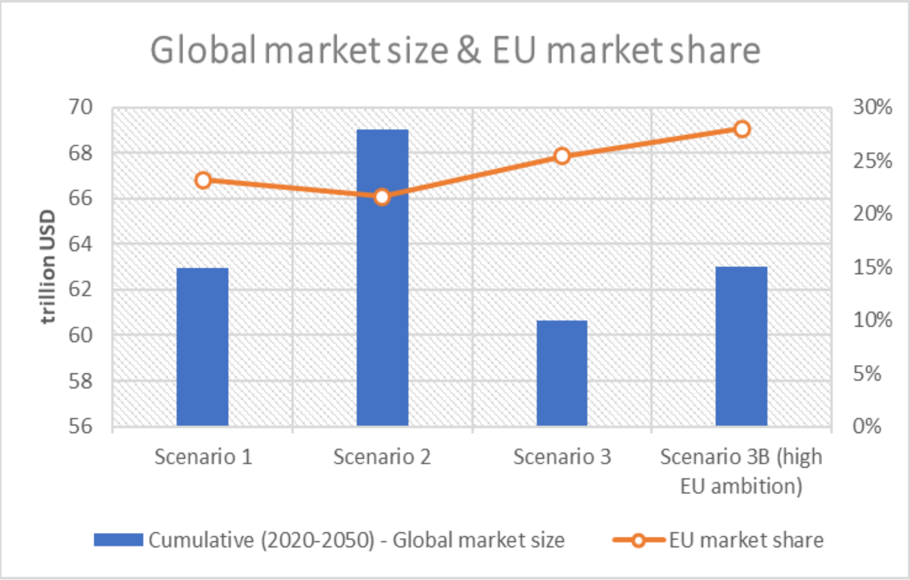
→ Use in this study

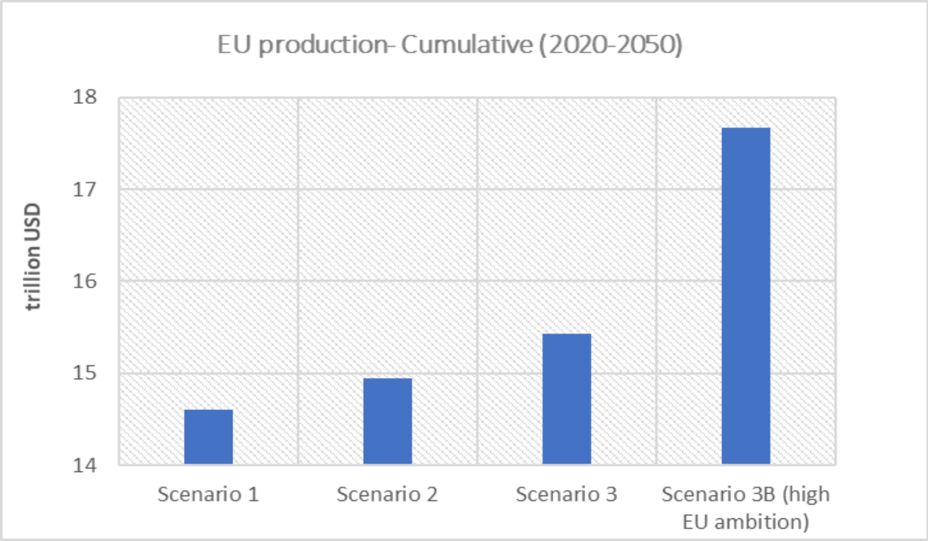
- Estimate the market size in different scenarios (global and EU)
- Indicate the dependence of EU on imported technologies
- Estimate R&D expenditures for EU potential development of domestic capacity

GEM-E3 model

Overview of the results from the GEM-E3 model – Global market size & EU clean energy production

- The demand for clean energy technologies peaks in scenario 2 (~69 trillion USD – cumulative over the period 2020-2050). A concerted action towards GHG emission reduction provides a steady signal to investors that accelerate investments and R&D expenditures.
- EU achieves its highest average market share in scenario 3B (high EU ambition) , reaching 28%.
- For EU, scenario 3B (high EU ambition) stands out in terms of clean energy production, significant impact that trade policies can have on the EU's domestic clean energy production levels, highlighting the importance of trade dynamics in shaping the outcomes of the clean energy sector.
- The dominant technology in terms of market size across all scenarios is electric vehicles

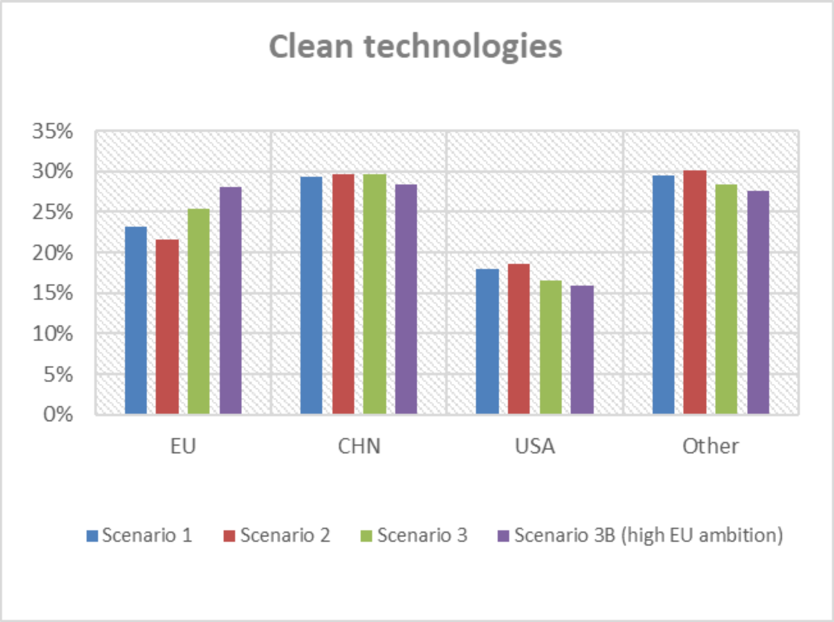




GEM-E3 model

Overview of the results from the GEM-E3 model – Clean energy technologies market shares

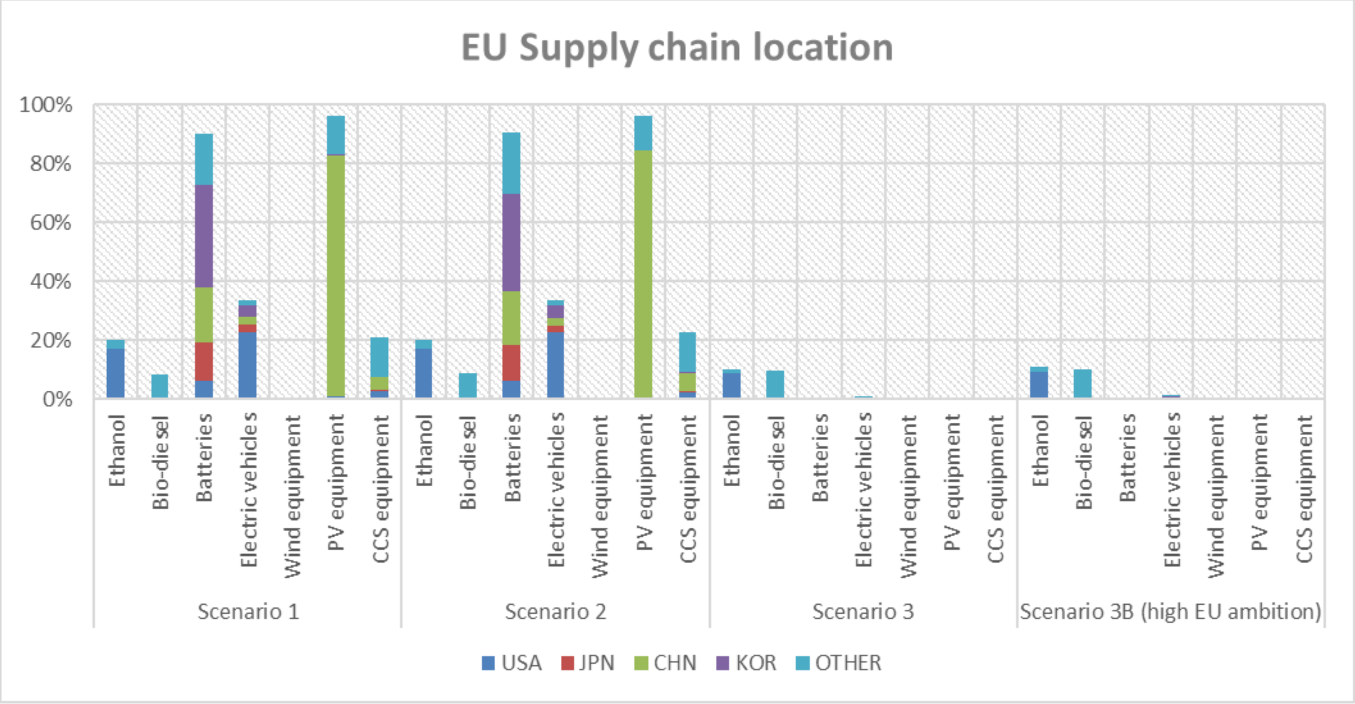
- In scenarios 3 and 3B (high EU ambition) , where trade restrictions are implemented, the EU experiences an increase in market shares for PV equipment and batteries
- Scenario 3B (high EU ambition) , EU have highest market share compared to other scenarios. This is attributed to the EU's ambitious climate targets and a strategic emphasis on self-sufficiency in clean energy technologies, contributing to its leading market position.
- Scenario 2 exhibits the lowest market share for the EU, driven by the global effort to mitigate greenhouse gas (GHG) emissions, resulting in a substantial increase in clean energy production in non-EU countries and diminishing the EU's relative market share.



GEM-E3 model

Overview of the results from the GEM-E3 model – EU dependency on imports by location

- Scenarios 3 and 3B (high EU ambition) , there is a low dependency on imports
- In scenario 1 and 2, PV equipment is primarily imported from China, showcasing a concentrated import dependency
- The import dependency for batteries is more diversified, with imports sourced from various countries



Task 2: Energy security assessment of clean energy value chains

Aims

- **Assess potential energy security risks** in a harmonised way across all technology value chains in scope
    - Using a broad, comprehensive understanding of energy security, including both technical and non-technical aspects
    - Assessing the risk levels relative to other value chains
- **Develop a list of key criticalities for energy security of clean energy technology value chains**, to serve as a basis for the identification of R&I interventions

Energy security assessment of clean energy value chains

Step 1	**Identification of representative value chains for each technology category** • 1-4 value chains per technology, 48 value chains total
Step 2	**Definition of a comprehensive set of relevant energy security indicators** • 10 energy security indicators
Step 3	**Assessment of energy security indicators for each value chain** • Harmonised approach for each energy security indicator • Relative energy security risk scored: 1 = low risk, 2 = moderate, 3 = high
Step 4	**Long-list of energy security criticalities for 2030 and 2050** • At the value chain level • Making use of the scenarios as a stress test for the indicators over time
Step 5	**Short-list of key energy security criticalities** • At the technology category level • Based on multicriteria analysis including number of scenarios through which the criticality was shortlisted, development in time, expected scale, comparison across technologies, etc. • Validation by workshop participants

Energy security assessment of clean energy value chains

List of energy technology value chains

Wind energy (4)
- Wind turbine – onshore
- Wind turbine – offshore
- Airborne wind system
- Downwind rotor

Hydropower (1)
- Hydropower plant for electricity generation

Photovoltaics (4)
- Silicon-based PV
- Copper indium gallium selenide PV
- Cadmium Telluride PV
- Perovskite cells

Geothermal energy (1)
- Geothermal plant for heat and electricity generation

Smart energy grid tech (3)
- EV smart charging
- Advanced meter infrastructure
- Home energy management systems

Energy building and district tech (3)
- Advanced control technologies
- Thermal energy storage
- Combined heat and power

Bioenergy (2)
- Primary crop-based and forest-based bioenergy

Other energy storage (2)
- Compressed air storage
-

RFNBOs (1)
- Synthetic kerosene

CCUS (1)
- Carbon capture and storage infrastructure

Heat pumps (2)
- Industrial heat pumps
- Domestic heat pumps

Smart city (1)
- Autonomous driving

Off-grid energy (3)
- Biogas tank
- Pellet stove
- Thermal collector

Direct solar fuels (2)
- Photochemical or photobiological routes
- thermochemical routes

Advanced Biofuels (3)
- Algae-based advanced biofuels
- Primary crop-based advanced biofuels
- Waste-based advanced biofuels

Batteries (4)
- Batteries containing several critical raw materials
- Batteries without critical raw materials
- Redox flow batteries
- Molten salt batteries

Ocean energy (4)
- Tidal energy technologies
- Wave energy technologies
- Ocean thermal energy conversion
- Salinity gradient energy technology

Concentrated solar energy (1)
- Concentrated solar energy plant for heat and electricity generation

Hydrogen (4)
- Alkalyne electrolysis
- Polymer exchange membrane electrolysis
- Solid oxide electrolysis

Energy transmission and distribution tech (2)
- Hydrogen storage and distribution
- High voltage direct current transmission

Energy security assessment of clean energy value chains

Energy security indicators

The energy security assessment of each value chain was carried out with ten energy security indicators. Each indicator was assigned a score from 1-3 (1: low risk, 3: high risk) for the intrinsic risk carried by the technology value chain.

List of energy security indicators
1. Geopolitical availability of Critical Raw Materials 2. Abundance of Critical Raw Materials or biomass 3. Circularity 4. Supply chain complexity 5. Supply chain location 6. Digital vulnerability 7. Physical vulnerability 8. Broader sustainability 9. Affordability 10. Skills

Energy security assessment of clean energy value chains

Stress-testing future energy security with the scenarios to compile the long-list

Each energy security indicator was given a Red-Amber-Green rating for 2030 and 2050 based on how much the energy security indicator would be stressed compared to now. For example, a scenario with rapid decarbonisation would stress the skills indicator to amber or red depending on the pace of decarbonisation. The RAG rating was used to provide a futures element to the energy security assessment, determining which elements of the value chains should be included on the long list of criticalities based on the matrix below.

Scenario RAG rating / Energy security indicator score	Green	Amber	Red
1	Not included on the long-list	Not included on the long-list	For discussion to include on the long-list
2	Not included on the long-list	For discussion to include on the long-list	Long-listed
3	Long-listed	Long-listed	Long-listed

Energy security assessment of clean energy value chains

Going from the long-list to the shortlist of key energy security criticalities

Qualitative assessment based on expert judgement for the following criteria

- Number of scenarios triggering the longlisting of the criticality (1-3)
- Development over time (2030, 2050, both). Risking delay or disruption?
- Consideration of the nature of the criticality. E.g. single risk or accumulation of various risks in the same category?
- Expected scale of the technology and role in the energy system
- Comparison across technologies (harmonisation of repeat criticalities)
  - Critical Raw Materials-related criticalities were automatically included in the shortlist
  - All technologies that rely on large amounts of renewable electricity for production or operation, the vulnerability of the electric grid was considered key.

Energy security assessment of clean energy value chains

Key results of energy security assessment (1/2)

- Geopolitical availability and abundance of Critical Raw Materials (CRM), digital vulnerability and skills came out as key energy security risks
  - In several cases, digital vulnerability and skills were originally not shortlisted but validation workshop participants viewed them as important risks

- Risks identified in supply chain location & complexity, as well as broader sustainability, often were related to CRMs

- For the majority of technologies, the listed CRMs are “generic” ones, like Copper and Aluminium. Therefore, the related supply risks should be considered as a systemic vulnerability instead of related to specific value chains

Energy security assessment of clean energy value chains

Key results of energy security assessment (2/2)

- In addition to advanced electronics for “smart” technologies, validation workshop participants pointed at the importance of “standard”, low technology electronics as well

- Digital vulnerabilities were mainly identified for “smart” technologies and technologies where cyberattacks may cause significant physical damage. Workshop participants added to this the vulnerabilities arising from interconnectivity among several devices (which is a systemic vulnerability)

- For skills, it was noted that there is a general shortage of installation skills, arising from competition among clean energy technologies. On the other hand, the current situation does not necessarily pre-empt skills availability in the long term

Task 3: Developing a R&I action plan to strengthen energy security

Aims

- Define **R&I challenges** to address the key energy security criticalities
- Assess **what relevant R&I is already taking place in the EU** and the **EU's ability to address** the R&I challenges (R&I ecosystem strength and weaknesses, external threats and opportunities)
- **Develop feasible, impactful and futureproofed R&I interventions to include in an action plan** (to be delivered by 2030)

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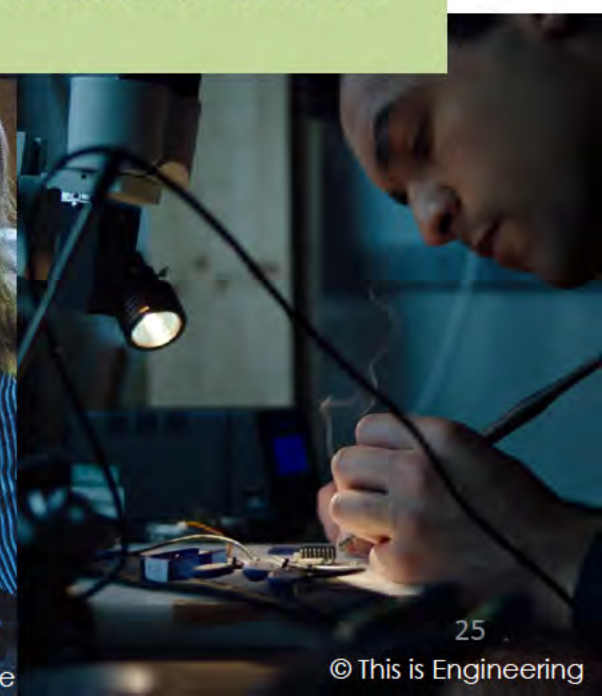

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Developing a R&I action plan to strengthen energy security

Step 1	**R&I landscape analysis**
Step 2	**Identification of corresponding R&I challenges to address criticalities** → Initial prioritisation: exclusion of existing R&I programmes/not R&I
Step 3	**SWOT analysis to better understand the EU's R&I ecosystem and ability to address the challenge** → Prioritisation of challenges and definition of potential R&I interventions
Step 4	**Refine the R&I interventions for impact, feasibility and futureproofing** → Validation workshop feedback
Step 5	**R&I action plan**

Defining R&I interventions

Key energy security criticalities → corresponding R&I challenges

R&I landscape analysis and desk-based research →

SWOT analysis per technology

EU R&I strengths e.g. global R&I leadership, already addressing the criticality with R&I	**External opportunities** e.g. shared international challenge, existing collaborations, technological solution in development
EU R&I weaknesses e.g. not globally competitive for R&I	**External threats** e.g. non-EU support for private sector investment, competitive environment, evolving risk

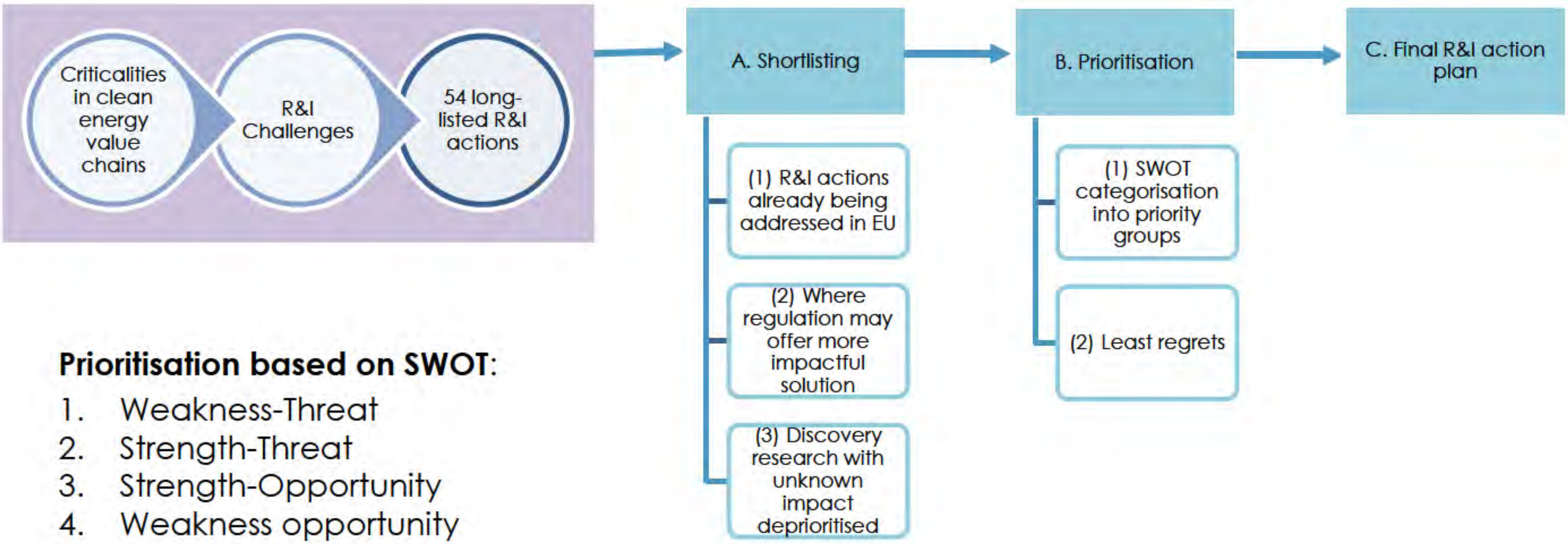
→ **Factors to determine appropriate type of R&I intervention**

and

Prioritisation for R&I challenges to be addressed:

1. Weakness-Threat
2. Strength-Threat
3. Strength-Opportunity
4. Weakness opportunity

R&I action plan: prioritisation and least regrets lens



Prioritisation based on SWOT:

1. Weakness-Threat
2. Strength-Threat
3. Strength-Opportunity
4. Weakness opportunity

Least regrets and futureproofing:

- Identification of opportunities to address more than one criticality with one R&I intervention.
- Considerations for successful implementation including future trends or opportunities for early action that is required across more than one future scenario.

Task 4: Validation workshop

Aims

- Validate the methodology and findings so far, in particular on energy security criticalities.
- Refine the R&I action plan with consideration of feasibility, potential impact and futureproofing.

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Workshop structure and participation

- Morning session (9:30-12:00 CET) – study methodology and activities to validate the energy security assessment of clean energy value chains.
- Afternoon session (13:30-17:00 CET) – activities refining and validating R&I interventions.

- 50 participants total, 41 online, from research organisations (12%), academia (18%), trade bodies (26%) or think tanks (4%), industry (16%, nominated by ETIPs), and the European Commission were also present (24%, from DG RTD, DG ENER and JRC).
- Participants brought expertise in 16 technologies and expertise on CRM, sustainability, international trade, energy policy and climate adaptation.

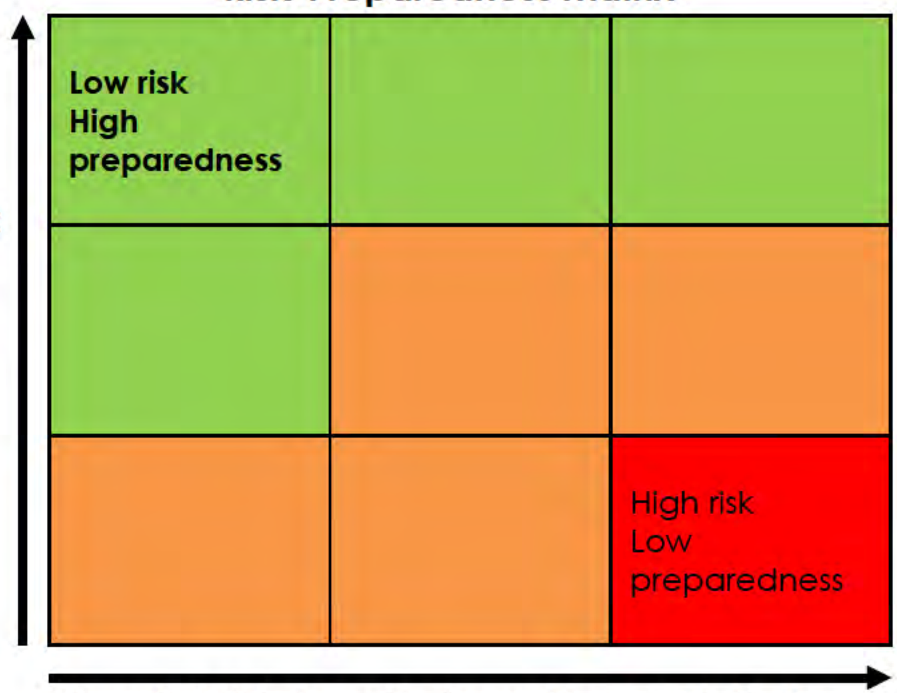
Activity 1

Objective of the activity:
- **Validate and feedback on the shortlist of key energy security criticalities**

→ Discussion to assess the severity/prioritisation of key energy security criticalities
→ Discussion of possible future scenarios and implications for energy security criticalities

Risk-Preparedness Matrix

EU Preparedness: How ready and equipped is the EU to mitigate this risk if it occurred?



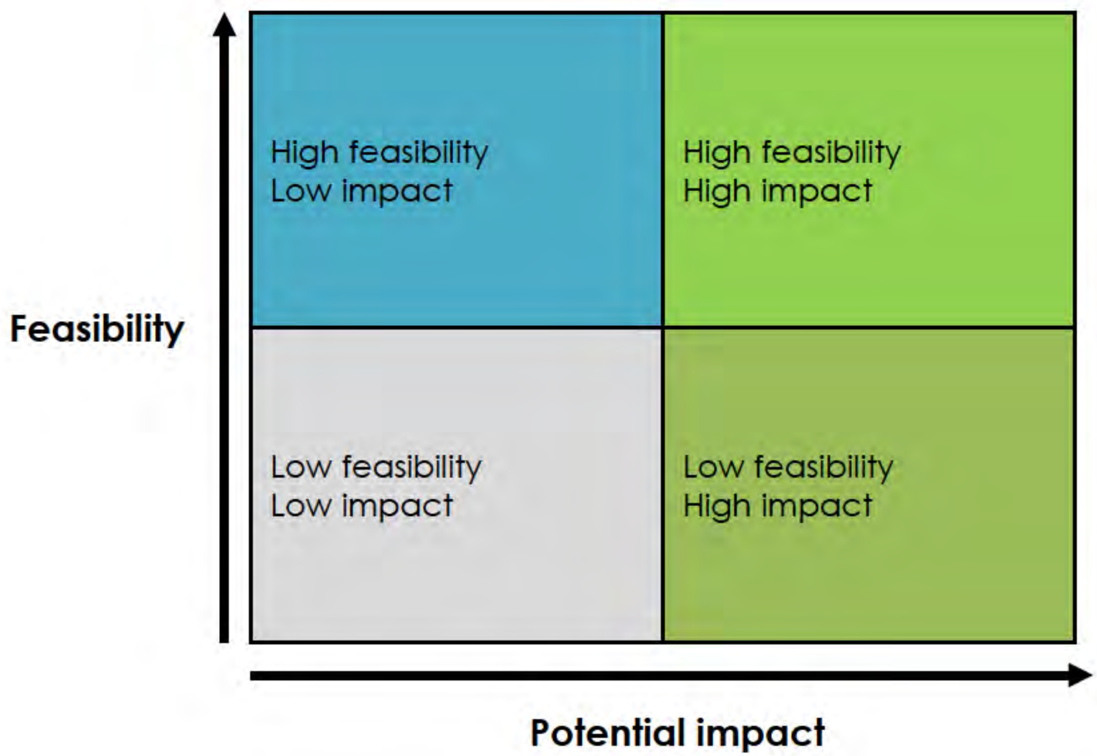
Level of risk: how likely and impactful is the criticality for EU energy security?

In groups, participants placed a selection of criticalities on the matrix and discussed any gaps, nuance, key considerations

Activity 2

Objective of the activity:
- **Develop and refine R&I interventions to address the energy security criticalities**

→ Discussion to assess whether R&I interventions are the most effective approach
→ Discussion of impact, feasibility and futureproofing for R&I interventions

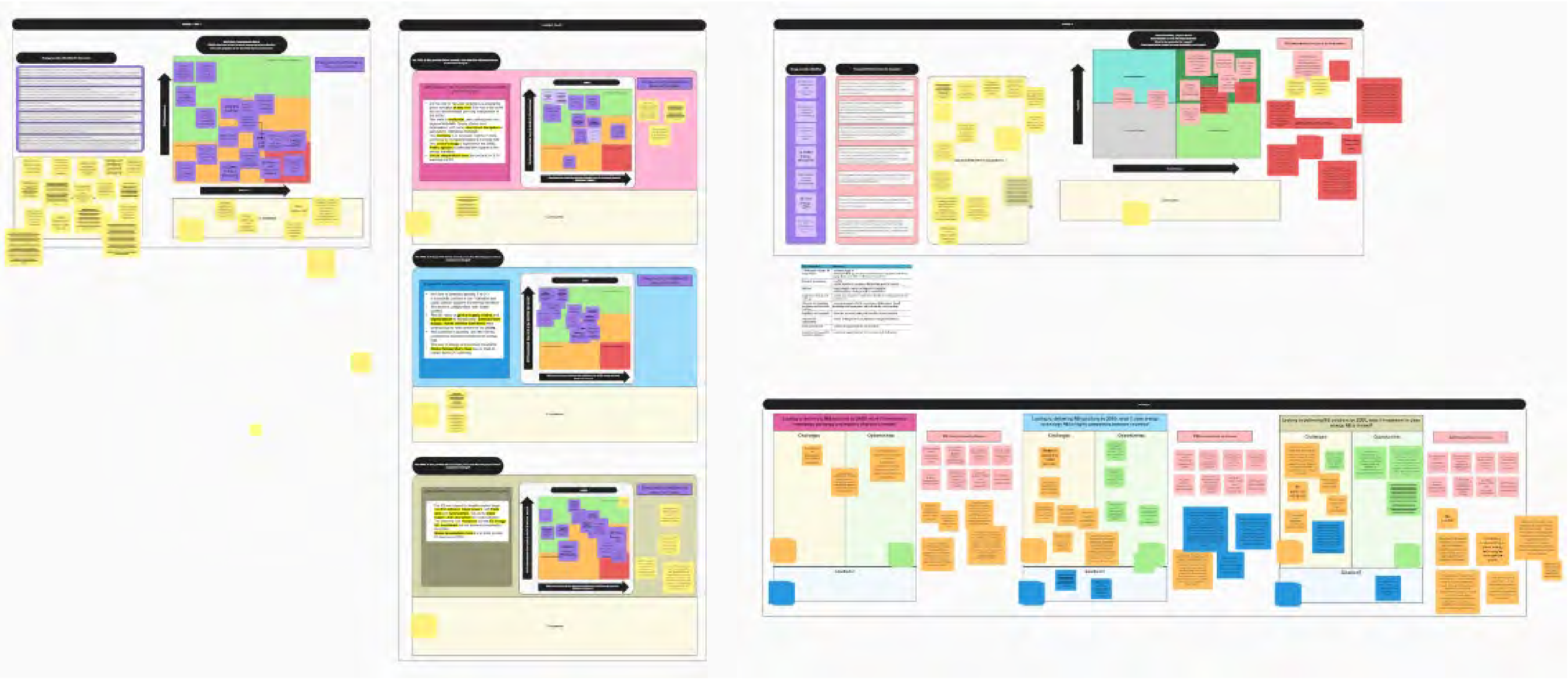


In groups, participants placed a selection of R&I interventions on the matrix and discussed what would be better alternatives

Validation workshop: outcomes

- Input from participants was collated into a workshop summary, included in the final study report.

Mural board from Break Out Group 1 with participant input



Participants identified criticalities that weren't shortlisted across technologies, and alternative or missing R&I actions. **The workshop input fed directly into the finalised set of key criticalities, R&I challenges and informed the selection of R&I actions included in the action plan.**

Results: R&I action plan

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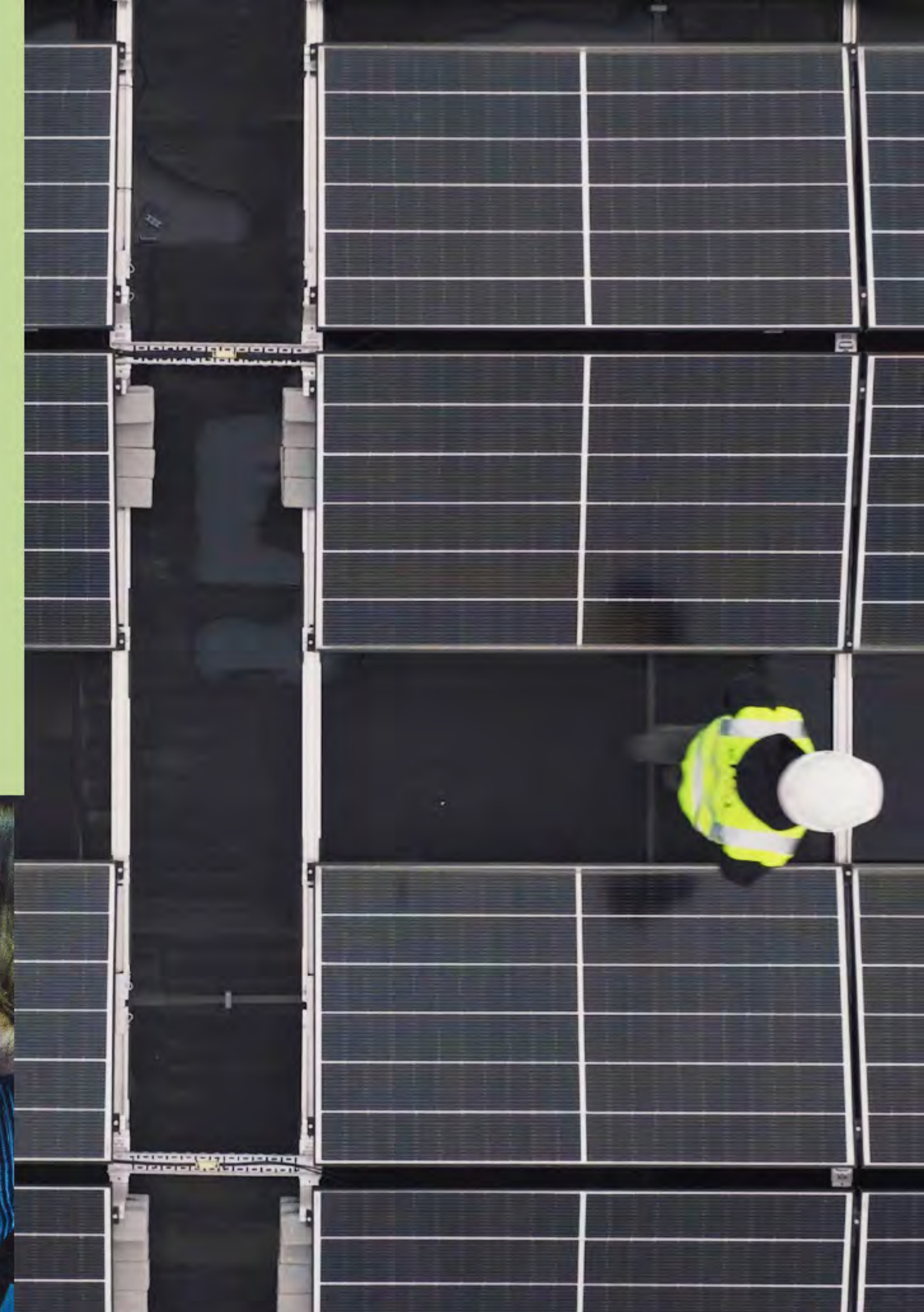

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Defining R&I interventions: types of intervention

R&I intervention	Relevance
Collaborative industry R&I programmes	- medium to high TRL - develop technology towards commercialisation, support to initial new supply chains and skills in industry and academia
Research programmes	- low TRL - resolve uncertainty, increase understanding, proof of concept
Missions	- signal strategic interest and demand for solutions - multidisciplinary challenge and/or market failure
Support for start-ups and scale-ups	- enable new innovative companies to develop innovative products and commercialise
Networks for knowledge exchange and community building	- ecosystem support to build connections, collaborations, shared knowledge and engagement with policymakers and regulators
Regulation and standards	- driver for innovation setting out desirable outcome/certainty
International collaboration	- shared challenges and complementary strengths/weaknesses
Public procurement	- create and support demand for innovation
Incentives and support for innovation adoption	- create and support demand for innovation and deployment

R&I action plan: Priority group 1 (W-T)

Supply chain location & complexity

CRM abundance & availability

Batteries

Horizon Europe programme focused on improving the energy efficiency of battery manufacturing and recycling.

PV

A Horizon Europe collaborative industry programme to support initial new supply chains focused on increasing the efficiency of solar photovoltaic manufacturing processes in the EU.

Hydrogen

Horizon programme with an open call for solutions to increase the resilience of hydrogen value chains.

Energy Transmission & Distribution

R&I programme to increase recycling and re-use in energy transmission and distribution and develop the sustainable production of aluminium and other alternatives.

Geothermal Energy

Open Horizon Europe call with the aim of implementing a “design to recycling” scheme, including reducing and reusing critical raw materials in geothermal energy.

Smart Cities; Buildings & District Tech; Grids

R&I programmes to increase circular economy processes, recycling and re-use of electronics for smart energy technologies.

CRM

Research and public engagement on mining of critical raw materials.

Other Energy Storage (CAES)

Research programme with the aim to develop a better understanding of the potential locations for underground CAES.

Smart grids

Ongoing R&I programmes to address cybersecurity risks, ensuring cybersecurity can be maintained for legacy systems and understanding of the evolution of threats informs regulation and standards.

Sustainability & other environmental impacts

Digital vulnerability

R&I action plan: remaining 21 actions

Further R&I actions by theme

21 further challenges identified, in need of R&I intervention

Cost-competitiveness

Challenge: how can the cost of production be reduced to competitive levels and products brought to market?

Relevant technologies: Hydrogen and RFNBOs – Ocean energy

Supply chain resilience

Challenge 1: how can supply chain resilience be increased?

Relevant technologies: Solar fuels – Hydrogen

Challenge 2: how can an EU-based supply chain be supported to be globally competitive?

Relevant technologies: Batteries – Silicon-based PV

Performance in a changing climate

Challenge: how can performance be maintained or managed with a changing climate?

Relevant technologies: Hydropower

Energy systems

Heat pumps – how can the vulnerability to wider energy system disruption be mitigated?

System-level – How can the physical and digital resilience of the smart and flexible clean energy grid be strengthened?

Public opinion

Challenge: what factors influence public opinion?

Relevant technologies: Hydropower – Ocean energy

Availability of feedstocks

Challenge: how can the security and availability of feedstocks be improved?

Relevant technologies: Bioenergy – Advanced biofuels

Environmental impact

Challenge: how can the environmental impact be reduced or mitigated?

Relevant technologies: Hydrogen – Hydropower – Off-grid technology – Other storage (CAES)

Digital vulnerability

Challenge: how can the digital vulnerability of wind energy be reduced and mitigated?

Relevant technologies: Wind energy – Smart energy grid technologies and smart cities – Energy transmission and distribution technologies

Critical raw materials

Challenge: how can the use of critical raw materials be reduced?

Relevant technologies: Photovoltaics – Batteries – Geothermal energy – Smart energy grid technologies – Smart cities – Energy building and district technologies – Energy transmission and distribution technologies

R&I action plan

Proposed R&I intervention

Horizon Europe research programme focused on understanding crop growth conditions, potential biodiversity and carbon sequestration co-benefits, credible sustainable governance systems, and sustainable exploitation of unused areas and biomass volumes.

This intervention is proposed to address the shared challenge faced by bioenergy and advanced biofuels drawing on gaps and areas for further research that were identified during the validation workshop. Specific suggestions include research and innovation on crops and their growth conditions for potential application to marginal or abandoned land areas, potential co-benefits such as improved biodiversity and carbon sequestration, feedstock flexibility and development of sustainable value chains.

This intervention was considered to have potential for high impact and high feasibility by validation workshop participants.

Key energy security criticality addressed: abundance of feedstock

- **Potential for collaboration:** A number of existing collaborations could be leveraged including with the UK, US and Canada.

- **Links to other key criticalities and R&I challenges:** This intervention is linked to the other Advanced Biofuels and Bioenergy interventions, with potential for synergies and added value to be considered.

- **Consideration for successful implementation:** Policy intervention is crucial to resolve uncertainty with regards to advanced biofuels feedstocks. R&I is complementary in this case, and will not form the primary solution to the criticality.

  With consideration of the future, cybersecurity may be an important factor to include in such a programme if solutions in development are highly digitised.

  For implementation in line with the Sustainable Development Goals, consideration should be given to ensure alignment with sustainable agriculture and food security, water security, affordability, biodiversity and sustainable land management.

R&I action plan: additional actions

Discovery research programmes

- Four technology groups had no currently known solution for the question "*how can the use of critical raw materials be reduced?*"
- A discovery research programme is proposed → this carries high risk and is likely to take a number of years before a solution is developed to application → not included in the action plan due to uncertainty of their potential impact.
- **Relevant technology groups:** Other storage (flywheels & CAES); Off-grid energy tech; Solar fuels; Smart energy grid technologies, smart cities, energy building and district technologies, energy transmission and distribution.

Energy systems

- An additional action is proposed, to address the common criticalities and start to address the interconnectedness of the energy system and co-dependencies of different technologies.
- **Action:** Mission for the future resilient and secure EU clean energy system, to address skills questions, critical raw materials needs for energy technologies, cybersecurity and other challenges such as permitting or management of the smart distributed energy system.